Sustainable Water Resources Management with Special Reference to Rainwater Harvesting – Case Study of KartaManTul, Java, Indonesia

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von

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Dissertation

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Karlsruhe, 17 June 2008 Widodo Brontowiyono

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ZUSAMMENFASSUNG

Für die kommenden Jahrzehnte sagen Experten für die Entwicklungsländer erhebliche Wasserprobleme voraus, die die vielfältigen Bemühungen um ökonomisches Wachstum und verbesserte Lebensbedingungen der Menschen zunichte machen können.

- Durch das Bevölkerungswachstum werden die pro-Kopf zur Verfügung stehenden Mengen an Wasser ständig weniger; um den Bedarf zu decken, werden die vorhandenen Wasserressourcen häufig übernutzt.
- Das Sinken der Grundwasserspiegel und, in küstennahen Aquiferen, das Eindringen von Meerwasser in die Grundwasserleiter sind häufig die Folge.
- Abholzungen in den Wassereinzugsgebieten erhöhen den Spitzenabfluss in der Regenzeit und verstärken die Gefahr von großflächigen Überschwemmungen.
- Die globale Klimaänderung verschärft das Problem von Dürren in der Trockenzeit und von Überschwemmungen in der Regenzeit, wie sie für die Tropen typisch sind.
- Ein weiteres Problem ist die Urbanisierung, d.h. die Ausbreitung der Städte, die zu einer starken Versiegelung der Landschaft führt, bei gleichzeitiger Erhöhung des Wasserbedarfs der Menschen.
- Diese Ausbreitung der Siedlungsgebiete, fehlende sanitäre Einrichtungen wie auch ungenügende Überwachung gewerblicher und industrieller Betriebe führen zu einer starken Wasser-verschmutzung, die noch durch eine ungeregelte Abfallentsorgung verstärkt wird.

Die oben aufgezeigten Probleme findet man auch in starkem Maße in Indonesien, wo eine besonders hohe Verstädterungsrate registriert wird, verbunden mit einer starken Reduzierung in Menge und Qualität der pro-Kopf zur Verfügung stehenden Wassermengen. Indonesien hat zwar vergleichsweise reiche Wasservorkommen, aber die Verteilung ist sehr ungleich und die Bevölkerungsdichte ist auf einigen Inseln, wie der Insel Java, extrem hoch.

Das Bewusstsein, das man auch in Indonesien auf eine ernsthafte Wasserkrise hinsteuert, ist bei der Bevölkerung offenkundig noch nicht vorhanden und die Behörden haben bisher kein überzeugendes Konzept zur nachhaltigen Bewirtschaftung der Wasservorkommen entwickelt. Die vorhandenen Informationen zu den Wasserressourcen sind nur unzulänglich und, falls vorhanden, häufig nur schwer verfügbar. Die Kommerzialisierung des Wassers hat bisher keine Fortschritte gebracht.

Das Untersuchungsgebiet: Die hier vorgelegte Studie wurde in dem „Special Territory of Yogyakarta“ (DIY) durchgeführt, einer kleinen Provinz in Zentraljava, Indonesien. Diese Provinz mit etwa 3,2 Millionen Einwohnern auf 3.185 km^2 Fläche zeigt die obengenannten wasserbezogenen Probleme mit besonderer Deutlichkeit:

- Eine hohe Bevölkerungsdichte (ca. 1.000 Einwohner pro km^2) bei weiterhin hohem Bevölkerungswachstum.
- Innerhalb der Provinz Migration aus den ländlichen Gebieten in die städtischen Räume.
- Migration aus anderen Teilen Indonesiens in das ökonomisch und kulturell bedeutende Yogyakarta.
- Übernutzung der Grundwasserressourcen mit sinkendem Grundwasserspiegel.
- Abwasser-Entsorgung und Dränung des Überschusswassers in der Regenzeit in die Flüsse.
- Starke Veränderung der Landnutzung bei verminderter Grundwasser-Neubildung, etc.

Die Provinz Yogyarta (DIY) teilt sich auf in vier Distrikte (Bantul, Gunungkidul, Kulonprogo, Sleman) und ein städtisches Gebiet (Yogyakarta City). Von diesen fünf Gebieten wurden drei für diese Studie herangezogen: Bantul, Sleman und Yogyakarta City (Abb.1). Der Begriff „Kartamantul“ hat sich herausgebildet als ein Begriff, der diese drei Einheiten umfasst. Er setzt sich zusammen aus den Endsilben der Namen Yogyakarta, Sleman und Bantul. Yogyakarta City ist eine Stadt von etwa 520.000 Einwohnern mit einer Bevölkerungsdichte von durchschnittlich 12.200 Einwohnern pro km^2. Das Bevölkerungswachstum liegt in Bantul bei 1,9% p.a., im Gebiet des Sleman - Distriktes bei 1,5% p.a.. Die Stadt Yogyakarta zeigte, nach vielen Jahren stürmischer

Entwicklung, ein „Null-Wachstum“ bzw. eine leichte Abnahme in letzten Jahren, bedingt durch die räumliche Begrenztheit der Stadtgebietes.

Die Provinz Yogyakarta (DIY) erstreckt sich vom Berg Merapi, einem sehr aktiven Vulkan, an der Grenze zur Provinz Zentraljava gelegen, bis zum Meer. Der Vulkan Merapi (Gunung Merapi „Feuerberg“) hat eine Höhe von etwa 2.910 m und ist einer der aktivsten Vulkane Indonesiens. Die Geomorphologie des Untersuchungsgebietes ist bestimmt durch die vulkanischen Aktivitäten. Die Gegend steht auf einer Felsbasis aus Tertiär- und Quartärformationen. Strukturell liegt Yogyakarta auf einer aktiven Plattenzone, die zum „Pazifischen Feuerring“ gehört. Das vorherrschende Erdbebensystem ist das Merapi-Beben-System oder auch Merapi-Yogyakarta-Beben-System genannt.

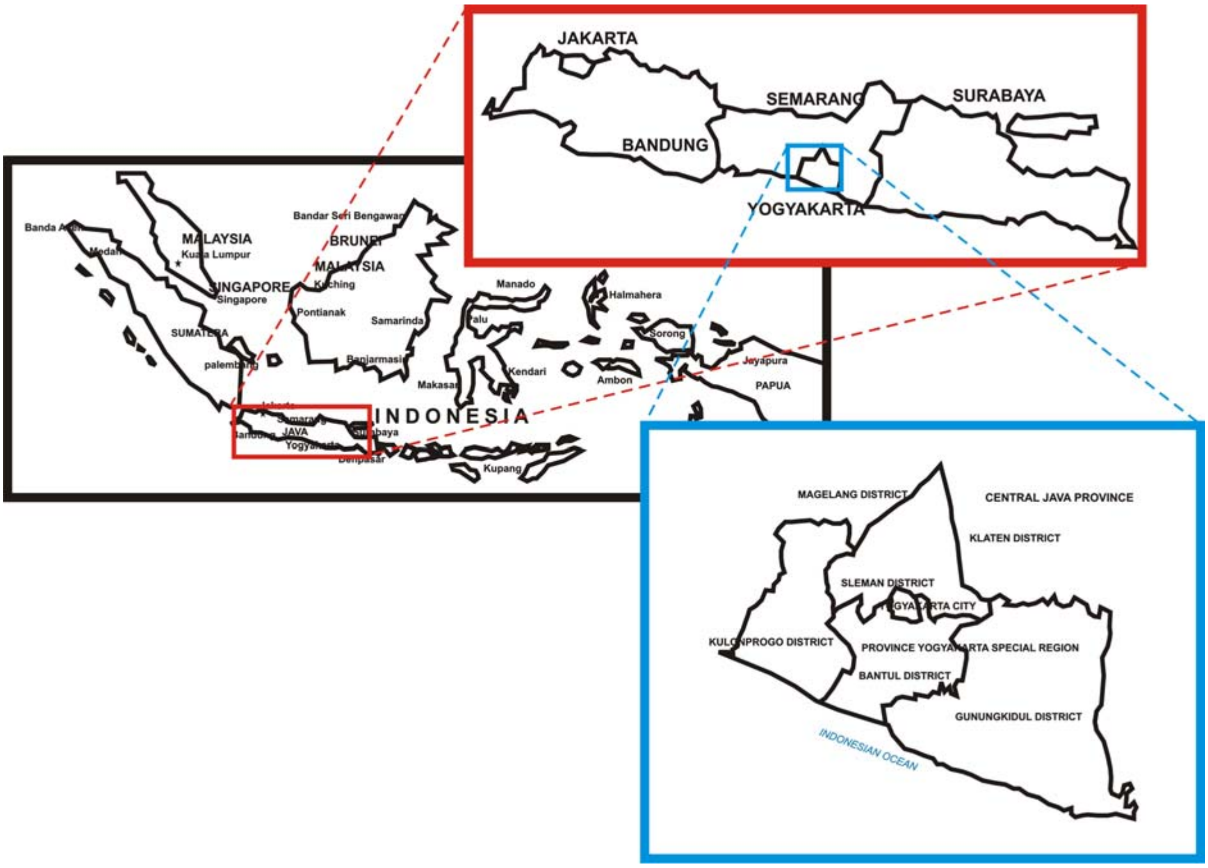


Abb. 1: Die Lage des Untersuchungsgebietes in Zentral-Java. ‚Kartamantul’ umfasst den zentralen Teil der Provinz Yogyakarta (DIY) mit den Teilen Yogyakarta, Sleman und Bantul
Quelle: Bappeda, 2001, verändert; Widodo, 2004

Das Untersuchungsgebiet ist durch relativ gleichbleibende Temperaturen (22°-23°C) und wechselnde Niederschläge im Jahresverlauf geprägt. Während der fünfmonatigen Regenzeit fallen etwa 80% der Niederschläge. Die Niederschlagsmenge im Untersuchungsgebiet liegt bei etwa 2.000 mm/a mit großen Unterschieden zwischen den einzelnen Landschaften (1.500 mm bis 3.500 mm/a). Hydrologisch ist das Wassereinzugsgebiet in Sleman von besonderer Bedeutung, da es am Fuße des Merapi-Vulkans liegt und die höchsten Niederschläge erhält. Veränderungen der Landnutzung in diesem Gebiet haben besonders große Auswirkungen auf die übrigen, tiefer liegenden Gebiete, d.h auf Yogyakarta und Bantul.

Alle drei Gebiete haben einen fast gleichen historischen Hintergrund und in allen drei Gebieten herrschen ähnliche sozio-kulturelle Bedingungen. Religiöses wie staatliches Oberhaupt ist der Sultan von Yogyakarta, der sehr hohes Ansehen genießt.

Die hohe Bevölkerungsdichte in den 3 untersuchten Gebieten beeinflusst, zusammen mit dem Bevölkerungswachstum, die Entwicklung der Landnutzung. Der städtische Raum breitet sich auf

Kosten der Ackerfläche permanent aus und beeinflusst Wasserbedarf wie auch Grundwasserneubildung.

Ziele der Arbeit: Bisher sind keine umfassenden Forschungsarbeiten in diesem Gebiet Indonesiens zu dem Komplex Bevölkerung–Landnutzung–Hochwassergefährdung–Grundwasserübernutzung-Regenwasser-Managementl durchgeführt worden. Die vorliegende Arbeit hat daher das Ziel, die wissenschaftliche Basis für ein Beispiel des „Integrierten Wasserressourcen - Managements“ unter indonesischen Bedingungen zu erarbeiten. Darüber hinaus soll die Arbeit Empfehlungen für politische Entscheidungsträger bieten, die zu einer besseren Nutzung der vorhandenen Ressourcen, insbesondere auch der Niederschlagsressourcen, dienen können.

Die Arbeit befasst sich daher mit folgenden Themen:

- Analyse der Bevölkerungsentwicklung und der Landnutzung in der Untersuchungsregion ‚Kartamantul' (Yogyakarta, Sleman und Bantul) (Abb. 2)
- Erfassung und Analyse der vorhandenen Niederschlagsdaten
- Berechnung des oberflächlichen Abflusses in Abhängigkeit von Niederschlag, Landnutzung und Topographie
- Bestimmung geeigneter Methoden des Regenwassermanagements, in Abhängigkeit von den sonstigen vorhandenen Wasserressourcen, zur Vermeidung von Hochwasser wie von Wassermangel
- Abgleich des Wasserbedarfs der einzelnen Gemeinden der 3 ‚Kartamantul'-Gebiete mit den vorhandenen Wasserressourcen. Erarbeitung von Plänen zur Regenwasser-Bewirtschaftung (Rainwater Harvesting) in Abhängigkeit von den human-geographischen und geo-hydrologischen Bedingungen
- Ausarbeitung von Empfehlungen zu einem optimal angepassten „Integrierten Wasserressourcen Management - Systems“ unter besonderer Berücksichtigung der verbesserten Nutzung des Niederschlages und des oberflächlichen Abflusses.

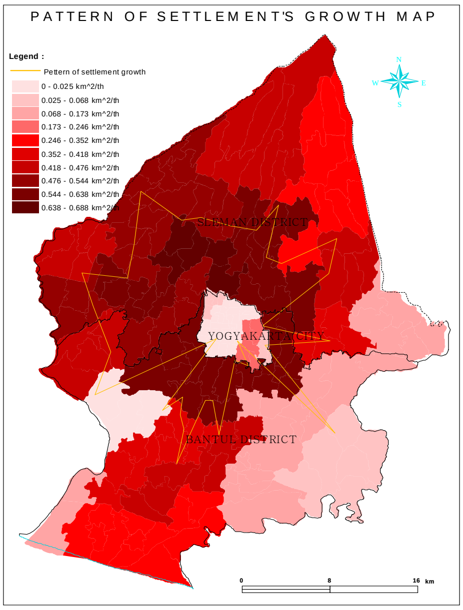


Abb. 2: Bevölkerungsveränderungen der Gemeinden des Kartamantul-Gebietes im Zeitraum 1994 – 2000
Quelle: LANDSAT-Satellitenbilder 1994-1996-1998-2000 (Arc/View Analyse)

Datenbasis: Die in zum Teil sehr aufwändiger Arbeit geschaffene Datenbasis umfasste Daten zu folgenden Bereichen: Bevölkerung, Urbanisierung, Landnutzung, Niederschlag, Bodenbedingungen, Vegetation, Geo-Hydrologie, Grundwasserqualität, Grundwasserspiegelfluktuation und zur städtischen Wasser-versorgung (PDAM). Zu den erfassten primären und sekundären Daten gehörten auch LANDSAT-Satellitenbilder. Die Daten wurden auf Plausibilität geprüft, analysiert, Trends ermittelt und dann im Rahmen eines Geographischen Informationssystems miteinander abgeglichen (Abb.5).
Ein Ergebnis dieses Abgleichens war das Erstellen von Gefährdungskarten (Vulnerability Maps), die Auskunft darüber geben können, welcher Art die Gefährdung durch Wassermangel ist, welche Größe der Mangel im Laufe eines Jahres und unter extremen klimatischen Bedingungen erreichen kann und wie man diesem Mangel sinnvollerweise begegnen kann.

Landnutzung: Basierend auf LANDSAT TM - Bildern der Jahre 1994 bis 2000 wurde der Wechsel in der Landnutzung erfasst, insbesondere der Wechsel vom Ackerland zu Siedlungsgebieten, und Trends ermittelt. Bei einer Fortsetzung der gegenwärtigen Veränderungen würden im Jahre 2034 das gesamte Ackerland des Untersuchungsgebietes Kartamantul verschwunden sein und Siedlungen Platz gemacht haben. Mit der Ausbreitung der Siedlungsflächen geht eine verminderte Infiltration, ein erhöhter oberflächlicher Abfluss und ein erhöhter Wasserbedarf der Bevölkerung einher.
Im Rahmen dieser Studie wurden folgende Maßnahmen auf ihre Wirksamkeit untersucht:

- Maßnahmen zur Begrenzung der Siedlungsfläche
- Ein verbessertes Dränsystem, das einerseits Überschwemmungen verhindert, aber andererseits das Wasser zurückhält für eine Nutzung in der Trockenzeit
- Maßnahmen des Regenwasser-Managements.

Regenwassermanagement: Unterschieden werden Maßnahmen der Speicherung von Regenwasser bzw. oberflächlichem Abfluss und Maßnahmen der geförderten bzw. ‚erzwungenen' Infiltration.

(1) Speicherung

Diese Regenwasserspeicherung kann „on-site“ und „off-site“ erfolgen. Bei dem erstgenannten Typ erfolgt die Speicherung in der Bodenmatrix (für landwirtschaftliche Zwecke) oder in Behältern verschiedenster Art bzw. in Zisternen. Diese Behälter können größere Krüge, Fässer oder große Tanks sein. Zisternen werden unterirdisch angelegt und können von wenigen Kubikmetern bis zu Hunderten, ja Tausenden von Kubikmetern Wasser speichern.

Die „Off-site“-Speicherung von Regenwasser erfolgt zum Beispiel in Rückhaltebecken oder in Reservoiren verschiedener Größe, von kleineren Teichen bis zu Talsperren.

(2) Infiltration

Die zweite Möglichkeit des Regenwasser-Managements ist die Infiltration des überschüssigen Niederschlages, die im einfachsten Fall durch Rasen-, Busch- oder sonstige Vegetations-Flächen erfolgt. Innerhalb des Siedlungsraums können Gehwege, Parkplätze etc. mit Versickerungs-Pflasterung versehen werden, deren Wirkung noch weit übertroffen wird durch das Anlegen von Versickerungsgräben, das Anlegen von Versickerungsteichen oder die Nutzung von Injektionsbrunnen.

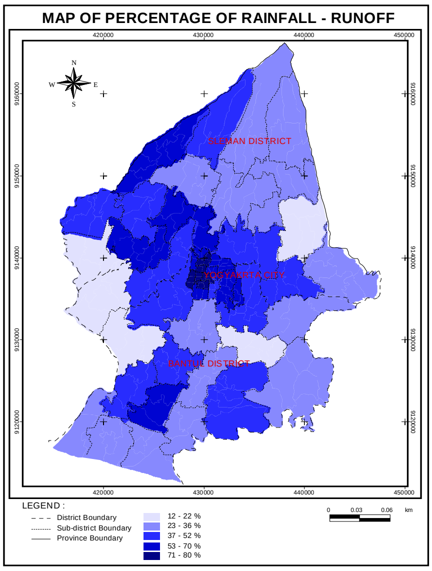


Abb. 3: Der durch Anwendung der ‚Curve Number'- in Kombination mit der Thiessen-Polygon-Methode ermittelte Niederschlags-Abfluss-Koeffizient für Kartamantul

In Indonesien wird bereits die „On-site“-Regenwasserspeicherung angewandt, indem man das Wasser von Hausdächern in Tanks speichert. Insbesondere in sehr trockenen Gebieten hat die Regierung entsprechende Maßnahmen ergriffen und die Bewohner in der Anschaffung solcher Tanks unterstützt. Die Wirkung scheint aber nicht optimal zu sein; die Untersuchung ergab, dass viele dieser Regenwasser-Sammeleinrichtungen nicht funktionierten. Gemäß einem Bericht der WHO / UNICEF aus dem Jahre 2004 wird das Sammeln von Regenwasser von Hausdächern in Indonesien von weniger als 2,3 % der Bevölkerung praktiziert. Die Untersuchung ergab, dass Projekte nur dann erfolgreich waren, wenn die angebotene Technik optimal zum Standort passte, wenn der Staat die Aktion sinnvoll unterstützte und wenn die Menschen sich des Ernstes der Lage bewusst waren und die Neuerungen als notwendig und sinnvoll betrachteten.

Oberflächen-Abfluss: Ob Niederschlag infiltriert oder oberflächlich abfließt, hängt, neben der Niederschlags-Intensität, von der Landnutzung, den Bodenbedingungen (Bodenhydrologie) und der Landbewirtschaftung (z.B. Terrassenbau) ab. In dieser Arbeit wurde die international weit verbreitete ‚Curve Number'-Methode des US Soil Conservation Service angewandt und an die lokalen Bedingungen angepasst (Abb. 3). 37 von 153 Dörfern wurden einer Vor-Ort-Überprüfung (Field verification) unterzogen und Modifikationen vorgenommen.

Wasser-Vulnerabilitäts-Index: Es wurde eine Formel zur Bestimmung der ‚Wasser-Vulnerabilität' entwickelt, die folgende Parameter beinhaltet: Landnutzung, oberflächlicher Abfluss (auch in Abhängigkeit von der Regenintensität), Grundwasser-Verfügbarkeit, Grundwasserspiegel-Fluktuation und die Versorgung mit Wasser aus dem städtischen Leitungsnetz. Die Vulnerabilität der Wasserressourcen ist ein relativer, nicht-messbarer, dimensionsloser Parameter. Die Genauigkeit der Schätzung hängt ab von der Menge, Qualität, Darstellung und Verlässlichkeit der vorhandenen Daten. Die im Untersuchungsgebiet durchgeführten Forschungen haben ergeben, dass etwa 70% Überschuss an Regenwasser in der Regenzeit gegeben ist, das in der Trockenzeit genutzt werden könnte.

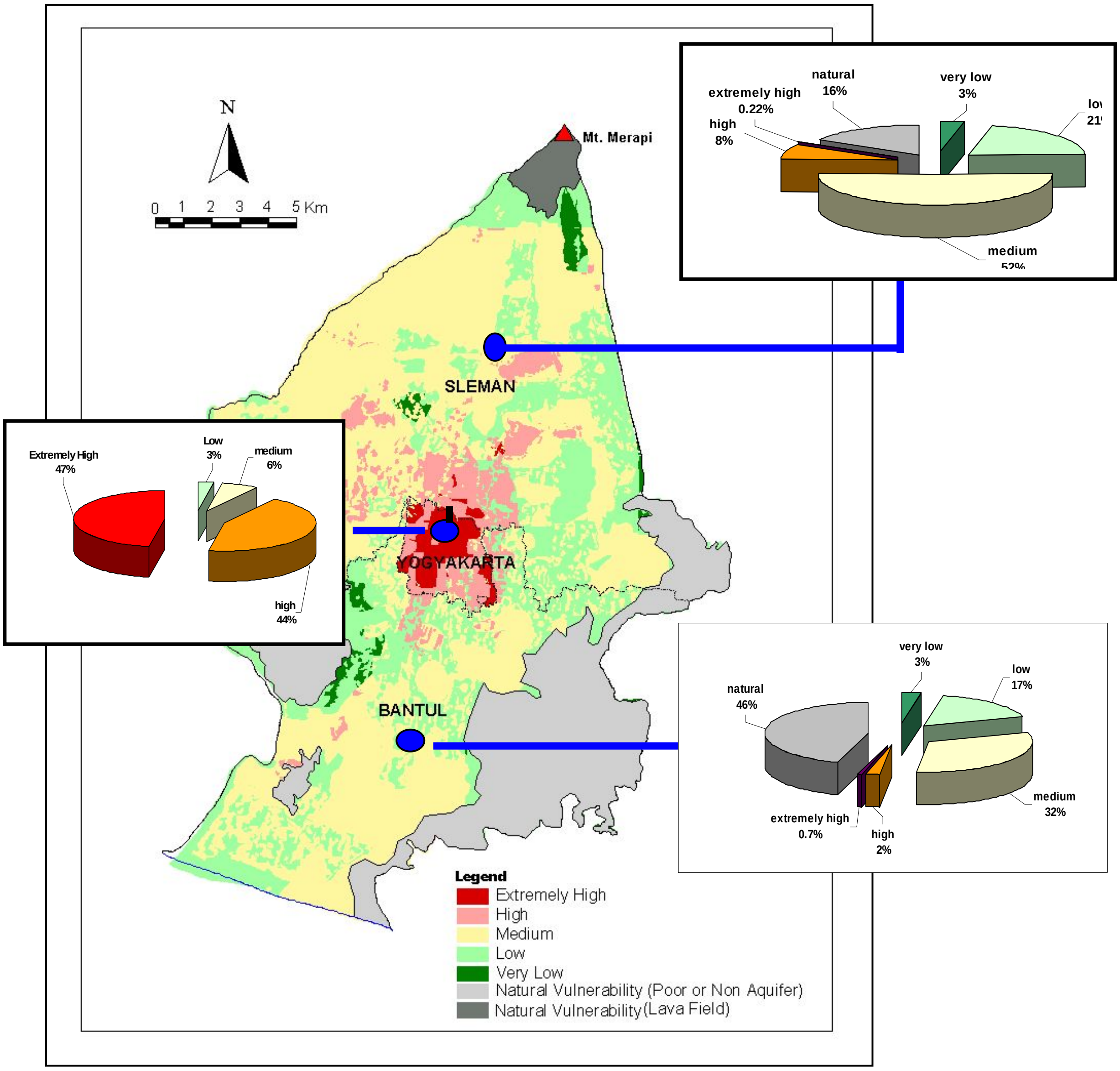


Abb. 4: Zusammenfassende Darstellung der Wasser-Vulnerabilität im Untersuchungsgebiet. Unterschieden werden 5 Stufen der anthropogenen Vulnerabilität und 2 Stufen der natürlichen Vulnerabilität.

Die Wasserressourcen-Vulnerabilität wurde unterteilt in drei Hauptgruppen: (1) Wassereinzugsgebiet, (2) Gebiet anthropogener Vulnerabilität und (3) Gebiet natürlicher Vulnerabilität (Abb. 4). Es werden 5 verschiedenen Kategorien der anthropogenen Vulnerabilität unterschieden. Für jedes dieser Gebiete werden spezielle Maßnahmen des verbesserten Wassermanagements empfohlen.

Neben den bereits o.g. Maßnahmen des Regenwasser-Managements werden noch folgende Methoden diskutiert: Injektions-Brunnen, Infiltrations-Becken, Flusspolder, neue Formen von Dränsystemen für Straßen und Wege, teilweise kombiniert mit Anlagen zur Abflusswasser-Sammlung. Für jede Gemeinde werden Maßnahmen empfohlen und in den Gesamtzusammenhang des Wasserressourcen-Manage-ments gestellt.

Auch die Ökonomie der empfohlenen Maßnahmen wird ausführlich behandelt, wobei die ökonomische Analyse immer mit der sozialen verknüpft wird, um die Implementierung zu erleichtern und die Nachhaltigkeit zu sichern. In diesem Zusammenhang werden die Ergebnisse einer Befragung im Untersuchungsgebiet vorgestellt, die die Einstellung der Bevölkerung zum Regenwasser-Management beinhaltet, wobei zwischen dem generellen Interesse, der Fähigkeit zur Finanzierung (‚Ability to Pay') und der Bereitschaft zu investieren (‚Willingness to Pay') unterschieden wird.

Die Beteiligung der Wassernutzer an die Planungen wird als essentiell herausgestellt, Ferner werden die Maßnahmen diskutiert, die von staatlicher Seite benötigt werden, um diese Konzepte durchzusetzen.

Da dieser Studie das Konzept des ‚Integrierten Wasserressourcen-Managements' zugrunde liegt, werden nicht nur die Fragen des Angebots-Managements, z.B. durch verbesserte Grundwasser-Verfügbarkeit, sondern auch Aspekte des Nachfrage-Managements dargestellt.

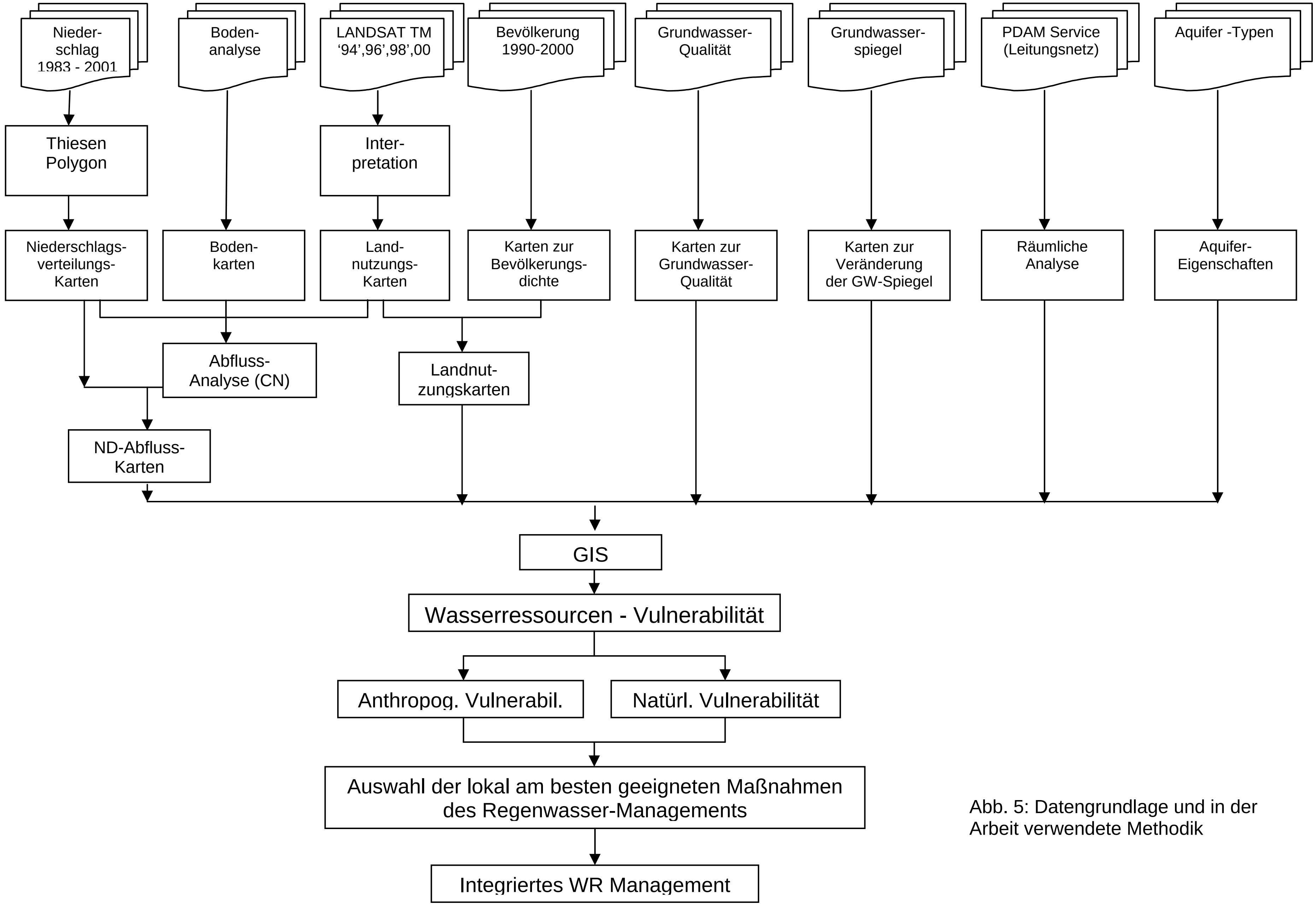


Abb. 5: Datengrundlage und in der Arbeit verwendete Methodik

ABSTRACT

Water-related problems continue to hinder people's efforts towards health and prosperity on a global as well as on national scale; this is also true for Indonesia. Population growth triggers the expansion of cities and suburban areas, leading to high urbanization rates, paralleled by grave land use changes. This reduces the capacity of the land to let rainwater infiltrating into the ground and, consequently, reducing groundwater recharge. While the groundwater level in urban areas is sinking**,** urban population demands a continuous water supply to cover its daily water needs. The problem is often aggravated by the inadequate service of the public water authority.

Indonesia, as many other tropical countries, has to cope with pronounced seasons: droughts in the dry and floods in the rainy season are indisputable elements of the water resources problem of the country. Consequently, diseases and social problems threaten people's life. In addition, the habit of throwing solid or liquid wastes into the rivers increases surface- and groundwater contamination, resulting in scarcity of clean-water resources. These conditions generate conflicts over water resources among the stakeholders.

Sustainable water resources development aims at providing (clean) water accessible for all, controlling the damaging power of water and preserving the environment. It should be implemented in the harmony of socio-cultural, economic and environmental orientations.

This dissertation shall contribute to 'sustainable water resources development' in Central Java, Indonesia. Yogyakarta City, Sleman Regency, and Bantul Regency were selected as research areas, located in the 'Special Territory of Yogyakarta' (DIY). So far, no research work in that area has been done to study in an integrated manner (I) the long-term development of the population, including migration, (II) the past and anticipated changes of the land use system and their effects on water resources, (III) the surface and groundwater resources in quantity and quality and (IV) the potential of rainwater harvesting as a viable element of water resources management. This research work is complemented by a description of climate, geology, socio-cultural conditions, economy and legislation in that part of Indonesia. This study shall provide the scientific basis for a true 'Integrated Water Resources Management' under Indonesian conditions. Furthermore, it offers recommendations for implementation, focusing on rainwater harvesting.

Research on population and land use changes in their relation to the conditions of water resources have been found as lacking in this area. Therefore, the activities in this research study were:

(a) Analyzing the conditions of the existing land use and the pattern of the land use change,
(b) Investigating in seasonal and spatial distribution of rainfall,
(c) Calculating the distribution of runoff according to rainfall and land use status,
(d) Determining methods and a priority scale of rainwater harvesting, based on critical levels of spatial water resources availability,
(e) Correlating rainwater harvesting with the local geo-hydrologic conditions, and

(f) Developing the best rainwater management practices based on the analyzed physical data and socio-cultural factors.

The data used in this research work cover the features: population, urbanization, land use, rainfall, soil texture, vegetation, geo-hydrology / aquifer system, groundwater quality, groundwater fluctuation, and piped water supply (PDAM) service. The primary and secondary data, including LANDSAT images, were analyzed, based on their characters and their objectives of data-use. After they are examined, corrected, and collocated as needed, the whole data then were overlaid, and finally the vulnerability of water resources in the research area was identified. Ultimately, based on the vulnerability conditions of the various areas, recommendations how to overcome water problems were elaborated, giving special attention to the best suited rainwater management practices.

Rainwater is the most important component, which is discussed in this study, seen as essential element of integrated water resources management. The various types of collection are described, as well as the different modes of storage: either in tanks, cisterns etc. for direct use or underground by applying artificial groundwater recharge. The results of this research work are presented in the form of scientific recommendations, for improved planning as well as to raise people's awareness how to make best use of the water resources available.

A practical usage of this research work could be its consideration in development programs, not only for Yogyakarta area (DIY), but also for Indonesia in general. The figures compiled as well as the analyses done, together with the recommendations developed, could be used by policy makers and planners alike to protect the environment, specifically the water resources, and to serve the people better in order to arrive at sustainable water resources management.

In regard to the study area, a potential rainwater surplus that can be harvested for fulfilling domestic, industrial, and irrigation needs, is given in Sleman and Bantul, whereas Yogyakarta shows a deficit. The whole research area of Yogyakarta, Bantul and Sleman experiences about 70% surplus of rainwater that can be managed properly by developing rainwater harvesting (RWH). The technical approaches of RWH mentioned are to develop technologies mainly for optimizing groundwater recharge in DIY, providing potable water and water for irrigation, and preventing annual floods and droughts.

The types of RWH that can be applied in the main study area are artificial groundwater recharge, conservation ponds, river polders, and eco-drainage systems. The eco-drainage system can be adopted in the dense urban areas, especially along the streets, and finally the RWH model suitable for a poor aquifer area is the rainwater storage in tanks or cisterns.

The analysis comes to the conclusion, that droughts in the research area can be avoided, if the rainwater is well managed. A problem is the large dimension of rainwater to be handled / stored; hence, various parties should be involved. As RWH can meet people's basic water needs as well as improve their welfare, rainwater harvesting methods should receive the required backing by politicians and planners. To yield optimal results, rainwater harvesting should be combined with the development of (other) water conservation methods.

CHAPTER 1

INTRODUCTION

1.1 Background

Droughts, floods, water pollution, and regional conflicts over water resources occur in different corners of the world. Water-related problems take different shapes, mirroring the looming water crisis, which will undoubtedly increase during the 21st century. The water crisis overshadows the development efforts in most of developing countries in the world, hindering economic growth and well being of the population (Prinz, 2005).

In fact, the global demand for fresh, potable water has increased over fourfold in the last 50 years mainly due to population growth and development; the world population has almost doubled during the same period. Furthermore, Tukiran (2000) projected that 13-20% of the global population will live in countries with a water scarcity problem by the year of 2050.

A country is defined as having a water scarcity problem when less than 1000 m^3 of water/capita/year are provided for the residents. In reality, many regions in the world experience a much more severe problem, having less than 500 m^3 of water/person/year (Hong and Zehnder, 2003). On the other hand, the threshold of 2000 m^3/persons/year already indicates that a region is water stressed. It happens to most countries in the Middle East and Africa. Meanwhile, many other countries will face physical and economical water scarcity issues due to periods of drought and mismanagement of water resources in the future (Pereira, 2002).

There are two types of water use in human activities: (1) Uptake type, where industrial activities, power plants, agriculture, and municipal services are typical agents of it, and (2) *Non-uptake* type that includes such activities as water transportation, fishing industry, recreation and water tourism/sports. For all those activities, water resources management plays a major role to avoid a water crisis.

Obviously, there is an imbalance between the demand and supply of water, between the water discarding and water scarcity, and between the urban and rural development. This has led many countries to adopt an integrated water resources management approach. Its objectives are to minimize water waste, to maximize the efficiency of water use, to maximize the availability of water by limiting the degradation of water supplies and through reuse, to optimize water allocation to all competitors and to the environment as well and finally to limit the access to sustainable levels (Grigg, 1996). In order to realize integrated and optimal solutions, a conscious and systematic consideration of the different elements that create a resource management issue must take place.

Therefore, it is necessary to implement a more intensive management of rainwater through the application of rainwater management (Prinz and Malik, 2002). This system is expected to lessen the probability of flood risks during the rainy season and at the same time to lessen the water shortage during the dry season as well as to increase the supply and the surface level of groundwater.

1.2 Global and Indonesian Water Resources Problems

Some of the global water-related problems quoted from Prinz (2005) are as follows:

1) Nearly one-third of the population of developing countries in 2025, or 2.7 billion people, will live in regions of severe water scarcity; they will have to reduce the amount of water used in irrigation and transfer it to the domestic, industrial and environmental sectors.
2) In India, 460 million people and more than 500 million people in China will live in regions that face absolute water scarcity.
3) Groundwater reserves will be increasingly depleted in large areas of the world. In some instances, this will threaten the food security of entire nations, such as India.
4) Groundwater contamination by human interference, e.g. by industrial effluents, agricultural pollution or domestic sewage water intrusion, will increase.
5) The world's primary water supply will need to increase by 41% to meet the needs of all sectors in a sustainable way in 2025. This increase in water demand is largely due to the increase in the world population, which is estimated to increase to some 80 million people every year, at least up to 2015. This means another India for the world to feed every decade (Mishra et al., 2003).
6) The phenomenon of urbanization faced mainly by the Developing World: "Safe water and sanitation close to the home for everyone", as demanded by the Mar del Plata Action Plan, seems to remain a dream when acknowledging that in 2025 nearly 4 billion people will live in urban areas – and the process is most dramatic in countries with relatively few resources (GWP, 2001).
7) Seawater intrusion in coastal aquifers due to over-drafting in most tropical and subtropical countries accelerates, in some areas, the already-existing natural problem of poor groundwater quality, e.g. of high salinity. In Tunisia, 26% of surface water, 90% of water pumped from shallow and 80% from deep aquifers has a salinity of more than 1.5 g per litre (Vrba, 1994).
8) Other problems like water-related diseases, frequent floods, soil salinization, acid rain, the extinction of freshwater species, the disappearance of wetlands, etc., are encountered worldwide (Prinz, 2005).

Indonesia is located between Asia and Australia. The length of Indonesia is more than 5000 km and its width is more than 2000 km, and it consists of 17.508 small and big islands. Geographically, Indonesia lies on the *Intertropical Convergence Zone* (Tjasyono, 1999). Since Indonesia has a specific characteristic of climate, i.e. it has high temperature and high air humidity (Weerf, 1994).

According to Moeljono (2000), the water resources in Java, Madura, Bali, and the Lesser Sunda Islands have been in very serious conditions, while in the islands of Borneo and Papua they have not. Java Island as the most densely inhabited area in Indonesia is exposed to a hard pressure of high population and very limited natural resources, including water. During the dry season, many people face difficulties in getting water not only for irrigation but also for drinking purposes. Ironically, floods occur every year due to the high rainfall during the rainy season. This high rainfall should have been infiltrated into the ground to recharge groundwater. But large portions of it turn into runoff because the land surface is sealed to a large extent, covered with buildings or infrastructure. Consequently, most of the rainwater is ineffectively flowing away to the river or sea, or it contributes to floods.

In fact, the complexity of water resources problems compounds the problems happening in Indonesia nowadays. Although the government policy and programs relating to water resources seem to be ideal, in fact, the predicament of water resources in Indonesia is still unavoidable. Some facts and figures shall be given below.

Until today, no political party in Indonesia pays very much attention to the more intensive use of rainwater (Kodoatie and Sjarief, 2005; Asdak, 2007). Therefore, the national development program must include a sustainable water resource management that involves all stakeholders and respects the nature.

Moreover, the increasing water resource problems in Indonesia due to land use changes must not be ignored. According to Wisnubroto (1994), one of the most pressing issues of global change research is the interaction of land-use changes with water resources related to climate. So far, rarely have studies been done to estimate the impacts of land-use changes on water related issues. Therefore, this research study brings up the issue and discusses rainwater harvesting as one of the alternatives for water resource management in Indonesia.

1.2.1 Population Growth and Urbanization

Urbanization is one of the most significant processes affecting human societies. Until recent times, urbanization has been regarded as a direct sign of modernization and development. Throughout the history, industrialization and urbanization have tended to occur together. However, this relationship, one that has been held for more than 6000 years since the emergence of the first cities, has changed fundamentally since 1945 (Mantra, 2002).

In 1800s, only about 3% of the world communities lived in urban area, and in 1900s, it increased up to about 14%. After the Second World War, the world community living in urban area reached 40% and went up again until 50% in 1991 (Yunus, 2005). Meanwhile, in Indonesia, the number of people living in urban areas showed a 16-fold increase between 1920 and 1990. Tjahjadi (1998) estimated a 60% increase in the number of people living in urban areas between 1990 and 2025. This development will certainly influence changes in land use. According to the status and history, Yogyakarta region has experienced a very rapid development, especially the extension of housing area, which reflects the development of society and land-use change (Yunus, 2001).

Furthermore, Suryantoro (2002) assumed in his research that in Yogyakarta City as in other development centres, the number of people living in the outskirts of the city determine the magnitude of land-use changes. The areas along the highways such as Ring Road, Jalan Kaliurang, and others contribute strongest to the land-use change. The development of the city and regions surrounding it may generally decrease the environmental quality, including the quantity and quality of water resources.

1.2.2 Urban Water Problems

The increasing water demand is caused not only by the increasing population but also by the lifestyle. In urban areas, in compliance with the level of economic and social development, the water demand can reach 200–300 l/head/day (Prinz et al., 2007). Furthermore, industry usually contributes significantly to the increasing water demand especially in urban and peri-urban areas.

In Developing Countries like Indonesia, urban water problems are also related to the poor performance of public water service system. The system cannot provide water for all urban water consumers, for example in the Philippines in 1999, only 47% of households in urban areas were connected to municipal water service; in Indonesia, it was even less with only 37% (UNEP, 2004). This is worsened by the fact that about 40-60 % of distributed water is lost due to leakage, theft, and poor accounting. In addition, about more than 80% of public water suppliers in Indonesia are near to collapse due to limited budget, lack of attention on water system, and inefficient, fragmented water management (Widodo, 2003).

1.2.3 Flood and Drought

Indonesian people recognize two seasons, i.e. dry season and rainy season. However, those two seasons have been termed flood season and drought season. This last decade has proved a worsening impact of drought in some regions in Indonesia. Millions of hectares of agricultural crops, including rice/paddy, failed to harvest, worsening the malnutrition problem. The bloat disease due to starvation (“*busung lapar”*), which attacked children in some regions in Indonesia during May 2005, is regarded as one of the impacts of drought. Around 36.1 million people or about 16.6% (Yunus, 2005) of Indonesians living under the poverty line will be continually threatened by the disease caused by many factors, including drought.

Moreover, Indonesian people, especially those who live in Yogyakarta are dependent on groundwater to fulfil the domestic, industrial, and commercial water needs (Sudarmaji, 2004). In the dry season, people dig wells surrounding the domestic water resources, like in Yogyakarta and Bantul. On the other hand, floods destruct some regions in Indonesia, including Jakarta, in the rainy season. In March 2005, Yogyakarta was also surprised by a flash flood from Code River. Hundreds of houses could not be prevented from being destroyed by the swift flow of water from the river.

1.2.4 Groundwater Degradation

Sudarmaji (2004) said that 83.5% of domestic water required by the people in Yogyakarta city is taken from shallow groundwater through wells. In addition, compared to the service quality of PDAM in Yogyakarta city, the PDAM service quality in Bantul and Sleman Regency has driven the people to rely mostly on groundwater as well.

However, groundwater degradation is unavoidable today. The expansion of housing and industrial areas decreases the space for water absorption and threatens the environment’s capacity to supply water. This even worsens the groundwater degradation; moreover, the management of groundwater is still very apprehensive as stated by Kodoatie and Sjarief (2005), "Groundwater is still managed as a can of soda with many straws". On the other hand, the capacity of water reservoir infrastructure, such as dams and basins, keeps decreasing as the impact of sedimentation. Consequently, the reliability of water supply also decreases, while actually the potential rainfall, which is still considered useless since it can cause floods, can recharge the groundwater to increase water supply. The low quality of operation and maintenance even compounds this problem. Another issue is the high population density, especially in urban areas, that has the potential to contaminate groundwater and river water through solid or liquid waste discarding.

For cities lying on a fluvial volcanic area, such as Yogyakarta, it is not difficult to get domestic water from the ground, and the groundwater in such area has relatively good quality (Vrba, 1994), unless the groundwater has experienced degradation, in either quality or quantity (Sudarmaji, 2004). Based on several reports, such degradation happens to the groundwater in Yogyakarta (Sudarmaji, 2004; UGM, 2001; Bapedalda, 2001). The quality degradation is marked by the high concentration of coli bacteria, nitrate, and nitrite, while the quantity degradation is indicated by the surface decrease in some regions. This damaged groundwater is very difficult to cure. If it happens continuously, it will end up with an environmental disaster, which has a wide implication.

1.2.5 Uneven Distribution of Water Resources

Indonesia, located in a tropical area, is the fifth biggest state in the world in terms of water availability (Asdak, 2007). However, Indonesia naturally faces the constraint on fulfilling the water demand because the distribution is not flattened out spatially and seasonally. Spatially, Java Island, dwelt by around 65% of Indonesian citizens, only has about 4.5% of the potential national fresh water. Moreover, the water quantity and quality in Java, Madura, Bali and Nusa Tenggara islands are becoming more critical, whereas in Kalimantan and Papua, water resources are still plentiful (Moeljono, 2000).

Then seasonally during a year, 80% of water is available in the rainy season for five months while the other 20% is in the dry season for seven months (Moeljono, 2000). The abundant water during the rainy season is beneficial and hazardous at the same time, causing such social threat as floods, while during the dry season water scarcity is potential to be another social threat, i.e. drought. In 2002, floods at low to high intensity hit 20 provinces; in the same year, droughts occurred in 17 provinces.

1.2.6 Watershed Degradation

The environmental damage has significantly decreased the carrying capacity of river watershed to restrain and store water, accelerating the destruction of water catching area. It is shown by the increase in deforestation, which reached 1.6 million hectares per year during 1985-1997 and 2.1 million hectares per year during 1997-2001. Another indicator is the increasing number of critical river watersheds: 22 river watersheds in 1984, 39 in 1992 and 62 in 1998 (Widodo and Malik, 2007).

The numbers lead to the more serious water scarcity and increase the damaging capacity of water. Water scarcity has forced people to use water resources inadvisably; the abundant exploitations of groundwater cause a rapid degradation in the surface and quality of groundwater, intrusion of seawater, and land subsidence (Moeljono, 2000). Furthermore, land-use change due to urbanization pressure and modernization also makes river watersheds more environmentally unbalanced.

1.2.7 Water Conflict Potential

In line with the increasing standard of living, the amount of water required for domestic, agricultural, and industrial sectors will also increase. As reported by Public Work Department of Yogyakarta Province (2003) the need for water nationally reached 112.3 billion meter-cubic in 2003 and estimated 117.7 billion meter-cubic in 2009. This will definitely make water scarcity worse. During the dry season in 2003, Java and Bali islands experienced water deficit of 13.1 billion meter-cubic, while in Nusa Tenggara, it reached 0.1 billion meter-cubic. The worsening water scarcity can potentially trigger various forms of water conflicts, either inter-group of water consumers, interregional, or intergeneration. The uncontrolled conflicts of water are potential to involve a wider dimension; they can trigger various forms of disintegration (Prinz et al., 2007). Moreover, the conflict among political elites will be a potential cause of disintegration of water resources management or even national disintegration.

1.2.8 Coordination, Institution, and Application System

Up to now, the water resources in Indonesia are managed by various institutions, such as Department of Mineral Resources and Energy, Department of Settlement and Regional Infrastructure (*Kimpraswil*), Department of Agriculture, Department of Forestry, the Office of State Minister of Environment, the Local Government of Province, the Local Government of Regency/City as the local autonomy agents, which cover the Public Work Service, Department of Forestry/Forestry Service, Mining Service and Local Environmental Protection Agency. Each of those institutions works based on the need and interest often without any cohesive and integrated coordination, leading to a chaos in management. According to Kodoatie and Sjarief (2005), one of the constraints is because the government officers are still slow, selfish, and inflexible in bureaucracy.

The weak law enforcement worsens the situation. Although the basic principles have been arranged in Law No. 7/2004 on Water Resources (GOI, 2004), some efforts to publish its operational guides should follow. Furthermore, breaking laws to express reform euphoria and natural resources irrational exploitation, including water, prove the negative impacts of regional autonomy. The change of development paradigm, which is in line with the spirit of reform, needs some adjustments to arrange the governance, society role, and private party role in managing the water resources infrastructures.

1.2.9 Data and Information System

The management of water resources has not been supported by an adequate database and information system. The available data and information do not have a fixed quality standard and are still not ready when needed.

Nevertheless, public cannot get a good service to access the data. Many institutions collect and manage the data and information on water resources, but there are still many obstructions in the exchange of data and information among institutions. Another problem is the negligence and lack of appreciation of the importance of data and information.

1.2.10 Water Privatization

According to Section 33 Article (2), (3), and (4) of UUD (Indonesian Constitution) 1945, the natural resources including water should be managed by the state and optimally used for the prosperity of people. However, based on Law No. 7/2004 on Water resources, especially Section 7 Articles (1) and (2), Section 8 Article (1), and Section 9 Article (1), the right of water utilization is given to private sectors more freely. Then, all representatives of religious community refused the sections in this law, worrying the practice of water privatization. Nevertheless, according to Irianto (2005), 16 community organizations which focus on water resources conservation activities officially refused the Law of Water resources by filing a lawsuit No. 059-060/PUU-II/2004 to the Constitution Law Court.

Academics, non-governmental organizations, and other activists refuse water privatization at any forms and characteristics for many reasons. It is a great concern that the right of water utilization will lead to:

1) Commercialization of water: It will shift the function of water as a social goods according to either custom, social, or even religious belief.
2) Different water prices: Water will be allocated for those in high priority of being able to give maximum profit, i.e. rich people.
3) Liberalization of water use: Strong groups of general industry, commercial sectors, and packaged drinking-water industry will beat the weak groups of farmers and the poor.
4) Difficulty in stopping the practice of water commercialization although it clearly causes financial loss especially to people and generally to the environment.

Water private-ownership and water pricing represent two different matters, which interconnect to each other; water pricing is not always related to water private-ownership. However, the fact shows that water pricing gives a very significant impact in conserving water resources through the economizing of water use. This rule is run in Germany and other countries (Prinz, 2005). It is also stated that increasing the water price in Germany is in fact able to decrease the amount of water use, from about 150 liters/capita/day (lcd) to about 130 lcd.

1.3 Water Resources Management Policy

The government states that the development of water resources is an effort to give a fair access to all people to get water more easily since it plays an important role to create a healthy, clean, and productive life. Besides, the development of water resources is also purposed to control the damaging capacity of water for society’s life safety. The general targets of water resources development stated by the government cover:

1) Attaining the integrated and continual management pattern of water resources,
2) Establishing a good control of potential conflicts on water,

3) Establishing a good control of the exploitation of groundwater,
4) Increasing the ability to accomplish water demand for domestic, agricultural, and industrial needs with the major priority on households and farmland,
5) Decreasing the impact of flood and drought disasters,
6) Establishing a good control of water contamination,
7) Protecting the coastal area from seawater abrasion, specifically in small islands, boundary areas, and strategic regions,
8) Increasing the active participation of the society,
9) Increasing the quality of coordination and cooperation among institutions,
10) Emerging the continual fund pattern,
11) Providing an actual, accurate, and accessible data and information system,
12) Recovering the condition of water resources and infrastructure, the availability of water resources for the society, and floods control in urban areas.

Therefore, the management of water resources should consider the compatibility between the conservation and utilization, upstream and downstream, exploitation of surface water and groundwater, water demand management and water supply management, and fulfilment of the short-term and long-term demands. In the past, the focus of development was utilization, but then the conservation effort is more dominant to balance the short-term and long-term supply. Besides, fairness is reflected in the development of upstream and downstream areas. Moreover, applying the conjunctive use system in surface water and groundwater exploitation is more encouraging to create a synergy.

The synergy is also mirrored in the effort to make water demand and water use balanced. Supplying the demand only is proven less effective and efficient to solve the problem of water resources management. It should be accompanied by limiting groundwater exploitation, especially for domestic and agricultural needs. Furthermore, rainfall as one of the forms of water resource should be exploited more seriously and comprehensively.

The vegetative approach for water resources conservation is important because the function of vegetation for the environment is irreplaceable. However, since it takes a long period to obtain the result, this approach should be combined with other efforts for at least 5 (five) years, for example technical engineering which is focused on quick yielding. Furthermore, the development of small-scale water reservoir will be prioritized, but that of big-scale water reservoir needs more consideration because it faces a more complex problem, particularly relating to social issues and environment. Other efforts of water resources conservation are not only for preserving the water quantity but also for maintaining the water quality. Through the recharging process, the making of absorption well, or the application of other available and appropriate technologies, water resources are expected to have better quality and greater quantity.

The water resources conservation, supported by river watershed management, is also used for controlling the damaging capacity of water, particularly floods. This non-construction approach should be integrated with the regional planning. In addition, increasing society's participation and partnership among related parties is progressively conducted not only during the flood disaster but also during the recovery of the damaged area.

The development and management of water resources require resetting of the authority and the responsibility of each party involved. The council of water resources and the commission of irrigation are formed and strengthened, to place the coordination mechanism on a firm basis, either among the government institutions or between the government institution and community institution. The two water institutions are also an instrument for controlling various potential water conflicts. Although the authority domain of the central government or the government of province and regency/city has been orderly determined, the cooperation effort through partnerships among the three governmental levels will be carried out continuously to guarantee the integrity of water resources management in a certain area. It also needs the effort to strengthen the civil society, the community participation, and the participation of private institutions. In addition, in managing the water resources, the role of social capital to guarantee the continuity of the infrastructure function is very important, especially in urging people's sense of belonging towards water. The development of social capital will be done through the cultural approach, especially to find and to revitalize the widespread local wisdom.

1.4 Purposes and Objectives of the Research Work

Up to now, there is no comprehensive research study on the land use change and associated water management problems in the research area of KartaManTul, which is a term covering the municipality of Yogya<u>karta</u> and the regencies of Sle<u>man</u> and Ban<u>tul</u> of Yogyakarta Special Province (DIY) in Central Java. The existing research studies are still limited to a small location, such as a village - *kalurahan* (a political district administered by *lurah*), that borders Yogyakarta City (Yunus, 2001). A research study on the land use change in Yogyakarta has been done by Suryantoro (2002). However, this research only focused on the central urban, without evaluating the region of Sleman and Bantul, whereas in fact there are rapid developments lately in those two regencies. In addition, the research on the correlation of land use change and water resources condition has never been done seriously in this research area. The research done by the Mining Service of DIY Province and Department of Geology Engineering of UGM (2001, 2003) focused only on the condition of groundwater without correlating it to the surface water, rainwater and the use of existing land.

Moeljono (2000) conducted a research with a conclusion that the rainwater absorption wells in some parts of Yogyakarta City could increase the quantity of water. This research did not discuss how far the realization of the construction of absorption wells by the dwellers was, especially by those who live in Sleman and Bantul Regencies. Until now, there is not any research discussing the relation among the development of the land use system, the critical condition of water resources, and the rainwater potential. This research is expected to give an alternative solution in order to increase the sustainability of water resources in the research area, particularly by optimally exploiting rainwater.

In detail, the targets of this research can be formulated as follows:

1) Analyzing the condition of the existing land use and the pattern of land use change in the research area covering Sleman Regency, Yogyakarta City, and Bantul Regency. This analysis

uses the media of remote sensing called LANDSAT TM supported by the technology of GIS. The LANDSAT data used in this research are the data of the year 1994, 1996, 1998, and 2000.

2) Investigating the rainwater distribution that represents the natural water resources for supporting human life, living creatures, and ecosystem.
3) Analysing the distribution of runoff according to results of the rainfall and land use status analysis. The Curve Number of USCS is selected as the method to analyze the runoff distribution. The analysis results can become a factor to determine the areas that have insecure water resources.
4) Determining the priority scale and model in developing the rainwater harvesting based on the critical level of spatial water resources and relating it to the local geo-hydrologic factor. The spatial spread of water resources is analyzed using the data of land use change, groundwater degradation, groundwater fluctuation, and rainfall-runoff factor.
5) Developing scenario of the best rainwater management practice based on all analyzed physical data and social-cultural factors.

This study is also expected to offer as well scientific as practical benefits. The scientific benefit can be realized and developed through researches, discussions, seminars, and other analyses concerning the correlation between land use change and population growth, urbanization, regional planning, and the corresponding effects. The recent policy model of development implemented in Indonesia can be re-investigated in a more scientific order to prevent a damage of the existing ecosystem. Moreover, the more perturbing condition of water resources must always be examined based on various fields of knowledge in order to find a more comprehensive, integrated, appropriate management model for each region.

In this research, the critical level of water resources in a certain area is scientifically examined, so it can be delineated specifically for the locations where the problems need to be immediately overcome. In fact, the real culture and technology of rainwater harvesting inherited from the ancestors is abandoned since people apply newer approaches in developing water resources. Rainwater harvesting technology needs to be developed through a more scientific examination to get an optimum result. The role of science as well as scientists becomes very important in this case.

Therefore, the practical usage of this research is related to the development programmed for Indonesia including Yogyakarta region. In terms of development programs of environment and natural resources, the government faces many dilemmas. The growth of housing areas has swallowed farmlands and other agricultural fields, threatening the food resource ecosystem and generally the environmental balance. Although the government has specified the regional development plan with all its rules and laws, in fact, it is unable to face this development phenomenon. The degradation and critical condition of water resources are some of the important factors induced by this condition. Therefore, the results of this research are expected to be used by the policy makers of either central or local government not only in Indonesia but also in tropical Developing Countries in sustaining water resources.

1.5 Research Methodology

This sub-chapter briefly describes the methodology applied in this research. The data used in this research cover:

1) The rainfall data, as the basis to find the potential scale of water resources taken from the rain and the amount of runoff,
2) The LANDSAT imagery, as the basis to find the number of land use and its change and to count the quantity of runoff using the CN method,
3) The soil texture data analyzed together with the land use data for the need of curve number analysis in order to determine the runoff in a unit with a certain extent,
4) The population data for finding the population growth and density of net in the study area,
5) The data of groundwater degradation taken from the secondary data for finding the decrease in groundwater level,
6) The data of groundwater fluctuation, also as the secondary data for finding the groundwater fluctuation between the dry season and the rainy season,
7) The data of piped water supply (PDAM) service for finding the level of PDAM service to the society in getting domestic water,
8) Several types of aquifer, which extremely influence the condition of the local water resources. Merapi aquifer that dominates the study area is a good type of aquifer in terms of natural water resources availability. Therefore, in general, this area is actually prosperous if its water resources are well managed, and
9) Social and economical data to correspond the physical data.

The data are analyzed based on their characteristics and objectives of data-use. After they are examined, corrected, and analyzed, the whole data then are overlaid, and finally the vulnerability of water resources in the research area can be found. Ultimately, based on the vulnerability types, the models for overcoming the water resources crisis are analyzed, and the best rainwater management practice is recommended for each sub-area. The detailed research steps are given in Figure 1.1.

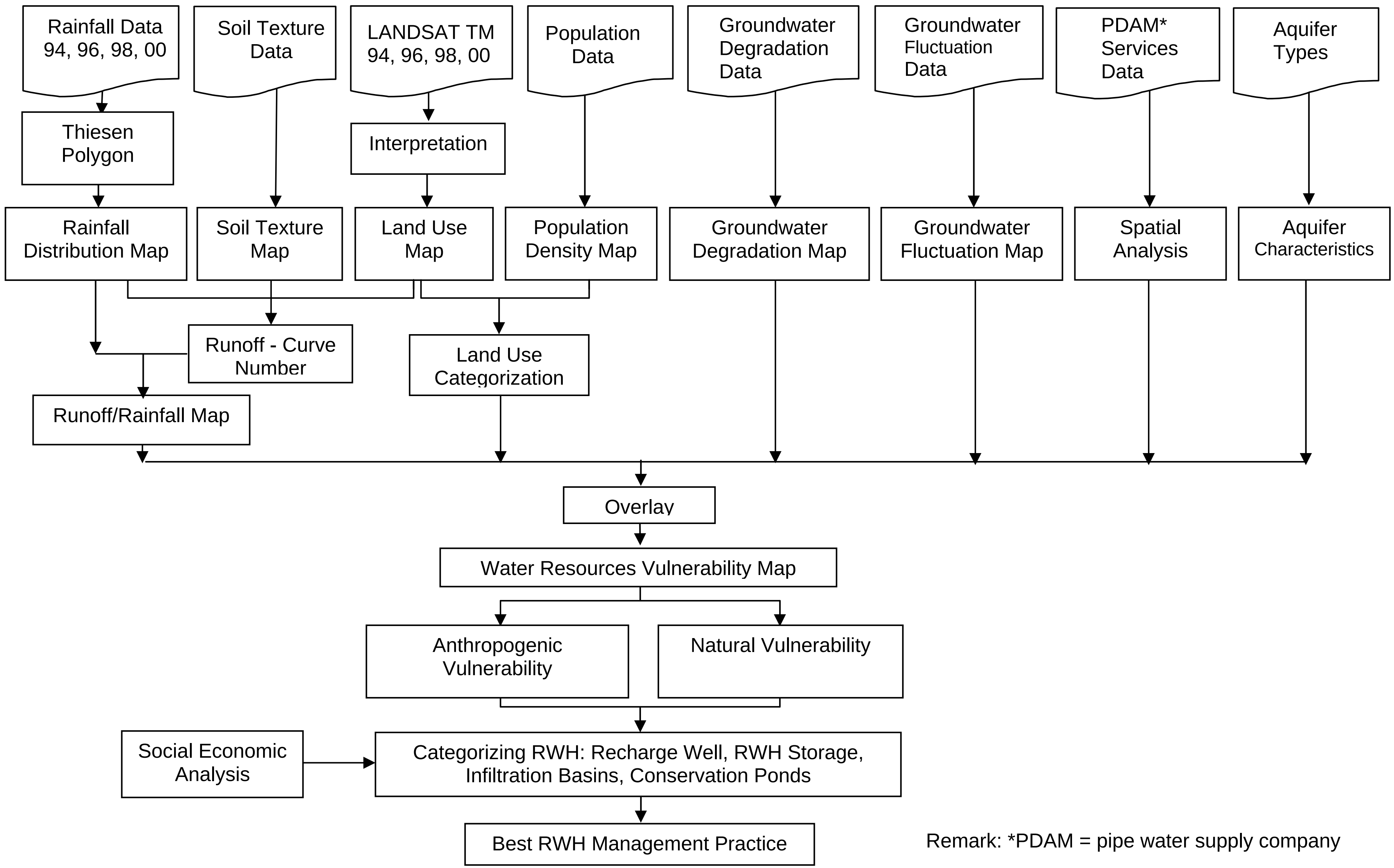


Figure 1.1: Research methodology step

CHAPTER 2
DESCRIPTION OF THE AREA

2.1 Historical Background

The Sultanate of Yogyakarta which is also known as *Ngayogyakarta Hadiningrat* (Figure 2.1 (a)) was established based on Giyanti Agreement in 1755 because of the Prince Mangkubumi's opposition against the Dutch colonial domination that was supported by Pangeran Paku Buwono II from Solo. Then, on 13 March 1813, Kasultanan Yogyakarta was divided into two parts, i.e. *Kasultanan* Yogyakarta and *Kadipaten* Pakualaman.

(a)

(b)

Figure 2.1: (a) A part of Yogyakarta Palace complex (*Pagilaran*) and the North Palace Square, (b) *Tugu* (pillar) as the symbol of Yogyakarta (Photos: www.tembi.org/dulu/tugu_yogyakarta_tahun_1928/)

Since Yogyakarta Palace was founded by Sri Sultan Hamengku Buwono (HB) I, several premises and infrastructures have been built to support the kingdom's activity. With their *golong-gilig* spirit, i.e. the unity of the king and his people, the succeeding sultans have also developed the means and its environment to support the people's social, cultural, business and property activities. The symbol its *golong-gilig* was represented by a pillar (Figure 2.1 (b)). The characteristics of means, infrastructures, aesthetics, ethics, symbols, and philosophy-religion, including their functions and meanings are reflected in the construction elements, spaces, buildings, building groups, and their environment.

The environment in the south and inside the wall of the palace illustrates the ideal characteristics of the palace. There is no drastic change and development in this area. Its style of traditional *kampong* illustrates the special characteristic of village as part of the palace structure. Today, the activities of the citizenry indicate the concurrence between social aspect, economic aspect, and cultural value (Adishakti, 2003). The loaded environment and competition between several aspects have changed and developed more quickly than before.

The axis of *Tugu* - *Keraton* - *Panggung Krapyak* illustrates the urban area, a continuously developing, expanding, and interacting area. In the present context, this area's components, including paths, edges, districts, nodes, and landmarks (Yuwono, 2003) illustrate its special meaning and unique characteristic. A European building style exists as well at the area (Figure 2.3 (a)). Therefore, this historic-cultural, philosophical and architectural “imaginary axis” needs proper management to make its existing environment and potential be evaluated in order to regulate the development growth.

Now, four main highways connect Yogyakarta with other cities in Java, i.e. the north one (to Magelang, Semarang, and others in the northern part), the west one (to Purworejo, Purwokerto, Bandung, and others in the western part), the east one (to Solo, Surabaya, and others in the eastern part), and the south one (to Bantul). The north, east, and west highways connecting Yogyakarta to big cities have a bigger influence on the development than the one to Bantul.

2.2 Geographical Aspects

DIY Province, consisting of four regencies (Sleman, Bantul, Kulonprogo, and Gunungkidul) and one municipality (Yogyakarta), is in the middle-south part of Java Island. Surrounded by Central Java Province in the west, north, and east, as well as the Indian Ocean in the south, the capital city of this province is Yogyakarta.

The study area covers Sleman Regency, Yogyakarta Municipality, and Bantul Regency. Sleman consists of 17 sub-districts, Yogyakarta Municipality has 14 quarters (suburbs), and Bantul has 17 sub-districts as well. Geographically, the study area lies between 07^{0}35’30” – 08^{0}00’40” Southern Latitude and 110^{0}12’33 – 110^{0}20’53” Eastern Longitude; as can be seen in Figure 2.2.

This study area, bordered by Progo River in the west and Opak River in the east, is located in the south of Mt. Merapi. In terms of geohydrology, the area is called Yogyakarta Aquifer or Merapi Aquifer, stretching from the north to the south, from Mt. Merapi to Indian Ocean, the Parangtritis beach (Hendrayana, 1993, DIY Province, 2003). Sleman is in the north, Yogyakarta lies in the middle, and Bantul is in the south.

Generally, the study area has a tropical climate with the temperature ranging from 22^{0}C to 32^{0}C; the lowest temperature is around the peak of Mt. Merapi. The topography is one of the factors that cause the temperature variation; yet, the temperature is relatively stable all the year. The remaining day-length is not quite different all the time because the area is not far from the equator. The urban area in Yogyakarta with only a few trees has a higher temperature than other urban areas with more trees. The average humidity of this area is about 80% with the variation between 85% during the rainy season and 75% during the dry season (Sumarwoto, 2003).

In the north part lays Mt. Merapi, a highly active volcano with the height of almost 3000 m above the mean sea level. Its eruptions cause loss of life, property, livestock, crops, and environment in general. On the other hand, the explosions result in highly fertile land, especially in Sleman, Yogyakarta, and Bantul. Those three regions become the preservation area of food resources, especially rice because Yogyakarta has been so dense with buildings that it is impossible to develop the farming sector. The infertile areas are those lying in most parts of Gunungkidul Regency and some parts of Kulonprogo Regency.

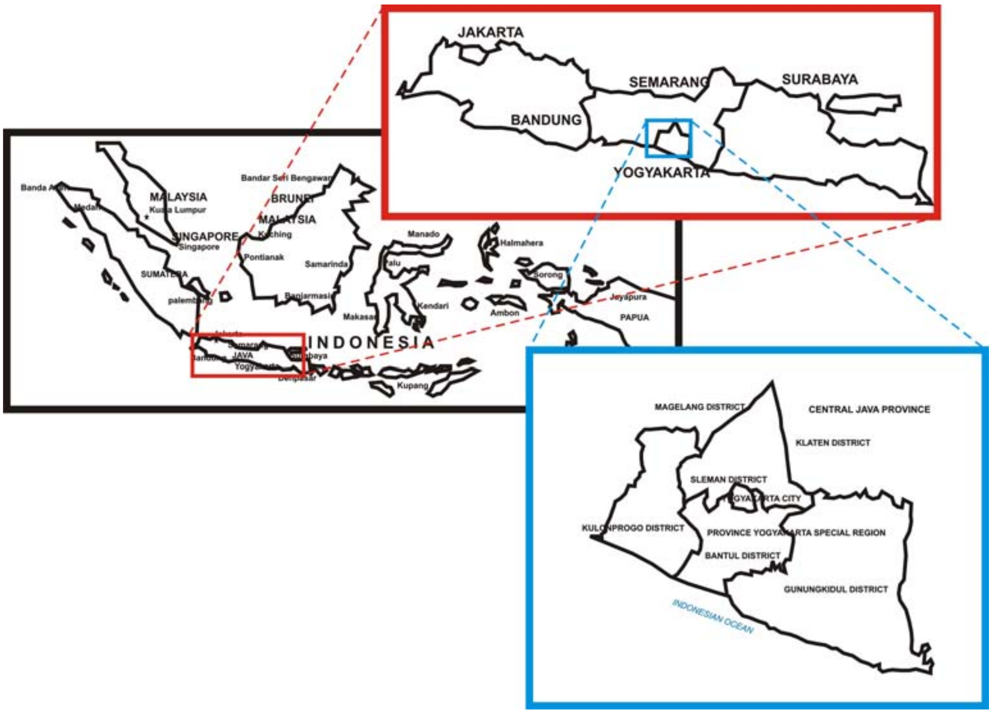
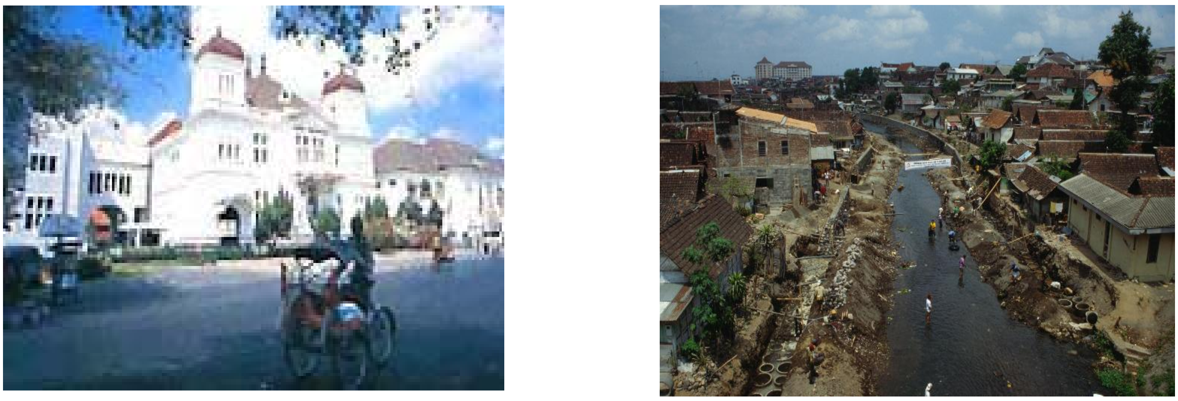


Figure 2.2: Location of the study (Source: modified from Bappeda, 2000, Widodo, 2004)

There is a topography variation from 0 meter above Mean Sea Level (MSL) to the top of Mt. Merapi. In general, it is increasingly higher to the north, and vice versa. In the southwest of Yogyakarta, there is a hilly region with around 150 m high above MSL, and there are sand dunes with around 15 m high in the coastal area.



(a) (b)

Figure 2.3: (a) Yogyakarta is one of the cities with a lot of histories and cultures. (b) It is also one of the most crowded cities in Indonesia (Photo: www.bluegumdata.com.au/../java/java16.htm)

The population of DIY is around 3,120,478 people spreading in the entire 3,185-km^2 area of the province. Its population density is around 1000 people/km^2; it is one of the densest provinces in Indonesia (Figure 2.3 (b)). Based on the population spread, Sleman is the first (28.9%), followed by Bantul (25.0%), Gunungkidul Regency (21.5%), Yogyakarta (12.7%), and Kulonprogo Regency (11.9%). Yogyakarta is the most densely populated area (12,206 people/ km^2), while Sleman has 1,568 people/km^2 and Bantul has 1,541people/km^2. Kulonprogo and Gunungkidul have the population density of 633 people/km^2 and 451 people/km^2 respectively. Sleman has the highest population growth (1.50 %/year), and Bantul has 1.19 %/year. The data show that Yogyakarta, Sleman, and Bantul have a very rapid population growth and development. Therefore, these areas are selected as the focus area of the research.

According to Sumarwoto (2003), DIY has succeeded in increasing its people's prosperity. It can be seen from its high Human Development Index (HDI), i.e. 68.7, and its Human Poverty Index (HPI) that is nationally low, i.e. 18.5 (Table 2.1). Based on the two indexes, this province nationally ranks the second after Jakarta Province. Yogyakarta is in the second rank and Bantul is in the twenty-seventh rank. HDI shows how far people's primary needs have been fulfilled, covering the life expectancy age, the educational degree, and the income level. HDI value ranges from 0 to 100. Meanwhile, HPI is the level of poverty covering 4 dimensions of primary needs, i.e. long healthy age, knowledge, economic needs, and social involvement. The lower the HPI value, the better the degree of people's prosperity, and vice versa.

Furthermore, the progress level of a certain community can also be seen from its gender point of view that consists of Gender-related Development Index (GDI) and Gender Empowerment Measure (GEM). From the same source, this province is nationally in the first rank, i.e. with the value of 66.4 and 58.8. GDI actually has the similar context to GEM, i.e. the sex discrimination. The closer the values of GDI to GEM, the better the gender development degree is.

Table 2.1: Score and national level of HDI, HPI, GDI, and GEM

No	Region	HDI (1999)		HPI (1998)		GDI (1999)		GEM (1999)	
		Score	Level	Score	Level	Score	Level	Score	Level
1	DIY Province	68.7	2	18.5	2	66.4	1	58.8	1
2	Yogyakarta	73.4	2	16.8	38	69,4	3	48.6	96
3	Sleman	69.8	27	18.1	46	67.4	5	55.8	14
4	Bantul	65.8	102	21.8	88	62.1	33	55.7	15
5	Kulonprogo	66.4	85	21.1	74	64.6	14	57.8	8
6	Gunungkidul	63.6	165	16.6	34	63.5	21	47.1	121
7	Jakarta	72.5	1	15.5	1	61.2	2	46.4	18

Source: Sumarwoto (2003)
Note: level means national rank

2.3 Geomorphology

Generally, the geomorphology of the research area (Figure 2.4) represents the form of area resulted from the volcanic activity with a radial flow pattern (UGM, 2003). The research area can be divided into six geomorphology units as follows (Wilopo, 1999, UGM, 2001):

- ***Merapi Volcano Cone Unit:*** The zone includes the area around the peak of Merapi located higher than 900 m above sea level and having the slope of more than 57%. This area has very low population density. In the area of Merapi peak, it is almost impossible to find a river or a spring. The water stream pattern on the surface is radial. This area is physically unstable with the danger of volcanic material from Merapi. According to Wilopo (1999), based on its hydraulic gradient and height, this peak area is a recharge area.
- ***Merapi Volcano Body Unit:*** It is divided into two, i.e. upper body and lower body (UGM, 2001). The upper Merapi body is located between the contour line of 900 m and of 500 m

above sea level with the slope of around 18%. The pattern of river stream is parallel with a steep river basin. A small number of dwellers live here in groups of houses. They get water from a well or a spring in the riverbank because many spring belts and some shallow wells can be found here. To the upstream, the groundwater surface is deeper, reaching 10.8 m – 17.4 m or more, so making wells becomes more difficult as it frequently results in boulders. Considering this problem, the water supply makes use of the existing springs with the gravitation distribution system. Meanwhile, the lower body, located between the contours of 500 m until 150 m, is coincidently in line with Mataram Channel. With the slope of about 10%, domestic water supply is not a problem; there are many shallow wells and small springs. Yet, some villages have dry wells at the end of the dry season. In general, the water quality is quite good, but in the densely populated area it is low (Sudarmaji, 2004). Then, the groundwater depth varies but not more than 15 meters from the ground surface. Based on its quite high hydraulic gradient and elevation, this area is a recharge area.

- ***Unit of the Foot of Merapi Volcano***: It is bordered with the contour line of 150 m around Mataram channel in the North and with the South Sea in the South. Covered by alluvial and fluvial sediment resulted from Wates Formation and sand dunes, this area has the slope of about 1% with a parallel river pattern. More to the South, the river valley becomes wider and meanders. Based on the hydraulic gradient and elevation, it is a discharge area. Divided into two, i.e. the upper and the lower area, its upper part is the densest housing area.

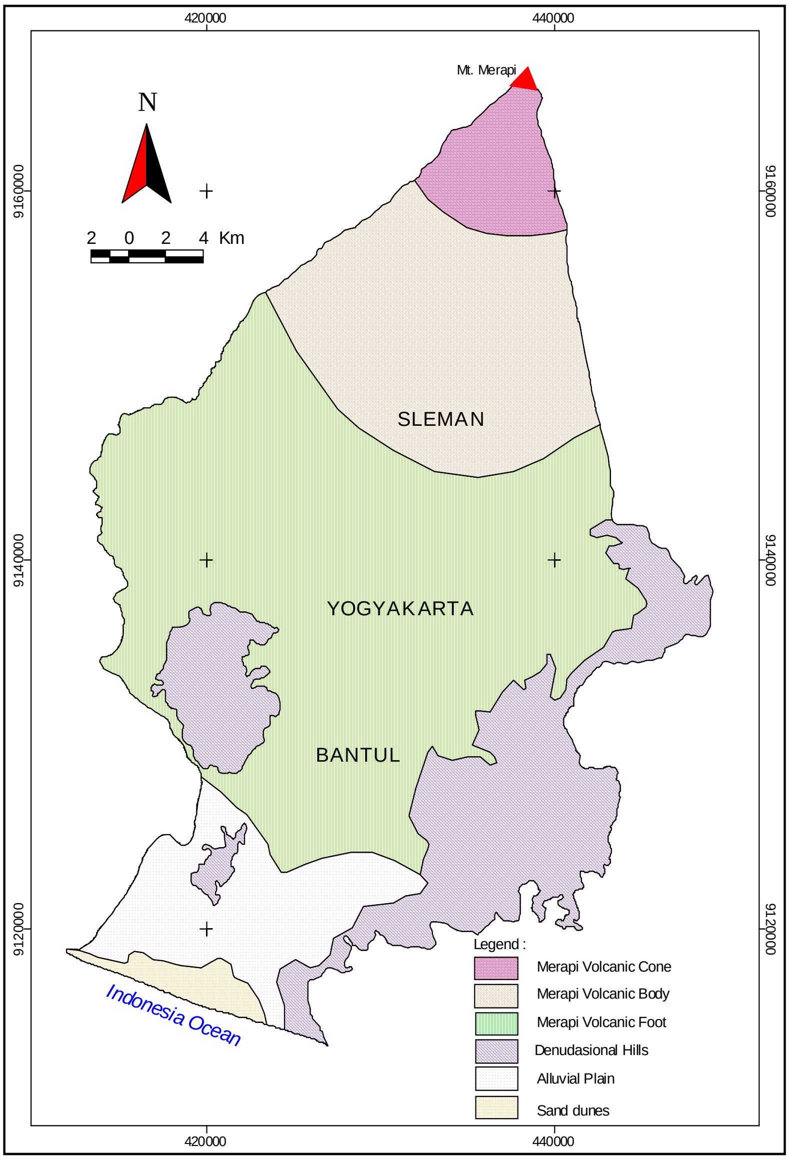


Figure 2.4: Geomorphology map of the study area (Source: adapted from Sir MacDonald and Partners, 1984-a)

The groundwater depth is not more than 12 meters (Wilopo, 1999, Bapedalda, 2003). At first, domestic water supply was not really a problem, but then, the quality of river water and groundwater have fallen because of the abundant domestic and industrial waste.

- ***Denuded Hills***: Its elevation is around 25 - 972 meters above sea level with the slope level of up to 90%. The channelling pattern is dendritic, and the lithology consists of sandstone, conglomerate, and limestone. The land use system in this area is dry-land agriculture. In the Bokoharjo hill unit, the geomorphology unit is structural hills dominated by *Kebo-Butak-Semilir-Nglanggran*. Its elevation above sea level is around 250 to 400 meters (UGM, 2003).
- ***Alluvial Plain Unit***: Its elevation is 0 – 25 meter above sea level. As an effluent river with the increasing flow pattern and meanders, this unit is an alluvial plain from Wates formation. The slanting level of the slope is less than 1%. The land use system in this area is in the form of farmland and groups of settlement.
- ***Sand Dune Unit:*** This sand dune is found along the beach between Opak River and Progo River with the width of 1 – 1.5 km and the thickness of up to 30 meters. Domestic water supply is a problem since rarely is a well or spring found here, moreover, the water quality is low and the taste is somewhat salty. However, in Parangtritis region, there are several wells and some fresh water (UGM, 2001).

2.4 Geology

Influenced by the volcanic activity of Merapi, the geology factor of this area really determines the natures of aquifer, permeability of aquifer, and existence of groundwater, including the groundwater quality. Derived from the Report of UGM (2001), the area stands on the basement of rock, which consists of tertiary formation and quarter formation. This tertiary formation is the basement of Merapi basin covering:

1) ***Old Volcanic Rock Formation*****:** It consists of breccias-volcanic rocks, agglomerate, tuffs, and insertion of lava-volcanic rocks (Putra, 2003), so it is a bad aquifer. Its age is included in Upper Oligocene until Lower Miocene, having the thickness of around 600 meters (Rahardjo et al., 1995). This formation is the basement in the western part of the basin.
2) ***Sentolo Formation:*** Its lower part consists of conglomerate basement, overlapped with tuffs, in which there is an inserted tuff (Rahardjo et al., 1995), so it is also a bad aquifer. Its age is estimated as the part of Early Miocene until Pliocene with the thickness of around 950 m. This formation is found as a basement in the west-south part of the research area.
3) ***Sambipitu Formation:*** This formation consists of sandstone and muddy-stone tuffs, and sometimes it is found as inserted breccias. The fragment that forms either breccias or sandstone is generally in the form of fragment of pumice, which has the acid character. It is presumed that the age of this formation is in Lower Miocene.

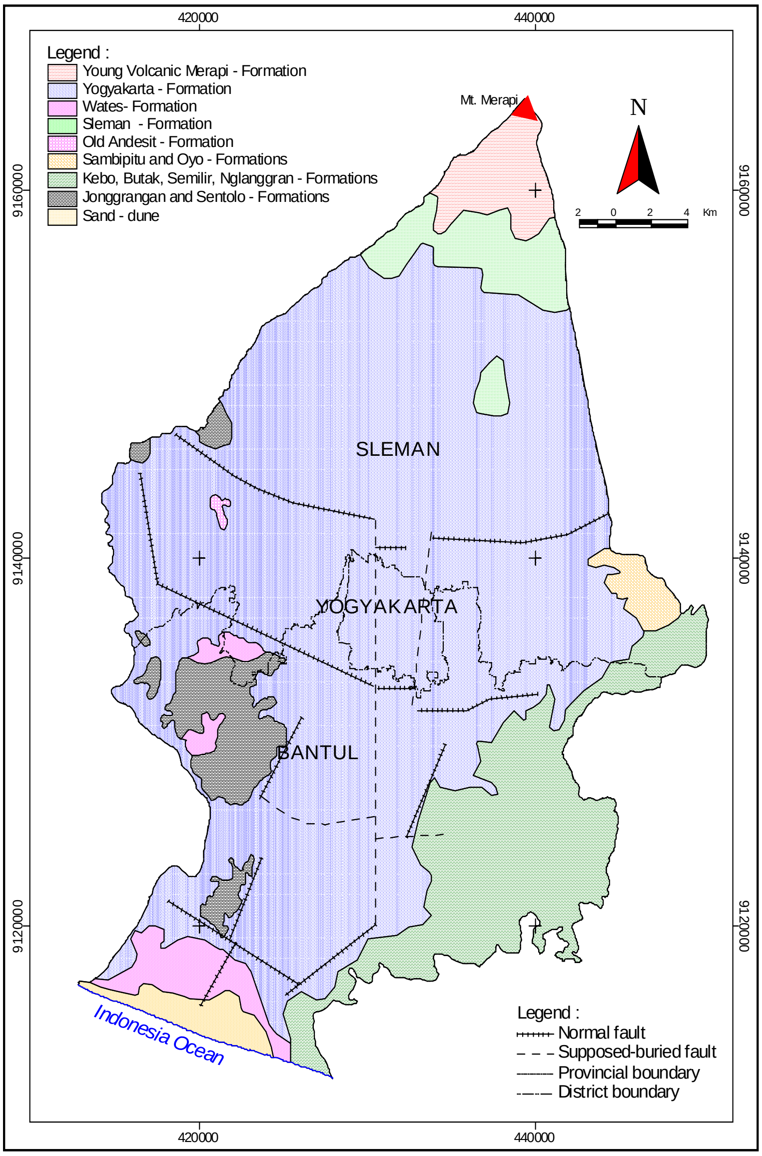


Figure 2.5: Geological map of the study area (Source: adapted from Sir MacDonald and Partners, 1984-b, Hendrayana, 1993)

4) ***Kebo-Butak-Semilir-Nglanggran Formation:*** this formation is characterized by its main compiler, which consists of breccias compiled by volcanic materials, it does not show a good coverage since it has a high thickness. Among the mass of the breccias, inserted lava whose major part has experienced the process of breccias is found. Its age is presumably included as Middle Miocene. This formation is a bad aquifer and as a basement in the East-South part of the basin. Another one is also found in Bokoharjo formation (UGM, 2003).

5) ***Old Merapi Volcanic Formation:*** The age of this formation belongs to Upper Pleistocene, consisting of breccias, agglomerate, lava, volcanic rocks, and basal (Noordianto, 2005). This formation represents a bad aquifer, found in the North part of the basin, and part of its basement lies in the middle of the basin.

The quarter formation is a lithology that forms Merapi aquifer system consisting of:

1) ***Young Merapi Volcanic Formation***: It is included in the upper Pleistocene, and it consists of materials resulted from the reform of Old Merapi sediment in the form of tuff sediment, sand, and breccias, which is weakly consolidated. Based on its lithology character, the Young Merapi sediment is divided into 2 formations, i.e. Sleman and Yogyakarta Formation (Sir MacDonald and Partners, 1984-a, UGM, 2001, UGM, 2003).

2) ***Sleman Formation***: Sleman Formation is the lower part of the volcanic clastic unit resulted from Young Merapi volcanic sediment. Stretching from the slope or Merapi body in the South to the area surrounding Bantul, this formation consists of sand and gravel interspersed with volcanic rock lumps. The thickness is various; it becomes thinner from the North to the South. Different from Yogyakarta Formation, Sleman Formation has more rough grain. Furthermore,

it has a good potential of aquifer.

3) ***Yogyakarta Formation:*** It represents the upper part of the volcanic clastic unit resulted from the youngest Merapi volcanic sediment. Compiled from the interchange among sand, gravel, silt, and clay, this formation stretches from the south part of the middle-lower slope of Merapi to area surrounding Bantul. In the North, generally it is in the form of tuffs, sand, gravel, and breccias, in which more to the South, its grain size becomes smoother. To the South, this formation is thinner, and it has good aquifer potential.
4) ***Wates Formation***: It can be divided into two forms, i.e. of river sediment and of coastal sediment. The coastal sediment consists of clay, sand, gravel with the thickness of about 30 meters. The river sediment is compiled from clay, silt, and smooth sand with the thickness of about 20 meters. It is in the south part, and it has bad aquifer potential.
5) ***Sand Dunes**:* This unit is compiled from the sediment of smooth to rough sand, which spreads along the beach. This unit has minor aquifer potential.

Structurally, the geology of Yogyakarta lies on the active plate zone (Figure 2.5). The main plate relatively directing to the South – Northeast is the one lying along Opak River and becomes longer passing through the Special Territory of Yogyakarta until the South Sea. The interchangeable plate also cuts the West-East from around Merapi foot in the form of graben, for example Yogyakarta graben and Bantul graben. These plates are estimated as active in the Final Pliocene and maybe until quarter, in which a quick process of sedimentation also occurred at that time because of the activity of Merapi (UGM, 2001).

2.5 Hydrogeology

Regardless the water quality, the aquifer in the study area can be classified based on water transmitting properties as follows (Sir MacDonald and Partners, 1984-a, 1984-b):

- ***Major aquifer***: It has high permeability and storage with well yields, fitting any purpose. The only aquifer here is Merapi aquifer, consisting of Sleman and Yogyakarta formations.
- ***Minor aquifer***: It has lower permeability and storage, supportive for potable use and too limited for irrigation and industry. Sentolo and Sand Dune formations are included here.
- ***Poor aquifer***: It has low permeability and storage, supportive only for potable use. The Old Merapi Volcanic formation, Wates, and Sambipitu formations are included here.
- ***Non-aquifer***: It has little permeability and storage. Kebo-Butak-Semilir-Nglanggran formation is included here. The category of the aquifers can be seen in Figure 2.6 (d).

The dominant aquifer system in the study area is Merapi Aquifer System (MAS) or Merapi-Yogyakarta Aquifer System, a group of Sleman and Yogyakarta formations. Two main rivers border MAS, Opak in the East and Progo in the West (Figure 2.7). On the South part, it is bordered by Indonesian Ocean. The basin lying on the East part of Opak is Kebo-Butak-Semilir-Nglanggran and Sambipitu formations. Figure 2.5 and 2.6 (d) show aquifer categories, which Sentolo formation on the South West of the study area and Wates formation on the south part of Bantul, closed to the sand dunes along the beach.

Based on the geological perspective, the basin of Merapi - Yogyakarta is bordered by two main faults along Opak River and along Progo River. In the basin of Yogyakarta, there are also some paired down-faults, for example those forming Bantul graben and Yogyakarta graben (Untung, et al., 1991, Sir MacDonald & Partners, 1984-b, Hendrayana, 1993). The main lithology that shapes the Merapi - Yogyakarta basin is Yogyakarta Formation at the upper part and Sleman Formation at the lower part, and they are volcano-clastic sediment of Merapi.

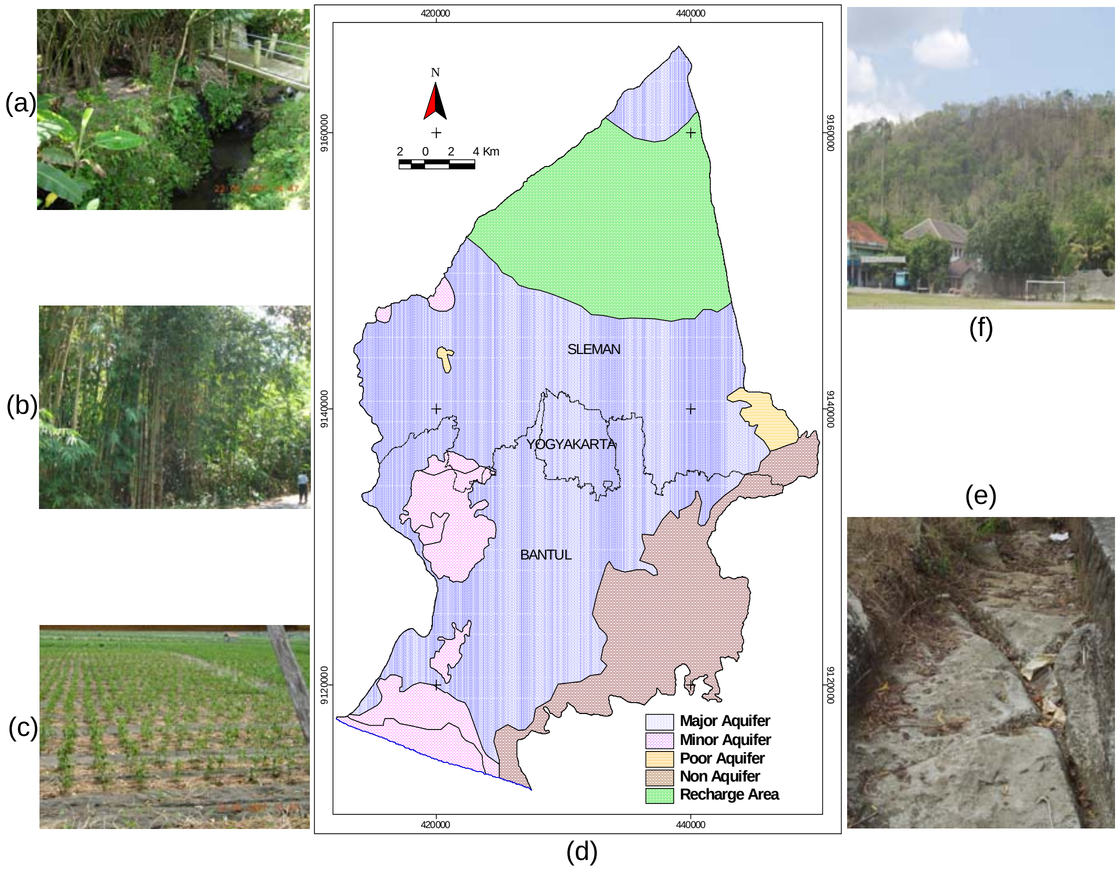


Figure 2.6: (a) Situation in a recharge rural area, (b) Other rural area of Merapi aquifer, (c) Agriculture in a sandy area of south coast, (d) Aquifer categories of the study area, (e) Out rock basement of the structure, an impermeable rocky area on high land, (f) Kebo Butak formation, a dry hilly area (Source: adapted from Sir MacDonald and Partners, 1984-a, Hendrayana, 1993, Photos by Widodo, July 2005 and May 2007)

These two formations function as the layer that flows and stores groundwater (Djaeni, 1992, Sir MacDonald and Partners, 1984-a, Hendrayana, 2003). Merapi aquifer area is of free type and half-free type. The materials forming the aquifer are delicate sand to gravel. Besides, it is also known that in the North part, Merapi aquifer system stands on the Old Merapi Volcanic rocks belonging to the Upper Pleistocene. In the East part stand the Tertiary Rocks from Kebo-Butak-Semilir-Nglanggran Formation and in the West and South parts stand the Tertiary Rocks from Sentolo Formation, they are considered as very dry areas (Figure 2.6 (f)). Based on its physical, natural characteristics and its groundwater behaviour reflected by the aquifer, the Old Merapi Volcanic Rock and those tertiary rocks are functioned as the basement basin of Merapi aquifer system (Hendrayana, 2003).

(a) (b)

Figure 2.7: (a) Downstream of Progo river, (b) Upstream of Progo river (Photo: Anuriyah, 2004)

In terms of hydrology, the Merapi system forms an aquifer system that consists of multilayer aquifers having relatively the same hydraulics and interconnected to each other. The topography gradient is lower in the South followed by a decrease in the hydraulics gradient; therefore, the speed of the groundwater flow is lower in the South. The groundwater generally flows from the North to the South with gradating smaller hydraulic gradient (Figure 2.6 (d) and 2.8).

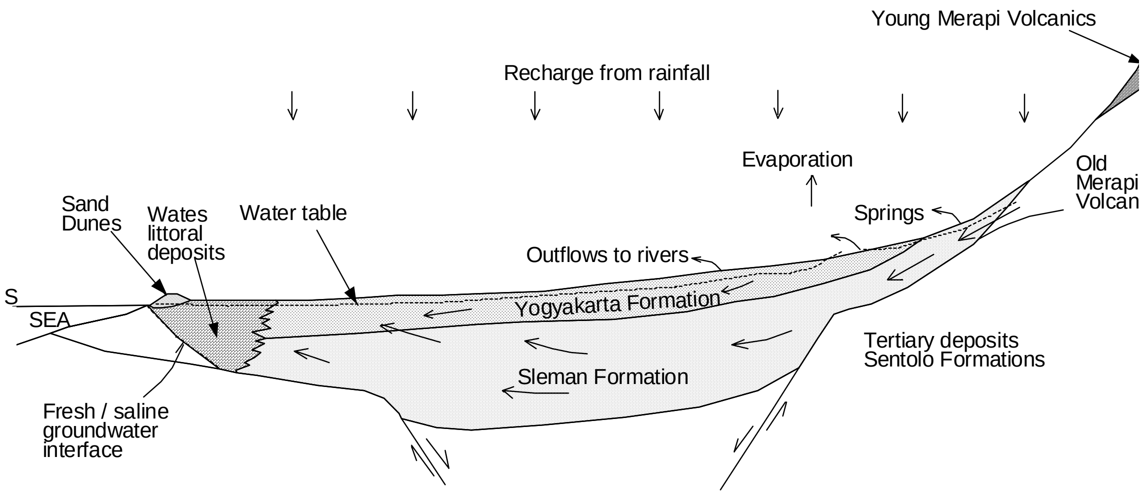


Figure 2.8: Conceptual section of Merapi aquifer system (Source: adapted from Sir MacDonald and Partners, 1984-b, Hendrayana, 1993)

The groundwater morphology is almost like cone-shaped and spread radially, a particular characteristic of groundwater around a volcano. The r*echarge area* lies on the slope or on the body of Merapi. The groundwater comes from rainwater absorption and indirectly also from the absorption of river water and of irrigation water in the agricultural area. Meanwhile, the discharge area is found around Mataram Channel until the region of South-Bantul. In the Southern area, the groundwater of Sleman Formation has relatively big potential energy and flows on the lithology whose physical character is relatively the same as that of Yogyakarta Formation, so there is a vertical flow of groundwater from Sleman Formation to Yogyakarta Formation (UGM, 2001).

The aquifer thickness is various; it is generally thicker to the South. In Yogyakarta graben, i.e. in Ngaglik region, the aquifer thickness reaches 80 meters, in Bedog and Karanggayam region, it reaches around 140 meters, and in Yogyakarta, it is 150 meters. This thickness decreases in outside of Yogyakarta graben, around 45 meters in the South of Yogyakarta. In Bantul graben that is exactly surrounding Bantul City, the aquifer thickness increases again and reaches 125 meters (Hendrayana, 2003).

The aquifer on the upper part is formed by the sediment of Yogyakarta Formation. In the North part, the lithology consists of gravel-sand, stretching from the North to the South. The aquifer thickness of this upper part decreases to the South. Another composition of lithology is clay-sand with a thickness of 1 – 2 meters, and muddy layer of around 0.5 – 1 meter. Based on the existing lithology, it can be seen that the more to the South, the smoother the material.

The lower aquifer consists of sandy-gravel, medium sand, and clay-sand. The sediment of sandy-gravel scatters continuously from the North to the South and has the thickness of around 10 – 50 meters, and the more to the South, the thinner. The sandy-gravel lithology is the best aquifer with a relatively high productivity level and hydraulic conductivity. Its thickness is around 5 – 10 meters. The sediment of clay-sand forms a lens on the sediment of either medium sand or gravel-sand with the thickness of around 5 – 20 meters. This thickness decreases to the edge of basin.

The aquifer systems of Kebo Butak, located on the foot of the hills until the plain, are the products of colluvial processes in which much of it is piled up over Merapi Aquifer System in several locations. Because the slanting of rocks-layer is to the South, the water level of this aquifer system in the South is very close to the ground surface, while on the foot of the hills, it is quite deep, around 15 meters (UGM, 2003). The basic rock of this aquifer system is closely related to Semilir Formation, which is dominated by the alternation of breccias-tuff, pumice breccias, tuff and tuff volcanic rocks, and also tuff pumice and silt; therefore, its aquifer system can no longer be an isotropic and homogenous aquifer, but it has become an anisotropy and heterogeneous aquifer.

The aquifer system of Kebo Butak on highland has heterogenic and anisotropic characteristic. Groundwater is shallow, especially at the valley of hills, but it is only temporary. The dominant compiler rocks are the combination of sandstone and tuff. The developed main system is the crevice of groundwater system, called fractured aquifer. The potential of aquifer with a very small productivity can be limitedly found in the local crevice or alley of valleys among hills; thus, it is more appropriate to be aquitard. This condition makes its status shift to non-aquifer (Sir MacDonald and Partners, 1984-b). This very small potential of water can only be found in the area with a low topography, i.e. the area close to Merapi aquifer that can produce adequate water dominantly containing sand and aquifer materials. Besides, the detected water carrier-layer does not have an adequate thickness level for drilling or making of deep-wells. Drought occurs in most parts of this region because its local potential cannot support the water availability and due to the physical characteristics of the soil and its compiler materials and the relatively difficult high topography.

The contour indicates that the majority of groundwater flows in the formation passing Merapi aquifer. The formation has small discharges, confirming the limited potential of the aquifer.

In case of higher spring, discharges probably relate through fracture zones and do not reflect the aquifer potential of the formation. The depth of wells in the aquifer ranges from 10 – 30 meters. Many of them run dry from July to September (UGM, 2003). Therefore, it is difficult to develop this area although the development of small village and small industrial supply is still possible.

Wates formation lies extensively through the coastal alluvial plain. Littoral and fluvial deposits have been identified with littoral sands and gravels in the plain to the south of Bantul. This formation is classified as a minor aquifer found mainly in Bantul area. Interrelated to Merapi aquifer and largely unconfined, it is merely an extension of the aquifer, the composed and reworked deposits from Yogyakarta formation. Throughout the southern part of the coastal alluvial plain, Wates formation is in hydraulic continuity with the sand dunes aquifer. In the plain of Wates formation, groundwater enters the aquifer from Merapi aquifer. Seasonal water level fluctuation varies over the aquifer. The smallest fluctuation is generally close to rivers (Sir MacDonald and Partners, 1984-b). Due to its characteristic, the area is difficult to develop. This aquifer development would be dependent on the groundwater of Merapi aquifer.

The sand dune aquifer lies adjacent to the coast on the coastal alluvial plain. This consists of fine to medium gravelly sands overlying Wates formation. Its thickness ranges up to 42 meters. Some parts of it have saline groundwater due to the seawater. The aquifer recharge occurs through the direct infiltration of rainfall. If the whole recharge is abstracted, saline groundwater can be a serious problem not only for the sand dune aquifer but also for Wates and Merapi aquifer. Very little surface runoff occurs from the sand dunes. A discharge from the aquifer takes place as a direct evapotranspiration where the water table is close to the surface, groundwater flowing to the sea, non-perennial springs, and seepage and drains to lagoon (Sir MacDonald and Partners, 1984-b). Minor groundwater abstraction is presently taken for domestic water supply through hand-dug wells.

2.6 Hydrology

DIY Province is a tropical area with a wet tropical climate. The annual rainfall varies from 3500 mm at around the peak of Mt. Merapi to 1500 mm at Bantul. The areas around Yogyakarta have an average annual rainfall of 2100 mm. The dry season occurs from June to October with the rainfall of less than 100 mm/month, while the rainy season occurs from November to May. The number of rainy days varies around 18.2 in December and 2.6 in August and September.

The river system in the research area has a radial pattern divided into two subsystems, Progo River Subsystem and Opak River Subsystem. The rivers flowing into Progo River are Krasak, Putih, Konteng, Jetis, and Bedog, whereas Denggung, Winongo, Code, Gadjahwong, Tambakbayan, and Kuning flow into Opak River (Figure 2.9). All those rivers are perennial rivers due to the high rainfall; their land characteristic is permeable, and they have a thick aquifer, so, the base flow of those rivers is quite big, even effluent. However, due to the very high rate of land use change on the river watershed, the base flow will possibly experience quantity degradation. Figure 2.7 (a) and (b) illustrate the parts of Progo River.

2.7 Recharge Area

The recharge area located in Sleman is an important zone for maintaining the sustainability of water resources of the areas below it, i.e. Sleman, Yogyakarta, and Bantul (Figure 2.6 (d)). The great amount of rainwater and the geo-hydrological factor make this zone a good medium for rainwater recharge (Adji and Noordianto, 2006). This can supply domestic water need in the three locations and recharge the river water. Besides its geo-hydrological factor, the climate also influences its characteristics (Widodo and Noordianto 2006).

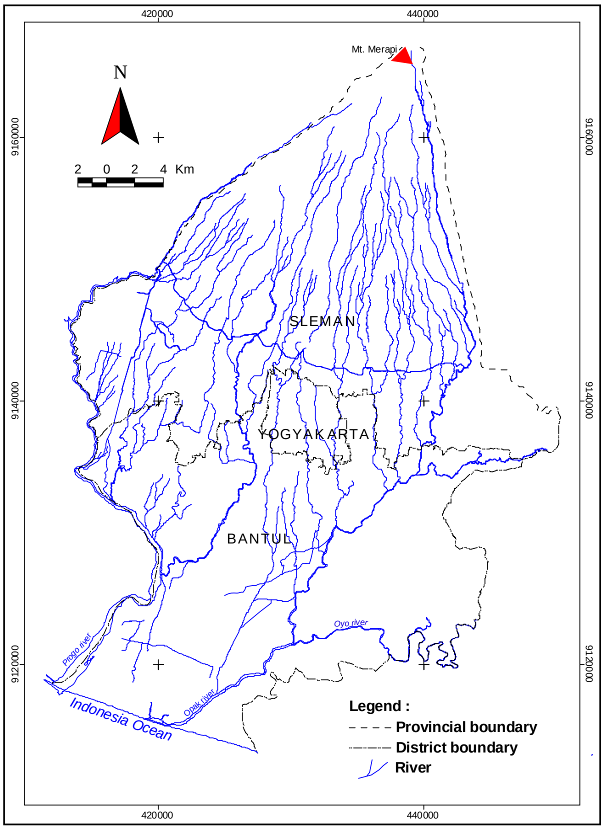


Figure 2.9: River system (Source: edited from Topographical Map Bakosurtanal, 2003)

As mentioned before, the formation of volcanic sediment of Young Merapi represents more than 90% of the total area. There are about 100 springs in Sleman, flowing to the main rivers: Boyong, Kuning, Gendol, and Krasak. Merapi groundwater flows as leakage moving below the ground surface to the lower area. When it is cut by the topography of a fault, it will result in a spring. In Sleman, including in the recharge zone, there are four lines of spring belt: Bebeng, Cangkringan, Ngaglik and Yogyakarta. These springs are used for domestic water resource and irrigation (UGM, 2003, Noordianto, 2005).

2.8 Drainage Systems

Drainage has been associated with channelling, depleting, discarding, or redirecting water, while actually drainage is a technique to reduce water surplus from either rainwater or runoff in order to maintain the function of an area. Drainage can also be defined as an effort to control the quality of groundwater in terms of salinity. Meanwhile, a drainage system is defined as a series of constructions for reducing and/or discarding water surplus in an area or land to optimize the land function. A drainage system consists of an interceptor drain, collector drain, conveyor drain, main drain, and receiving water.

As for Yogyakarta, the drainage system refers to the system of rivers. The rivers flowing across the urban area of Yogyakarta are Winongo River, Code River, and Gadjahwong River. The rivers having an upstream area at the slope of Merapi Mountain have the stream flow direction to the South with the declivity around 1% - 3%. The general characteristics of these rivers are stony and sandy with vegetation at their edge, except those located in urban areas, in which much of the edge-vegetation have been lost because of settlement buildings and reservoirs. These rivers function as natural drainage.

The system of rainwater drainage network in the research area is generally set up among those rivers. In general, the drainage channels are rectangular with open-system and made of bricks and concrete. In a densely populated urban area, the drainage systems are usually covered. Some areas without rainwater drainage system still use the natural system, and some others use the drainage channel system made of bricks. This natural drainage system can be in the form of holes, channels shaped through the flow of runoff, and ditches at each boundary of yards, dry land cultivation, or rice field.

Figure 2.10: Rainwater drainage system was being developed in Malioboro area, Yogyakarta. The rainwater is drained into Code River directly. There is no rainwater infiltrating into the ground. This system indicates the conventional paradigm of drainage system in Yogyakarta and other places (Photo: Widodo, 2004)

In conclusion, the drainage system in Indonesia is a conventional system, flowing rainwater as fast as possible from certain regions to rivers and/or to the sea. This is also known as 'drying effort'. The impact is highly possible flood in downstream areas and drought as well. The rainwater to be infiltrated for supplying groundwater becomes springs, or it is uselessly thrown to the sea. Therefore, this conventional paradigm should be changed into the principle of draining rainwater as slowly as possible to the sea. This can be achieved by making natural or artificial absorption area, reforestation, and other efforts.

Many drainage systems have been for rainwater and domestic waste as people logically thought that rainwater is the same as wastewater. Furthermore, the Public Works Department has been developing the drainage system without a system for rainwater conservation. Figure 2.10 illustrates the drainage system built around Malioboro in 2004 based on rainwater disposal.

Ironically, the system cannot prevent floods in heavy raining on streets and in dense settlement areas. The amount of flooding water tends to increase (Moeljono, 1995, Sudarmaji, 2004) because of:

1) A large number of land use changes that increase runoff,
2) The drainage channels, which are full of garbage hampering the stream flow,
3) The channel dimension that does not match the stream flow rate because of the increasing runoff,
4) The setting of drainage channel network that has not reached the entire regions,
5) The absence of control on the development of settlement area.

2.9 Sanitation

Sanitation is another problem related to the quality of water resources, particularly groundwater and river water. The availability of sanitation service is still concentrated in Yogyakarta with the service level around 70% (Environmental Agency, 2006), while in Sleman and Bantul it is less than 10%. The low quality is because the capacity of wastewater removal is low and the channels are damaged. So far, no specific evaluation is done to the quality of wastewater channels.

The disposed wastewater is neither included in the sanitation service nor specially processed. Hence, a large part of domestic wastewater is directly disposed to the river, land, or drainage channels. For the disposal of toilet wastewater, people usually use:

1) Septic tank and wastewater infiltration,
2) Septic tank in which finally the cleaner water is disposed to the river,
3) *Cubluk,* a very traditional WC model,
4) Wastewater disposal directly to the river,
5) Wastewater draining to the “riool” channel of the city, processed in the treatment plant.

On the other hand, the general ways people use to dispose the waste from the bathroom, washing activity, and the kitchen are:

1) Absorbing it into the ground through the absorption well,
2) Disposing it to the rainwater reservoir/channel,
3) Flowing it to the city “riool”,
4) Disposing it to the septic tank and after that absorbing it or disposing it to the river,
5) Mixing it with the rainwater absorption well,
6) Letting it flood.

This bad sanitation decreases the groundwater quality since the abundant waste is not well managed. The city “riool” system is already broken because other buildings push it aside; it is clogged up, cracked, or lost, making the groundwater quality worse in terms of its physical, chemical, or bacterial condition.

Wastewater, being drained to the wastewater channel but then directly thrown to rivers without process, contaminates river water and groundwater in densely populated urban areas. The low quality of groundwater should encourage the more serious and integrated development of RWH through a comprehensive development program of water resources.

2.10 Socio-Economic and Cultural Profile

2.10.1 General

The aspect of social-culture is important for describing the condition of society, either qualitatively or quantitatively. Located in the inter-connected physiographical area and having the similar historical background, the three areas have almost the same condition of social-culture; yet, it is quantitatively different. The three regions have the same culture rooted from Yogyakarta Palace. The cultural philosophy that becomes deeply rooted in their life is *Hamemayu Hayuning Bawono.* It gives guidance to the development efforts to consider the preservation of environment and local wisdom. The following explanation will focus more on the quantitative description, such as demography, education, employment, society’s health, and cultural resources.

During 1990-2000, the population growth rate of Bantul was relatively high, compared to other regencies in DIY Province that reached 1.1%; it was at the second place of highest population growth after Sleman. The highest population growth was found especially in the sub-districts affected by Yogyakarta urban agglomeration. This indicates the high urbanization rate caused by the gap between the suburban and urban of development. The number of poor households in Bantul reached 35% of the total households (BKKBN of Bantul Regency, 2002).

A problem will arise if many productive human resources are unemployed. The number of work force in Bantul in 2002 was 665,062 people; the unemployment rate was 32,650 or 4.9% of the existing number of work force (Disnakertrans, 2002). On the other hand, the education infrastructures are spread evenly without optimum quality. Moreover, the chance to get education has not been spread evenly; one of the indicators is the limited ability to pay the tuition fee.

Furthermore, the society's health degree has not been optimal, indicated by a quite high mortality rate of giving-birth-mother and the prevalence of malnutrition as well as anaemia of less-than-five year olds (BPS, 2004). The environmental factor still does not support the development of health as well. It is indicated by the low coverage of clean water supply, the spread of endemic region of dengue fever disease, the small number of healthy houses, and the low per capita income.

During the last ten years, the population growth in Yogyakarta is relatively slow; however, there was a sharp jump in 1997-1998 during the economic crisis. The more detail condition shows that there was an indication of population decrease in the centre of the city. Suburban areas, such as sub-districts of Umbulharjo, Tegalrejo, and Kotagede, indicate that the city expands towards the boundary of Sleman and Bantul. However, considering the micro dimension, the existing population makes the population density high, resulting in more problems for the city. This is especially caused by either daily commuters or temporary inhabitants. Temporary inhabitants are difficult to analyze and to handle by the government although they can stay for a long time; most of them are students and workers. The centre of worker-migrants settlement generally located in the marginal zone of the city has caused poverty problems. The number of poor households, although it decreased from 31% in 1999 to 26% in 2001, is still very high, i.e. 31,007 households (Health and Social Prosperity Service of DIY, 2001).

Yogyakarta as an icon of student area has shown the fact of real, adequate education condition. The facilities of basic education to higher education are available evenly in all regions, although there is still a gap between favourite schools and the non-favourite ones.

Yogyakarta is also a cultural city, which becomes the second tourism destination after Bali. Most of Yogyakarta people are Javanese, influenced by the cultures of Islam, Hindu, Buddha, China, and West or Netherlands with Yogyakarta Palace as the culture centre. The cultural resources and society's characteristics become the supporting elements of regional development.

Sleman has the highest population growth among the regions; it reached 1.5% in 2000. As the implication of activities overflow in Yogyakarta, a quite high population density is found in the sub-districts of Depok, Mlati, and Gamping. The high population growth is also due to the increasing number of housings in the recharge zone, such as Ngaglik and Ngemplak Sub-district. The conducible environment and the policy of local government influence this condition. In 1999, the number of poor inhabitants in Sleman was 90,673 people (10.18%). The spread of poor inhabitants is relatively even in each sub-district with the smallest percentage of 5.05%, and the highest was 17.33%. The urban and suburban sub-districts had a relatively lower percentage, but all sub-districts had more poor inhabitants from 1995 to 1999 due to the economic crisis.

The education in Sleman is also relatively good; yet, it has not been evenly spread because the good education facilities are centred in sub-districts that are contiguous with Yogyakarta, i.e. Gamping, Mlati, and Depok. The spread of basic and middle education facilities is almost even, but a quality gap between the aforementioned sub-districts and the others exists. In terms of employment, according to the census in 2000, about 37% of work age population in Sleman worked in service sector, 14% in trading sector, and 7% in industry. The rest (30%) worked in agriculture sector. School age population looking for jobs showed an increase, particularly in urban areas.

Furthermore, the degree of society's health is indicated by the decreasing Infant Mortality Rate, reaching 11.52 per 1000 people. The Giving-birth-mother Mortality Rate is 0.846 per 1000 childbirths. The Gross Death Rate is 5.12 per 1000 inhabitants, and the average life expectancy is 71.5 years, i.e. 72 years for women and 71 years for men. The problems relating to this sector are the lack of people's awareness of healthy life, the poor condition in the settlement environment, and the low proportion of poor household heads accessing health service (BPS, 2005).

DIY Province (2003) reported that the economic profile of a region in general could be identified by observing its growth rate and economic structure through the Gross Regional Domestic Product (GRDP). The research area, Bantul, Yogyakarta, and Sleman have a better economy condition than the other regencies in DIY, and they are considered the economic reference in DIY (Figure 2.11). Sleman contributes the biggest part (34%), followed by Bantul (26%) and Yogyakarta (25%).

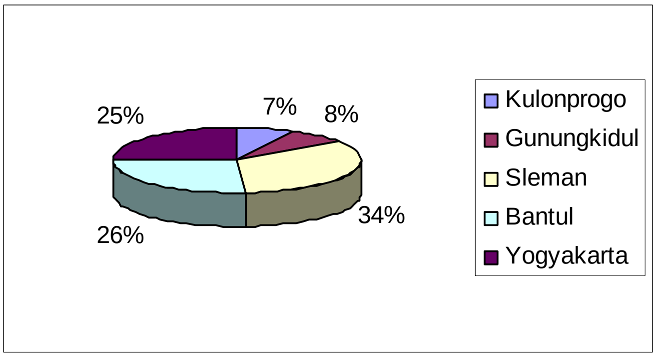


Figure 2.11: Economic contribution of each district to the province's GDRP in 2002 (Source: DIY Province, 2003)

2.10.2 Cultural and Religious Aspects Related to Water

Many countries in the world put water at the very high and prestige portion. According to Sunjoto (2005), Romans called water *fons vitae*, the source of life. The Greek called water *nectar* and *ambrosia,* the drink or the food of goddess. *Levens water* is the term that the Dutch people use; it means the water of life. For British people, water is the *elixir of life,* and German people call water *Lebens-Elixier;* both mean an absolute thing needed in life. French people call water *la source de vie*, and Arabics call it *maul khayat,* meaning that water is important in life. Maduranese people call water *somber odik* or the source of life, and Bugis people call water *gaga wae taue mate,* which means if there is no water then all will die. The Sanskrit mentions many terms relating to the predicate of water such as *tirta nirmala, tirta kamandanu, amerta njiwani, banyu bening pawita sari, banyu panguripan,* etc.; all of them explain the important, noble roles of water in life.

In addition, many epigraphic plaques in Java Island explain the development of water sector in the past. The epigraphic plaque of Tukmas in Magelang, Central Java built in 550 stated that water is ‘unsustainable’ and it is protected as the effort to maintain the spring source. The epigraphic plaques of Pananggaran and Sumundul in Kalayan, Yogyakarta built around 869 showed the effort of overcoming floods. The epigraphic plaque of Canggrang in Pasuruan, East Java built in 926 mentioned ‘*sang hyang tirta pancuran’*, meaning the importance of water conservation resource to make it long lasting under the goddess’ protection.

Traditional people in Indonesia also built the epigraphic of water-symbol that represents their care in protecting the water resource. Many temples of Hinduism and Buddhism were built on the source area of water to encourage people to protect water resources as a sacred place. Those temples are Bale Kambang, Kunthi Lerep, Semboja, Senjaya, Payak, Simbatan, Songgoriti, Jalatunda, and Tikus in Java, Goa Gajah, Tirta Empul, and Tirta Gangga in Bali, and Narmada in Lombok. Most of them are still in a good condition until now.

Besides epigraphic plaques and temples, the ancient people in Indonesia also immortalized the concept of water conservation by naming a certain region or river with an additional word referring to water. Donotirto, Tirtomulya, Tirtohargo, and Tirtosari village in Bantul Regency are examples of it; *‘tirta’* means water, symbolizing prosperity, because the village has a water resource. West Java with its Sundanese ethnic also name a certain location using the prefix ‘*ci*’, which means ‘water’, such as Cimahi, Cirebon, Ciberem, Cibaduyut city and Ciliwung, Citanduy river, etc.

To regard something as forbidden or taboo is another way of the ancient community to protect their water resource area. The prohibition of filling up a well with soil although the well has no longer been used is an example of a taboo act leading to misfortune. This belief is still strongly run among the villagers in Java. Logically, the misfortune is a lack of clean water resources as an unused well can actually become a rainwater catchment area for groundwater recharge. Another example is the prohibition to cut down a big tree wherever it grows because it is considered as the guard of the spring-source.

The tradition of using water in a series of sacred ceremonies also still runs in Javanese culture (Marwito, 2003). For a perpetuate life, a generation in the community has an obligation to preserve the clean water resource symbolized either by the wedding ceremony or by the preparation of a baby’s birth. Before the wedding, a Javanese engaged couple takes a shower with pure water taken from seven different springs to give an understanding that the community has to keep the purity of wells. The water taken from seven springs is also used in ‘*mitoni’* ceremony, the celebration of the seventh-month pregnancy for a mother, conveying hopes for the future baby that he/she is born safely and living in prosperity after he/she is showered with the pure water.

The religious ritual in Islam also uses water for taking ritual ablution (*wudhu*), a symbol of cleaning oneself from bad attitudes before praying. The Catholic Christians get the spread of holy water at certain ceremonies to make their soul clean. The Hinduism also use pure water called *‘tirta amerta’* as part of ritual series in their religion to get safety and prosperity. So do the Buddhists; pure water is used as an important part of each religious activity as a blessing, for safety and prosperity. Thus, it implicitly indicates that water is an essential element of the life system of this world.

It is also mentioned in the Holy Qur'an that the heaven is for people who care about the environment and the hell is for those who neglect the environment (Abdillah, 2005). Furthermore, God, in the Holy Qur'an, describes the heaven as a place in which the rivers have clean, pure, and beautiful water. In addition, many verses in the Holy Qur'an describe that the heaven is the place with clear and pure springs where fresh and delicious fruits grow. This reflects that the value of water and environment is very high even when human lives in the eternity. The good eternity world is described as a natural place completed with the sustainable availability of water.

Essentially, there is guidance in the Islamic religion for people to follow the management of rainwater resource in order to protect the people and other creatures from the rainy season and the dry season that turn into disasters. As written in the verses of Qur'an, God delivers the rain from the sky to create life for the dwellers of the Earth. In other words, if there is no rain, there will not be any life. God the Almighty repeatedly gives explanation about rain in at least 35 verses of Qur'an. It is explicitly and implicitly stated there that rain is meant to give life for creatures on the Earth instead of to be a disaster as long as the human beings know how to read the implicit meaning of this universe and as long as they are aware of how to be grateful and how to act towards the components of this universe.

God reminds in His saying "Say: What do you think if at early morn your waters shall have sunk away, who then will give you clear running water?" (Qur'an: 67/30 in Dahlan, 1998). That question should remind human beings that they, who believe in their religion, have to know about the limited amount of water resource existing in this planet. The data shows that the quantity of freshwater on this Earth is indeed very little compared with the total amount of water, which in fact is mostly salty water. The total amount of freshwater on this Earth is only about 2.5% of the total amount of water, and it consists of shallow groundwater, deep groundwater, river water, lake water, water on the air, and water in the soil moisture. The sustainability of the very limited freshwater is deeply influenced by its usage management as well as by its supply management. Actually, the main supplier of freshwater is the rainwater. God gives water from the sky to a part of this Earth to make the hydrology system in balance. Human beings and other creatures should be grateful since the rainwater that falls is no longer salty although actually its main material is the seawater containing high salt. The very sophisticated technology of desalinization that God owns occurs in this universe; it makes all the systems and life become sustainable. It has never been imagined if the rainwater still tastes salty, as the God saying "Brackish could we make it, if we pleased: will ye not then be thankful?" (Qur'an: 56/70 in Dahlan, 1998). Therefore, managing the rainwater well as the establishment of human's grateful to God can possibly minimize the disasters of drought and flood.

Based on the aforementioned explanation, it can be seen that the development of water resources by applying the cultural approach is very possibly to conduct. It is unnecessary to consider the wisdom of the local culture as the 'out-of-date', old-fashioned condition, without any visions. The experience shows that the handling of the water resource development, which is based merely on the technology and economical aspect, often urges the existence of new problems in the near future. Changing the people’s culture so that they will go back to the wisdom characters and attitude in treating the water resource is not an easy work. It requires the next step, which will connect the local culture and the water resource management in the context of present time. Holding a campaign is an effective method to move the people so that they will be more concern on the conservation of water resources.

CHAPTER 3

WATER RESOURCES MANAGEMENT AND RAINWATER HARVESTING (RWH)

3.1 Sustainable Water Resources Development

The World Commission on Environment and Development (WCED, 1987 in Prinz, 2000) defined the objective of sustainable development as "to meet the needs of the present generation without jeopardizing the possibilities of future generation to meet their own needs". Most definitions of sustainable development can be concluded into three broad notions (Loucks, 1994), i.e. justice for nature, justice for future generation, justice for existing own generation.

Therefore, the development of a region for increasing the prosperity and enriching the culture of its people should always conform to balance and sustainability. The balance in development covers the dimensions of economy, social life and environment (Yunus, 2005). Those three dimensions, also called *trilemma*, are closely related to each other (Figure 3.1).

The relationship between economic pole and environmental pole establishes the conservationism principle, i.e. the exploitation of natural resources for economic needs must consider the natural resources conservation to guarantee the continuity of the next generation. Meanwhile, the relationship between economic pole and social pole establishes the commitment of community to develop the economy and people's prosperity based on the principle of justice. In addition, the relationship between social pole and environmental pole establishes the commitment of people to consider the ecology whenever they exploit the nature for their needs.

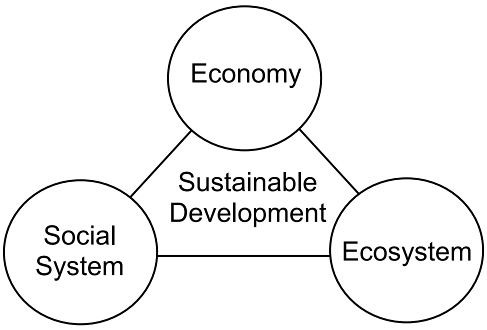


Figure 3.1: Three poles of sustainable development, the harmony of economic, social, and ecosystem factors

Hence, the environment and social components should become the controller of the growth-rate of economic needs due to population growth or life style. In terms of water, the population and economic growth make the demand for the functions of water-resource development increase at an alarming rate in most countries of the world.

According to Prinz (2000), water has subsistence, environmental, commercial, and ecological functions. Hence, the principles of sustainable water resources development, related to the new ecosystem paradigms of eco-development and eco-humanism, are intergenerational equity, the principle of precaution, biodiversity conservation, and environmental cost internalization

(Purba, 2005). Furthermore, the sustainable development of water resources imposes certain conditions on the process of water-resource development planning and design and on the operation and maintenance of water resources systems.

For achieving sustainability (Alaerts et al., 1991 in Prinz, 2000), an integration of technical, environmental, financial, social and institutional aspects is required (Figure 3.2). It must be applied to water resources system planning, design, and operation at any scale (Prinz 1999), for example a local system for providing more reliable and safer water supply for a small village. Therefore, any investment towards sustainable water-resource development must be considered within this broad, integrated context.

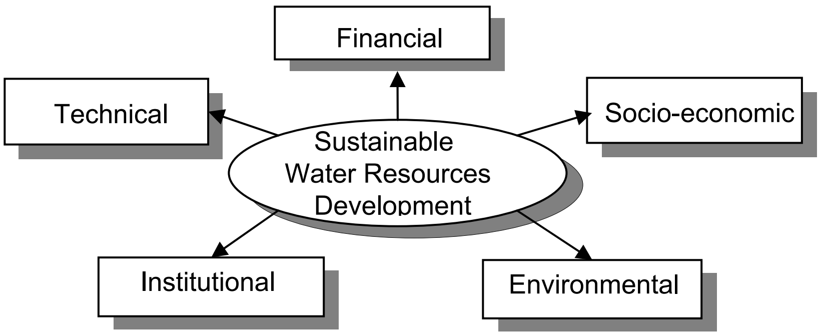


Figure 3.2: Important aspects for sustainable water resources development (Source: Prinz, 2000)

3.2 Reorientation of Development towards Sustainability

In practice, the term ‘development’ has captured the policy makers to emphasize an economy-oriented development in the name of social welfare instead of balance. The development highlights economy more than socio-culture and ecology. Consequently, in terms of the number of environmental degradations due to development, a positive economic growth could turn into a negative one (Kodoatie and Sjarief, 2005).

Besides the meaning of sustainable development, another aspect to concern is the natural resources. State officers still define natural resources as economic resources, which are ready to process merely for economic needs, neglecting such values as socio-culture and environment conservation.

This phenomenon can be observed from the high rate of land-use change in Sleman as an upstream region and a recharge area. The high settlement/housing growth in this area, in the form of either housing complex or individual-sporadic complex, has increased the frequency of floods and droughts in the downstream area. Yet, investors always claim housing-complex business as the development that contributes to the local economic growth, promoting the local business atmosphere, economy, price of land, modernization, and people’s welfare.

Considering the aforementioned phenomenon, the definition and implementation of sustainable development needs a reform. The domination of economy should be replaced by that of ecology; therefore, in terms of development, the key word order is ecology then social and economy. Moreover, it is necessary to reform the anthropocentric approach stating that the Earth and its content are only for human beings as the most powerful living creature on Earth. People can exploit natural resources for their prosperity, but other living creatures also have the same right. The exploitation should not destruct the natural resource functions to guarantee a harmonious, balanced life.

According to Abdillah (2005), God has created the environment to facilitate human life, as written in the Qur'an of Luqman Verse 20. Hence, environment conservation is considered an obligation in Islam. Human beings must take care of the environment for their own good and as a command from God because the Earth, universe, and its content belong to God only. However, human beings often neglect the environment destruction and disaster they have made consciously or unconsciously. Once, Mahatma Gandhi stated that actually this Earth is wide enough to support humans' life as long as they can control their greediness.

Human beings as religious creatures are obliged to develop their own awareness and attitudes to conserve the environment. God has chosen human beings as the special living creatures that have a heart and logical reasoning in exploiting the universe (Qur'an: 33/72 in Dahlan, 1998). This matter is in line with human's status as a caliph on Earth (Qur'an: 2/30 in Dahlan, 1998) who represents God's authority. God hates someone who damages the Earth and its environment (Qur'an: 30/41 in Dahlan, 1998). God has given the right and power to human beings to exploit the natural resources without neglecting the genuineness, and they must prevent themselves from being *over* in exploiting the resources. Actually, God has guaranteed that a nation would not be cruelly brought into chaos if its people were able to keep their environment well (Qur'an: 11/116-117 in Dahlan, 1998).

A good deed towards the environment and water resources is as worth as getting the benefit of the environment, and vice versa, there will be only punishment in the next life, which waits those who destruct the environment. God will punish human beings in hell for those who do not aware of their own attitude, which damages the environment. On the contrary, a beautiful heaven is provided to appreciate those who care for the environment conservation. Everything will be paid as the ecology-spiritual acts conducted.

3.3 Integrated Water Resources Management (IWRM)

3.3.1 General

According to Kodoatie and Sjarief (2005), the water resources need to be better managed because of some reasons, for example: the more critical condition of water resources, the future challenge, and the development of new paradigms. The growth of water demand in quantity or quality and associated problems, specifically in urban areas, has made many parties realize the importance of managing these resources comprehensively. IWRM is a process that promotes the coordination of developing and managing water towards other resources from the sub-sector system to the cross-sector in order to optimize the economic results and the socio-cultural fortune without causing any significant disturbance towards the ecosystem (GWP, 2001).

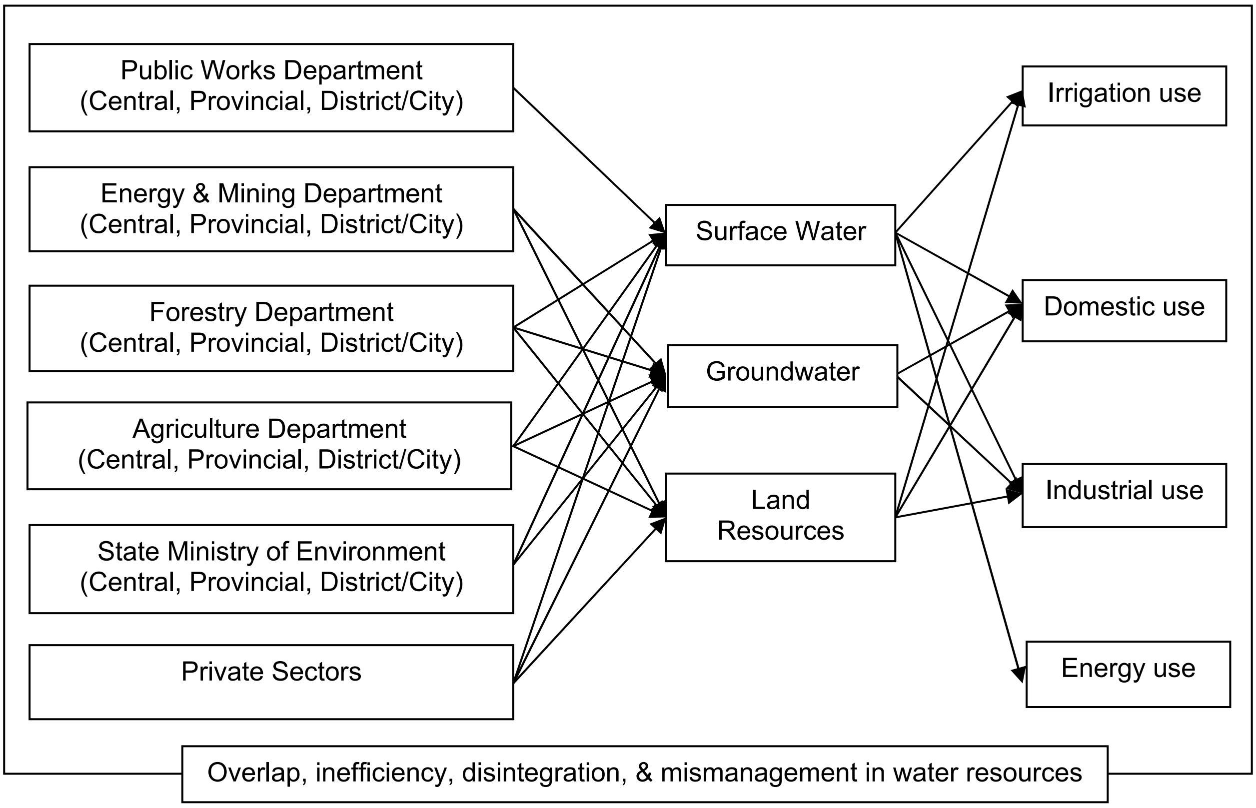


Figure 3.3: Stakeholders, the sources of water and land resources, and water use (Source: modified from Kodoatie and Sjarief, 2005)

Many government departments involve in water resources management in Indonesia that have in fact of overlapping and mismanagement (Figure 3.3). Public Works Department focuses on its authority to manage the surface water, while Energy and Mining Department focuses more on groundwater management. Due to a close, influencing relationship between groundwater and surface water, such separated management often creates action gaps. The same thing occurs in other departments or institutions having authorities relating to water resources management, such as land-use management. The fatal weakness in this chaos organization model is a low coordination, even a lack of it, among the existing sectors and the sectional ego.

In general, many parties accuse population growth as the main cause of decrease in water resources. The population growth has caused unacceptable exploitations of natural resources, land-use changes, and a decrease in the carrying capacity of the ecosystem. The multi-player effect of population growth and the changing life style promote a strong awareness of people's need for an integrated water resources management as an effort to solve and anticipate the problems. Figure 3.4 shows the connection between population growth, its impacts and the need for IWRM.

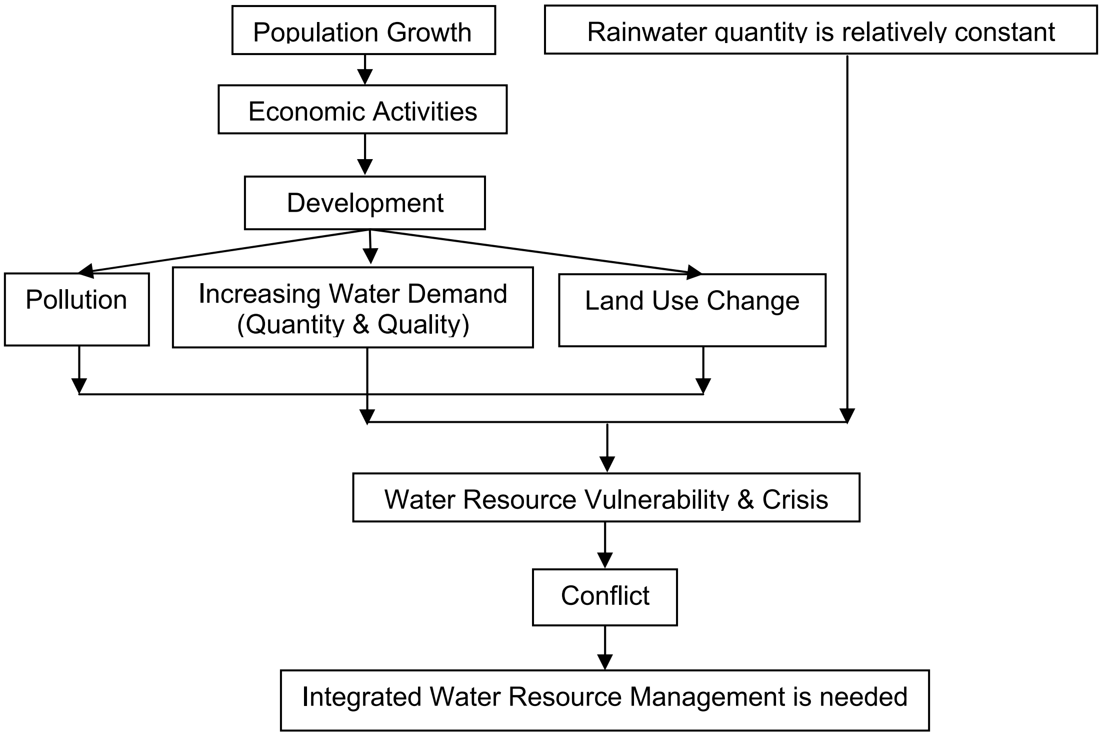


Figure 3.4: The need for IWRM caused by population growth and its multi-player effects (Source: modified from Kodoatie and Sjarief, 2005)

The population growth has pushed economy and development, bringing water crisis and water vulnerability. During these critical conditions, water resources will cause many conflicts between the upstream and downstream areas, the urban and rural areas, the rich and the poor, the industrial and agricultural sectors, and between the economic and conservation needs. Another conflict is related to land use. Industry or property agents often consider farmlands in urban or peri-urban areas as having low economic value; so, they change them into real estate complexes or industrial estates. The economy then indeed rises, but, as long as the change neglects the ecological aspect, it will surely turn into disasters in the future.

According to Prinz (2003-a), some factors to be considered in applying IWRM are:

1) Each party must realize that water resources problems are getting worse and more complex.
2) The water resources area is a cross-border part between regencies, cities, provinces, even countries, urban-rural areas, and others.
3) The regional planning must accommodate the importance of water resources development.
4) The boundaries of watersheds, groundwater basins, and administration units are generally not the same.
5) Water resources management shall be based on natural elements in combination with anthropogenic decisions.
6) The management can be based on function, e.g. irrigation, drainage, conservation of clean water, and others.
7) The management should refer to the integrated, comprehensive, and interdependency principles.

All the aforementioned concepts will be useless, however, without significant efforts in passing and executing laws. In Indonesia, the newest regulation about water is Law No. 7/2004 on Water Resources, reforming the old Law No. 11/1974 on water. This Law is ideally meant to:

1) Assure public that water is a gift from God, so its sustainability must be preserved,
2) Anticipate the increasing demand for water,
3) Harmonize the water resources management for social, economic, and ecological functions,
4) Integrate regions, sectors and generations,
5) Involve the society to be more active through a democratic, reliable, decentralized, open way,
6) Supply adequate information and data about water resources.

This law has susceptible parts, facing the refusal from social groups, especially from academics, NGOs, and farmers. They object the privatization of water resources management because the country gives freedom to private, state, and international parties to exploit water resources. The great concern is abandoning the rights of farmers and the poor due to a private domination that tends to gain financial benefit, neglecting that water is a social resource.

Moreover, this new law has some weaknesses, for example:

1) It has not been socially accepted.
2) The relationship between water resources and regional planning is not firmly explained.
3) It does not explicitly promote use of rainwater.
4) Until now, it is not completed by more detailed rules, such as the Government Rules or Local Rules as a practical guide.
5) It has not explained the mechanism of law enforcement or control; thus, the law enforcement will be as weak as other rules.

3.3.2 RWH as part of IWRM

RWH development should be a part of the IWRM (Figure 3.5). The principles of IWRM should be the cornerstone of any implementation strategy in the water sector. According to Prinz (2004), the IWRM principles focus on:

1) Integration of water quality and quantity management, use of waste water and other marginal water, conjunctive use of groundwater and surface water management, freshwater and coastal zone management, water supply and sanitation planning, upstream and downstream demands in regard to water quantity and quality, physical, economical and social aspects of water resources management, and water conservation,
2) Ecosystem management in recognizing all values of biodiversity and the integrity of ecosystems,
3) Communication between main actors in water resources management: politicians, government, water consumers such as industry, household, commercial, and agriculture, water specialists, and interest groups (Figure 3.6),

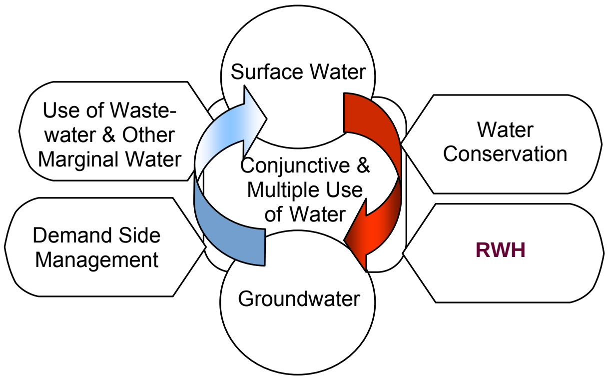


Figure 3.5: RWH as part of IWRM (Source: Prinz, 2003-b)

4) Capacity building by training of professional skills, raising public awareness, and
5) Public participation in decision making based on access to water-related information.

Many changes in institutional framework, laws and regulations, financial structures and technical standards have to be implemented in parallel with the principles of IWRM. The cooperation among Sleman, Yogyakarta, Bantul, DIY Province, and other regencies should be developed more cooperatively. A wide variety of actions are involved in its management; their decisions frequently have trans-national or even trans-regional impacts.

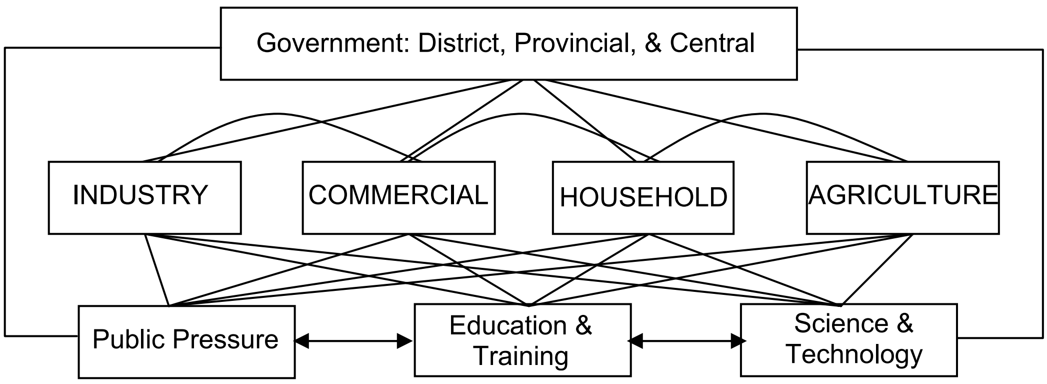


Figure 3.6: Interconnection among stakeholders in developing RWH as part of IWRM (Source: Prinz, 2003-a)

3.4 Historical Development of RWH

Lately, people become more dependent on groundwater reserves because surface water resources can no longer fulfill their increasing demands for water. Consequently, dry wells and saline water occur in coastal belts, leading to seawater intrusion and hydrological imbalance along coastal areas. The simple and most effective way to solve the problems is developing RWH technique (Prinz, 1996-a). RWH has been widely used in urban and peri-urban areas worldwide. However, RWH users are still extremely low.

For thousands of years, ephemeral stream water has been used in arid and semi-arid areas, promoting the development of desert cities (Evenari et al., 1971). Due to the development of technology expanded by Europe since 1850, less attention was given to small-scale and traditional irrigation techniques. Yet, for the last decades, water harvesting has been more popular. This positive development of water harvesting puts together the basic needs of farmers, local natural conditions, and existing economic and political conditions of a region (Prinz, 1994).

Gould (1999) clearly summarized the history of rainwater harvesting. RWH used to be the main resource of domestic water and irrigation water in dry areas because of the lack of deepwater pumping, large dams, lined canals, pipes, etc. and the employment of labors in the building of structures for water harvesting, the cleaning and smoothing of runoff surfaces, the maintenance of canals and reservoirs, etc. (Prinz, 1996-b). The following examples of RWH technique illustrate that:

1) In the Mediterranean and Middle East, hundreds of years BC, people used underground tanks, excavated reservoirs, cisterns with masonry domes, or a system of vertical shafts-horizontal tunnels-underground reservoirs (Wildenhahn, 1985).
2) In India, North Africa, the western Mediterranean, Thailand, China, Japan, Bangladesh, Nepal, Sri Lanka, Indonesia, and islands in the Pacific, the traditional RWH is found. Agarwal (2001), in Dying Wisdom, wrote about RWH practices in India.
3) In Southern Africa, Ghana, Kenya, and Tanzania, people still use small containers (Bruins et al., 1986).
4) In Western Europe, America and Australia, rainwater is still an important source for isolated homesteads and farms.
5) In Jordan, Syria, Iraq, the Negev, and the Arabian Peninsula, particularly Yemen, water harvesting structures left archaeological evidence (Oberle, 2004).
6) In Jordan water harvesting structures have been existed for more than 9,000 years.
7) In Southern Mesopotamia, simple water harvesting structures were used in around 4,500 BC.
8) In the semi-arid to arid Negev desert region of Israel, the most famous runoff-irrigation systems were found (Evenari et al., 1971). Nabataeens of the 10th century BC introduced runoff agriculture in this region (Adato 1987, Kolarkar, et al., 1983).
9) In North Yemen, farmers have been using a floodwater irrigation system (Adato, 1987, Eger, 1988) since around 1,000 B.C. (Bamatraf, 1994).
10) In Baluchistān (Pakistan), the Khuskaba system using bunds across land slopes and the Sailaba system using earthen bunds for capturing floods were developed (Oosterbaan, 1983).
11) In Libya, some runoff-based farming techniques are continually practiced on the slopes of the western and eastern mountain ranges (Al Ghariani, 1994).
12) In the Libyan pre-desert, the UNESCO Libyan Valleys team found structures of runoff irrigation as the basic of granary wealth of the Roman Empire (Gilbertson, 1986).
13) In Morocco's Anti Atlas region, Kutsch (1982) discovered many experiences and various well-adapted systems of water-harvesting techniques.
14) In Algeria, the traditional water harvesting used rainwater storage ponds; open ponds were mostly used for watering cattle.
15) In Tunisia, the Meskat systems consisting of an impluvium and a cropping area are found in Sousse region; meanwhile, the Jessour systems, earth dikes reinforced by dry stonewalls, are common in the South of Tunisia. In Central Tunisia, the Mgouds are used to redirect floodwater from the wadi to the fields (Tobbi, 1994).
16) In Egypt, some wadi terracing structures have been used for centuries in the Northwest coast and the Northern Sinai.

17) In the central rangelands of Somalia, the Caag system for storing runoff from small watercourses, gullies, or roadside drains by using earth bunds is used. For almost flat land and less runoff, the Gawan system, "grids" of basins, is utilized (Reij et al., 1988).
18) In Sudan, people have used various types of Haffirs for domestic and animal consumption as well as for pasture improvement and paddy cultivation (UNEP, 1983, Van Dijk and Reij, 1994).
19) In Niger's Ader Doutchi Maggia, the Haussa people changed a rocky area in a terraced one, using rock bunds, stalks, and earth to redirect water to their fields (Fatondji et al., 2001).
20) In Burkina Faso, Zay was applied in combination with bunds to conserve runoff (Wright, 1985), various small-scale traditional water harvesting techniques existed in the Ouaddai area in Chad (Somerhalter, 1987).

Many other existing traditional water harvesting systems still face the problem of extremely limited and fragmentary knowledge and information (Reij et al., 1988, Nabhan, 1984).

3.5 Technical Description of RWH

3.5.1 General

Water harvesting is a term describing techniques for collecting, concentrating, and conserving water from various sources for various purposes. Agarwal (2001) defined rainwater harvesting as the art, technique, and science of collecting rainwater where it falls, while Pacey and Cullis (1986) referred to rainwater harvesting as the principle of using precipitation from a small catchment.

Generally, rainwater-harvesting methods are classified based on the characteristics of the runoff producing and storage elements of the system. At the simplest level, the various methods can be divided into two groups (CSE, 2003):

1) Rooftop rainwater harvesting method: Rainwater is collected from roof of buildings, concentrated in gutters and conveyed by pipes to a storage system for domestic uses, groundwater recharging, and/or micro irrigation.
2) Non-rooftop rainwater harvesting, including micro-catchment and macro-catchment. Micro-catchment includes contour ridges, furrow dyke, strip planting, stone bunds, etc. Macro-catchment includes terraced systems, hillside conduit system, dam used for recession planting, etc.

According to Prinz (1994), all rainwater-harvesting systems have two main elements:

1) A catchment area to supply runoff to the run-on area: It can be a field, a hillside, a road, a roof, a river or any other area from which water can be collected.
2) Storage, cropped area or run-on area, where the accumulated water is stored and/or utilized, for domestic purposes: The accumulated water is stored in cisterns, wells, etc.

Compared to ground or land surface catchment areas, rooftop rainwater harvesting is a less complex way of collecting rainwater. Meanwhile, compared to roof catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. The water collected from ground catchments is usually of poor quality and not suitable for drinking water supply. In addition, rooftop rainwater harvesting is favored for drinking purpose.

3.5.2 Elements of Rooftop RWH

A rooftop rainwater harvesting system consists of the main following components: roof catchment area, conveyance system, and storage system (CMWSSB, 2004).

1) Catchment

The roof catchment is the most basic requirement for a rooftop rainwater harvesting system. Roof catchments are suitable for individual use, schools and other public buildings where sufficient impermeable roof cover exists. The style, construction, and material of the roof affect its suitability as a collecting surface for water.

The amount and quality of harvested water depend on the extent of the catchment area and the roofing material respectively. A smoother, cleaner, and impervious roofing material contributes to better water quality and greater quantity. Water loss is possibly from roof, gutters, storages, and evaporation.

Roof types used for rainwater harvesting include single, double, tent, hip and flat roofs. The single pitch roof is considered the most appropriate one because the entire roof area can be drained into a single gutter on the lower side, and depending on the area, one or two down pipes can be provided. The double pitch is also suitable, but it requires draining each half of the area into separate gutters emptied through down-pipes into a reservoir at the end of the building.

2) Conveyance system

Conveyance system is required to transfer the rainwater collected on the rooftops to the storages, consisting mainly of gutters and down-pipes. A gutter performs essentially two functions, i.e. to intercept the runoff on its way from roof edge to the ground and to transport the intercepted water sideways towards some concentration points. It may be constructed of tin, plastic or local materials such as wood, bamboo, etc.

3) Storage

The water storage usually represents the biggest capital investment element in a rooftop rainwater harvesting system (DGIS, 2001). It usually requires the most careful design to provide optimal storage while keeping the cost as low as possible. Common vessels used for small-scale water storage in developing countries include plastic tanks and buckets, jerry cans, clay or ceramic jars, ferrocement tanks, used oil drums, etc. For storing large quantities of water, the system usually requires a larger tank or a cistern. These can be made of burnt bricks, metal, or concrete. Tank is classified as an aboveground storage vessel and the cistern as an underground storage vessel.

There is a wide range of water storage options with various shapes, materials, sizes and prices. The choice depends on a number of technical and economic considerations, such as space availability, local traditions of storing water, cost of materials and labors for construction, materials and skills available, ground conditions, and style of RWH.

One of the main choices will be whether to use aboveground storage or underground storage (Figure 3.7 and 3.8). Both of them have their merits and demerits. The advantages of aboveground storages are: easy inspection for cracks or leakage, easily purchased, manufactured from a wide variety of materials, easy to construct from traditional materials, gravity water extraction, raised aboveground level to increase water pressure, and insusceptible to contamination. Meanwhile, the disadvantages of them are: requiring space, generally more expensive, more easily damaged, and prone to weather attack.

The advantages of underground storage are: generally cheaper, requiring little space, lower wall thickness due to the support of surrounding ground. On the other hand, the disadvantages are: water extraction requires pumping in many cases, leaks or failure are more difficult to detect, contamination of the tank by groundwater is more common, tree roots can damage the structure, danger of children and small animals falling in if the cover is left off, floatation of the cistern may occur if the groundwater level is high and cistern is empty, and heavy vehicles driving over a cistern can cause damage.

3.5.3 Land Surface Catchments

If water is required where there is no roof or rocky outcrop suitable for collection, the construction of an impervious surface can be established on the ground itself (Chrichley et al., 1992-a). Reinforced concrete can be used to make the surface; chicken wire reinforcing should be used to prevent cracking of the floor. An alternative technique is to lay a large piece of plastic sheeting in a hollowed out and leveled area of ground (Dixit and Patil, 1996). A layer of sand is laid over the bottom of the excavated area and raked flat. The sheet of plastic is laid out over the layer of sand and the edges rose up against the sidewalls of the excavation. A drainage system is now laid in the form of a slotted PVC pipe, which drains away in the reservoir used for storage. Finally, a layer of gravel or very coarse washed river sand is laid on the bed. The edges of the area should be raised with a rim of concrete work. The area should be fenced off to prevent access to animals. The construction of the reservoir is the costliest. It may be either in stone masonry and constructed either below or above the ground.

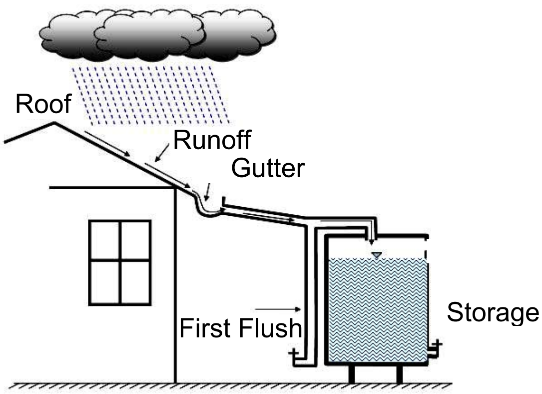


Figure 3.7: Components of RWH: catchments (roof), conveyance (gutter), and aboveground storage

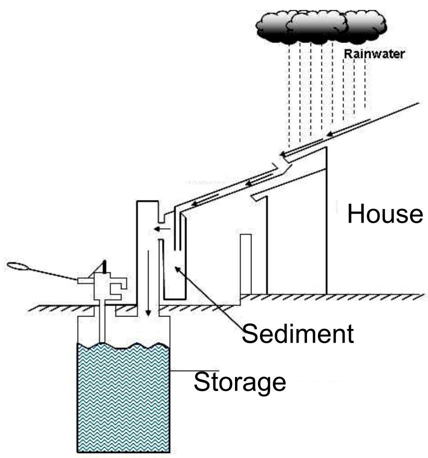


Figure 3.8: Roof water harvesting with underground storage

RWH using ground or land surface catchment areas is a less complex way of collecting rainwater. It involves improving runoff capacity of the land surface through various techniques including the collection of runoff with drainpipes and storage of collected water. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. By retaining the flows (including flood flows) of small creeks and streams in small storage reservoirs (on surface or underground) created by low cost (e.g., earthen) dams, this technology can meet water demands during dry periods (Chrichley et al., 1992-b). There is a possibility of high rates of water loss due to infiltration into the ground, and, because of the frequently marginal quality of the water collected, this technique is mainly suitable for storing water for agricultural purposes. Various techniques are available for increasing the runoff within ground catchment areas, involving clearing or altering vegetation cover, increasing the land slope with artificial ground cover, and reducing soil permeability by the soil compaction and application of chemicals. Clearing vegetation from the ground not only can increase surface runoff but also can induce more soil erosions. Using dense vegetation cover such as grass is usually suggested as it helps to both maintain high rate of runoff and minimize soil erosion. The surface runoff collected in storm water ponds/reservoirs from urban areas is subject to a wide variety of contaminant. Keeping these catchments clean is of primary importance, and hence water pollution control can be costly.

To be more efficient in collecting runoff, steeper slopes can be made. However, the rate of runoff has to be controlled to minimize soil erosion from the catchment field. Using plastic sheets, asphalts, or tiles along with slopes can further increase efficiency by reducing both evaporative losses and soil erosion. About 65 years ago, the use of flat sheets of galvanized iron with timber frames to prevent corrosion was recommended and constructed in the State of Victoria, Australia (UNEP, 1983).

3.6 Whether to Store or to Recharge Rainwater

Harvesting rainwater can be done in two ways; first, rainwater can be stored, and second, it can be recharged. Figure 3.9 explains the choices of rainwater harvesting. The decision whether to store or recharge water depends on:

1) The rainfall pattern: Areas where the total annual rainfall occurs during three or four months are examples of places where groundwater recharge is usually practiced (Figure 3.10). In places where rain falls throughout the year with a short dry period, a small sized tank is reliable enough for storing rainwater.
2) The sub-surface geology: The most important factor of sub-surface geology for recharging the water is the structure should be permeable. Wherever sub-strata are impermeable, recharging will not be feasible. Hence, it would be ideal to opt for storage with recommended groundwater level of more than 3 m depth from the ground surface.
3) Groundwater salinity: In places where the groundwater is saline or not of potable standards, the alternate system could be that of storing rainwater (DGIS, 2001).
4) Density of population in a given area.
5) Availability of water and availability of alternative sources of water, e.g. surface water.

6) Human induced (deterioration of) quality of the groundwater (need for improvement by surplus water of good quality).
7) Quantity of excess water during the monsoon season that has to be drained and could potentially be recharged.
8) Depth of the recharged aquifer and technical means to lift the water, etc.

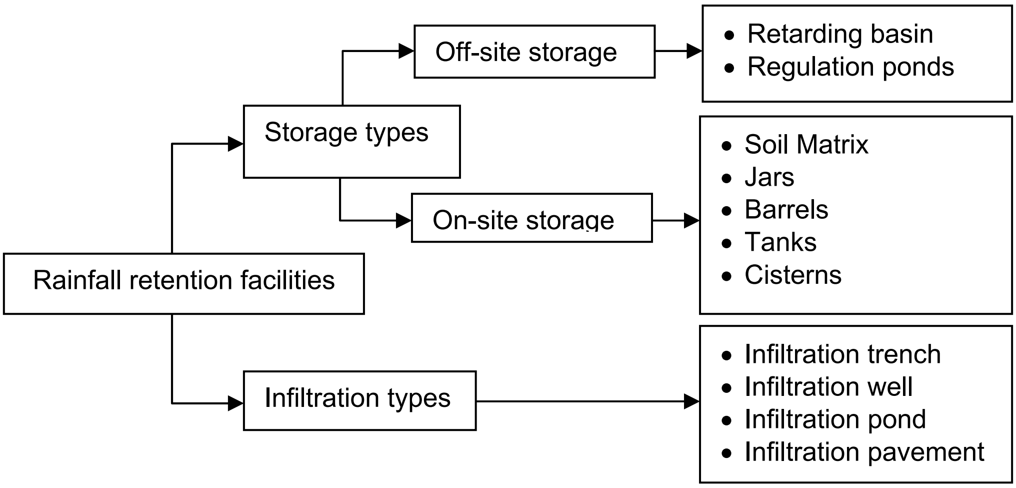
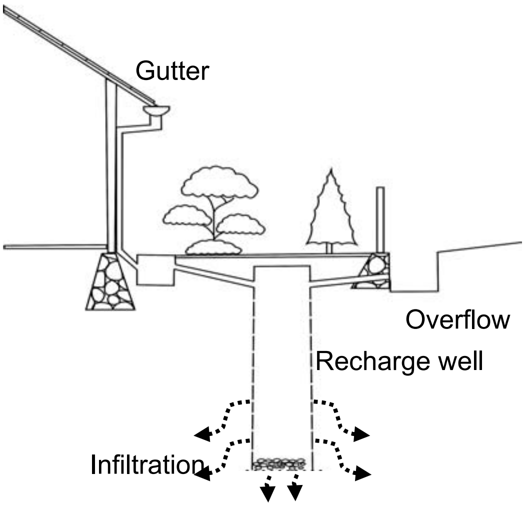


Figure 3.9: Rainwater harvesting types

Rainwater may be charged into the groundwater aquifers through any suitable structures like dug wells, drilled wells, recharge trenches and recharge pits. Various recharge structures are possible - some promote the percolation of water through soil strata at shallower depth e.g., recharge trenches, permeable pavements, whereas others conduct water to greater depths from where it joins the groundwater e.g. recharge wells. At many locations, existing structures, like wells, pits and tanks, can be modified as recharge structures, eliminating the need to construct any structures afresh (Figure 3.11).

Rainwater management had better be aimed at re-infiltrating rainwater into the ground with 100% efficiency for developed areas, so there is sustainable water availability for groundwater conservation. Therefore, recharge wells are required for tapping drainage water in urban areas. There are two types of recharge well, i.e. domestic recharge well and communal recharge well. Several requirements for building recharge wells are:

1) Simple construction,
2) No sophisticated tools required; easy, affordable, and quick making,
3) Deep enough and having ample water reservoir capacity,
4) Ample facilities for protection from contamination,
5) Safe for children,
6) Free from mosquito's lairs,
7) Easy operation and maintenance.



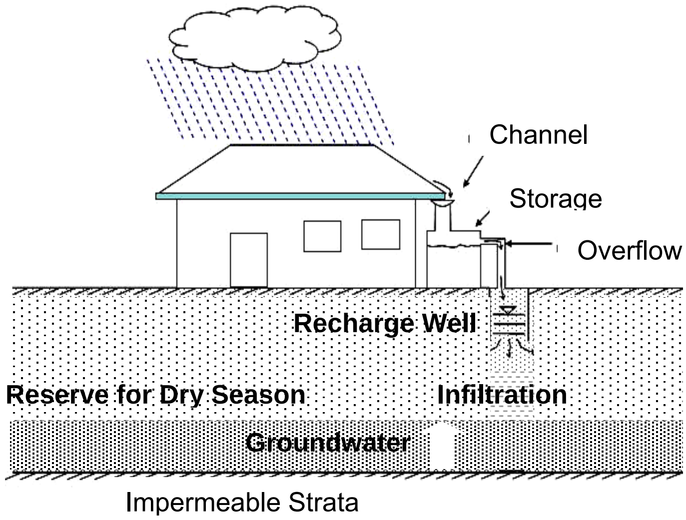


Figure 3.10: Rooftop RWH with artificial recharge well (Source: redrawn and adapted from Moeljono, 1995)

Figure 3.11: Rainwater can be stored and consumed directly, and/or recharged which is important for improving groundwater level (Source: Adapted from Prinz, 2005)

Recharge wells are meant to let rainwater that falls on the roof or waterproof area infiltrate into the ground by means of catching the water in an absorption system. Different from the conventional way in which rainwater is discarded or drained into the river to the sea, this technique can channel rainwater into recharge wells in house yards. These recharge wells are empty wells with ample capacity to reserve water before it infiltrates to optimize water recharge.

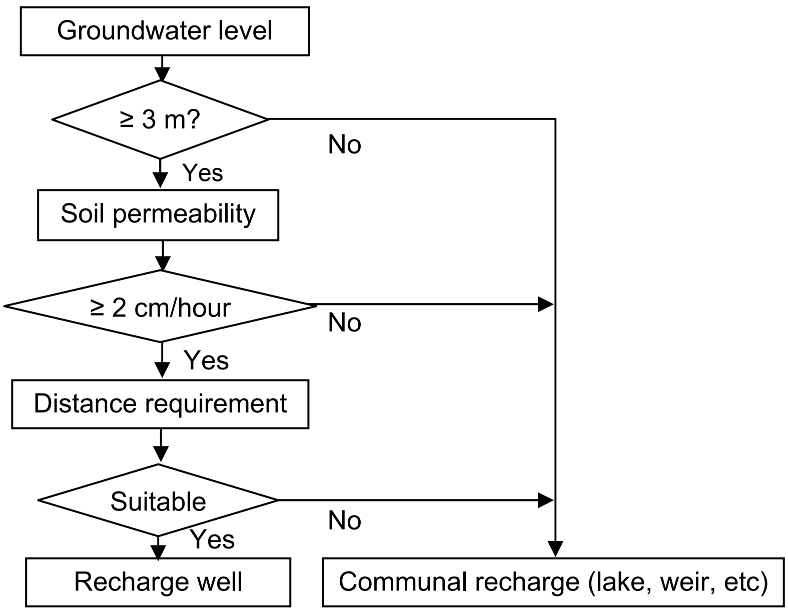


Figure 3.12: Flowchart of recharge-well planning

Based on the aforementioned concept, the dimension of wells for an area then depends on the following factors:

1) The dimension of coverage surface for the area, including the dimension of roof, parking lot, and other hardened surfaces,

2) The characteristics of rainwater, including rainfall intensity, rainfall duration, and rainfall interval; generally, the higher the rainfall, the longer the rainfall duration and the bigger the recharge-well dimension required,
3) The soil permeability coefficient, i.e. the soil ability to infiltrate/channel water per time unit; sandy soil has higher permeability coefficient than clay soil.

If the groundwater level is deep, recharge wells are made colossally because it means the soil truly needs water recharge. On the other hand, if the groundwater level is shallow, making recharge wells is not an effective way. Figure 3.12 illustrates the flowchart of recharge-well planning according to the standard of Public Works Department (Supirin, 2004).

Although recharge wells give many benefits, some requirements should be followed to make them optimally used, such as:

1) Rainwater recharge wells are built on permeable and landslide-free areas.
2) Rainwater recharge wells must be free from waste contaminant/pollutant.
3) Water flowing into recharge wells is rainwater.
4) For areas with bad sanitation, recharge wells are only used for collecting rainwater from the roof and channeling it through gutters.
5) The making of recharge wells should consider the aspects of geohydrology, geology, and hydrology.

For houses of limited dimension, such as plain or very plain housing complexes, good placement of recharge wells is difficult. Therefore, a communal recharge well can be made for several houses, for example per block or per neighborhood (”*RT”*), or even wider housing units. In order to guarantee the smooth flow of rainwater, the communal recharge well had better be placed in the lowest part of the recharged area.

3.7 Influencing Factors

The main factors influencing the rainwater harvesting in a site are, e.g. eco-climatic or rainfall conditions influenced by its quantity and pattern and the catchment characteristics that are considered the most important (CSE, 2004).

3.7.1 Rainfall

Quantity and pattern of rainfall are the most important factors in developing RWH. Rainfall is the most unpredictable variable in the calculation and hence, to determine the potential rainwater supply for a given catchment, reliable rainfall data are required, preferably for a period of at least 10 years (CSE, 2004). A precondition is the availability of rainfall data from a nearby station with comparable conditions.

The number of annual rainy days also influences the need and design for rainwater harvesting. The fewer the annual rainy days or the longer the dry period is, the more the need for rainwater collection in a region is. However, if the dry period is too long, big storage tanks will be needed to store rainwater. When the water is only for drinking, the storage dimension would be much smaller.

3.7.2 Catchment Area

Runoff depends on the area and type of catchments over which it falls as well as surface features. All calculations relating to the performance of rainwater catchment systems involve the use of runoff coefficient to account for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation contributing to reduce the amount of runoff. Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface. Table 3.1 is a list of runoff coefficient for various types of catchment. Based on the aforementioned factors, the water harvesting potential of a site could be estimated using the formula given below.

RWH potential = Rainfall (m) x Area of catchment (sq. m) x Runoff coefficient

Table 3.1: Runoff coefficients

No	Type of Catchment	Type of Material	Coefficients
1	Roof Catchments	▪ Tiles	0.8 - 0.9
		▪ Corrugated metal sheets	0.7 - 0.9
2	Ground surface coverings	▪ Concrete	0.6 - 0.8
		▪ Brick pavement	0.5 - 0.6
3	Untreated ground catchments	▪ Soil on slopes less than 10 per cent	0.0 - 0.3
		▪ Rocky natural catchments	0.2 - 0.5

Source: CSE, 2004

3.8 Amount of Harvested Rainwater and Storage Size

The total amount of water received in the form of rainfall over an area is called the rainwater catchment/endowment of that area. Out of this, the amount that can be effectively harvested is called the water harvesting potency. The collection efficiency accounts for the fact that not all the rainwater falling over an area can be effectively harvested.

When using rainwater, it is important to recognize that the rainfall is not constant along the year; therefore, planning the storage system with an adequate capacity is required for the constant use of rainwater even during dry periods (CSE, 2004). Knowledge of the rainfall quantity and seasonal rainfall, the area of the catchment surface and volume of the storage tank, and quantity and usage period of required water supply purposes is critical.

In reality, the volume of RWH can never be achieved since some of the rainwater evaporates from the roof surface and some may be lost to the drainage system, including the first flush. Furthermore, a portion of collected rainwater volume may be lost as overflow from the storage container if the storage tank has insufficient capacity to store the entire collected volume in a heavy rain. Thus, the net usable or available amount of rainwater from the roof surface would be approximately 70% to 80% of the gross volume of rainfall (UNEP, 2004).

3.9 Quality of Rainwater

Water quality for rainwater systems can be categorized into primary water quality criteria and secondary water quality criteria (Anjalipan, 2005). Primary water quality criteria focus on health related to bacteria like e-coli and salmonella and to physical contaminants like pesticides, lead, and arsenic. Falling rain is free from most of these pollutants but once it meets a roof or collection surface, it can wash many types of bacteria, moulds, algae, protozoa and other contaminants. The model of water treatment requirements depends on the purpose. If the water is intended for domestic use like drinking, cooking and showering, appropriate filtration and disinfection practices should be employed. For other use like garden irrigation, water quality treatment may not be required. Depending on where the system is sited, the quality of rainwater can vary, reflecting exposure to air pollution caused by industries such as dust, emissions from automobiles, etc. Secondary water quality criteria are concerned with aesthetic factors. Aesthetic concerns like color, taste and smell comprise the secondary testing criteria used to evaluate publicly supplied water.

According to these characteristics, rainwater proves to be of better quality than well or municipal tap. Inorganic impurities such as suspended particles of sand, clay, and silt contribute to the colour and smell of water. Proper screening and removal by sedimentation help to decrease problems caused by these impurities (Gould, 1999). Rainwater is the softest natural occurring water available, with a hardness of zero for practical purposes. Therefore, there is no build up of mineral deposits in faucets and water heaters. Rainwater contains almost no dissolved minerals, salts, and as such is near distilled water quality. It is sodium free and for this reason, it represents a decisive advantage for those who need salt free diets.

The reasons for variations in chemical constituents and bacteriological properties of water from rooftop could be many, but the most important ones are as follows (DGIS, 2001):

1) Even though the water flows for a short distance, it may dissolve some chemicals deposited on the roof or the residue of chemical reaction between atmospheric gases and the roof material.
2) In general, rainwater is pure and free from contamination; however, the air pollution does influence the chemical quality of water vapor in the atmosphere. The impact of this pollution on rainwater quality is not alarming, but it needs attention.
3) The rainwater passing on the roof may carry the dust and debris, so it changes the water quality.
4) The organic matter from bird drops, rotten tree leaves, seeds and algae formation will be carried by the rainwater flowing on the rooftop. This may also change the quality of water stored in the tank.
5) Mosquito breeding or entry of insects if the tank is opened may affect the quality of water.
6) The chemical and bacteriological contamination of roof water during the collection and storage processes can be prevented effectively through filters and proper, regular system maintenance.

Gould (1999) indicated that a number of collected rainwater samples have exceeded the WHO standards of total coli-form and faecal coli-form. The ratios of faecal coli-form to faecal streptococci from the samples indicate that the sources of pollution were bird droppings, rodents, etc.

In Indonesia, some cities are subjected to acid rain e.g. in Jakarta, Bandung, Surabaya and Medan (Sudibyakto, 2000). Acid rain is rainwater with pH level of less than 5.6 because of strong acid contamination. It can occur because the rainwater mixes with contaminants like SO_2, NO_2, and

CO from factory smoke or combustion smoke of motor vehicles, Pb, and other pollutants from human activities. Sometimes, acid rain in a certain area can be caused by industrial activity in another area, brought in by the wind. However, the acid rain potentially occurring in Yogyakarta will dominantly come from motor vehicles exhausts, as there are only few factories here.

The difference in rain intensity among places possibly causes the difference in rainwater quality. Rainwater is the washer of chemical substances in the air; hence, a high intensity and large amount of rain will lessen chemical substances and progressively clean the air. The distance among rain periods also probably causes the difference in rainwater quality.

Furthermore, the rainwater from the evaporation process of water bodies, such as seas, rivers, and lakes, contain the ion of Ca^{2+}, Mg^{2+}, Na^{+}, and Cl^{-}. According to Anjalipan (2005), rainwater contains H_2, N, O, CO_2, SO_4^{2-}, Cl^{-}, SO_2, etc. in the form of or the core of condensation. The contaminants from combustions of fossil fuel, i.e. CO_X, NO_X, SO_X, Pb and Cl^{-}, will be dissolved into rainwater, endangering living creatures' health and influencing the composition of surface water and that of groundwater.

Polluted rainwater can cause damages, for example: rotting of buildings/walls, damage of towers, eroding of land layers, rusting of metal and transmitter stations, death of living creatures in rivers and lakes, damage of road paves, diseases attacking human beings and animals, etc.

Some determinant factors of rainwater quality in an area are (Sutanto, 1996):

1) The distance between a rain event and the sea,
2) The types of industry, and
3) The influence of volcano activity.

Because rainwater quality is closely related to air quality, Dewi (1996) argued that pollutant concentration and weather conditions could influence each other. Martopo (1984) explained that the rapid population growth increases the existence of domestic waste, garbage, and other water and air contaminants, and it decreases the quality of rainwater. Dewi (1996) had done a research study on rainwater quality in Yogyakarta urban and rural areas. In general, the result indicated that the rainwater quality is still good. Sudarmadji (2004) did a research in Yogyakarta using a hypothesis that the change of rainwater quality represents the effect of city activities, especially the traffic of motor vehicles yielding smoke and dust dissolved in rainwater. However, Sudibiyakto (2002) said that some parts of Yogyakarta city have low pH of rainwater.

Another research conducted by Sulistyaningsih (1995) is about the rainwater quality from the coastal area until the peak of Merapi in Yogyakarta. This research stated that the rainwater composition in the coastal area is similar to the seawater composition, which contains chloride (Cl^{-}) and natrium (Na^{+}). The farther from the coast, the less the composition of chlorine and natrium will be, while in the downtown, the rainwater composition is dominated by elements of carbon dioxide. Sudibyakto (2000) conducted a research study on the pH level of rainwater in Yogyakarta. He found that in the downtown, along Malioboro, the pH level is about 4.5, while in the busy northern part of the city boundary, the pH reaches about 5.0, and in the suburb, it reaches 5.5. This means the acidity level of rainwater, especially in the downtown, has passed the threshold. However, some experts doubt the accuracy level of the equipment used in this study.

Cincotta (2004) and Lazaro (1990) emphasized that compared to other urban locations, the highest sulphate rate of rain occurs in the area closest to industrial areas. Linsley et al. (1986) said that the data gained from the area indicated that rainwater brought a lot of nitrogen and a small part of phosphorus to the river stream. Most of the chemicals in rainwater are absorbed into the ground and becoming the part of spread pollution source flowed into the river or lake. The rainwater directly falling on surface water can make the quality of lake water better through the dilution process. The rainwater containing a large amount of nitrogen and sulphur can disturb the entire biochemical life environment existing in the water. The decreasing fish population in some lakes may be caused by acidy in rainwater.

The recent research study using more accurate equipment was done by Anjalipan (2005) in Yogyakarta urban area. This research work reached the following conclusions:

1) The rainwater quality of Yogyakarta and its surrounding is still good enough. Based on the observation of five chemical and physical parameters (Cl^-, NO_3^-, SO_4^{2-}, Pb, and pH), the parameter values were still lower than the suggested threshold value. This is slightly different from the result of research work on air quality conducted by Bapedalda (2005-b), which showed that such natural chemicals as CO, hydrocarbon, and dust in some locations have reached the threshold value, whereas the rate of Pb in some locations in Yogyakarta has almost reached the Permanent Quality of Ambient Air.
2) The concentration of chemical contaminants in rainwater in the urban area is not very different from that in the suburb, possibly because the wind brings air contaminants from the area above Yogyakarta city.
3) The influence of rain intensity and its duration on rainwater quality is less significant.
4) The pattern of contamination spatial spread showed that the northern suburb has a lower concentration of rainwater contamination than the eastern part. In the meantime, Fany (2005) also reported that the rainwater quality in the densely populated area, i.e. Kraton Sub-district, was good. In conclusion, the rainwater quality in DIY Province is considered good, so that it can be directly consumed or soaked up into the ground. Drinking rainwater is possible as long as it has undergone an appropriate treatment, while the rainwater soaked up into the ground will possibly improve the existing groundwater quality, especially in urban areas.

In order to have a high quality of harvested rainwater, especially for drinking, some maintenance tips for RWH structures (Thomas, 1999) are given as follows:

1) Always keep the surroundings of the storage clean and hygienic.
2) Remove algae from the roof tiles and other surfaces before the monsoon.
3) Drain the storage completely and clean from inside thoroughly before the monsoon.
4) Frequently clean the gutters during rainy season and before the first monsoon rain.
5) Avoid first 15 or 20 minutes of rainfall depending on the intensity of rain, and use the first flush diverter to drain off this first rainwater.
6) Change the filter media every rainy season.
7) Cover all inlet and outlet pipes with closely-knit nylon net or fine cloth or cap during non-rainy season to avoid entry of insects, worms and mosquitoes.

8) Leakage of cracks in the Ferro cement storage tanks shall be immediately covered using cement plastering, which will avoid major repairs due to the cracks.
9) Heavy loads should not be applied on the lid; particularly many people should not stand on the lid.
10) Water should not be allowed to stagnate in the collection pit.
11) The tap should have lock system so that pilferage or waste of water is avoided.
12) The filter materials shall be washed thoroughly before replacing in the filter bucket.
13) The coconut coir in the filter unit definitely needs regular replacement in rainy season, because, in wet conditions, it rots and spoils water quality.
14) A filter is used to remove suspended pollutants from rainwater collected over roof. A filter unit is a chamber filled with filtering media, such as fiber, coarse sand, and gravel layers to remove debris and dirt from water; charcoal can be added for additional filtration. A simple charcoal filter can be made in a drum or an earthen pot using gravel, sand, and charcoal. Sand filters are easy and inexpensive for water treatment to remove effectively turbidity (suspended particles like silt and clay), color, and microorganisms. In a simple sand filter, the top layer comprises coarse sand completed with a 5-10 mm layer of gravel, followed by another 5-25 cm layer of gravel and boulders (Thomas, 1999).
15) Cleaning of cisterns and boiling water before consuming is the easiest and the most convincing way for disinfection although there is often a reluctance to accept this practice as the taste is affected. Chlorine in the form of household bleach can be used for this.

3.10 Demand Side Management

In making plans concerning water supply, municipalities have usually assumed that the future demand for water will increase. Typically, waterworks departments have made excessive estimation of the demand and built waterworks infrastructure based on a continual development of water resources and strategies to enlarge the area of water supply. The development cost is usually recovered through water rates, and when there is plenty of water in the resource area, conservation of the resources is not promoted (DGIS, 2001); this may create a conflict when drought occurs. It was even assumed that the lack of promotion of water conservation and rainwater harvesting is due to the need for recovering the infrastructure development costs through sales of piped water. The exaggerated projection of water demand leads to the over-development of water resources, which in turn encourages denser population and more consumption of water.

The sustainability of water supply system requires a change from coping with water supply without controlling demand into coping with supply by controlling demand. The introduction of demand side management encourages all citizens to adopt a water conservation approach, including the use of freely available, locally supplied rainwater.

3.11 Advantages and Disadvantages of RWH

Some advantages of developing RWH are (CSE, 2004):

1) RWH technologies are simple to install and operate. Local people can be trained to implement them, and construction materials are also easily available.

2) RWH is convenient because it provides water at the point of consumption, thus, greatly reducing operation and maintenance problems.
3) The systems can be both owner and utility operated and managed.
4) Rainwater collected using existing structures (e.g. rooftops, parking lots, parks, ponds, flood plains, etc.) has few negative environmental impacts compared to the other technologies.
5) Rainwater is relatively clean and the quality is usually acceptable for many purposes with little or even no treatment.
6) The physical and chemical properties of rainwater are usually superior to groundwater.
7) RWH can co-exist with and provide a good supplement to other water sources and utility systems, thus relieving pressure on other water sources.
8) RWH provides a water supply buffer for use in times of emergency or breakdown of public water supply systems, particularly during natural disasters.
9) RWH can reduce storm drainage load and flooding in city streets.
10) Users of RWH are usually the owners who operate and manage the catchments system; hence, they are more likely to exercise water conservation.
11) RWH technologies are flexible and can be built to meet almost any requirements. Construction, operation, and maintenance are not labor intensive.
12) Running costs are almost negligible.
13) Although local factors can modify the climatic conditions, rainwater can be a continuous source of water supply for both the rural and poor.

On the other hand, its disadvantages are:

1) The success of RWH depends on the frequency and amount of rainfall.
2) Low storage capacities will limit RWH to provide water in a low rainfall period. Increased storage capacities may be economically unfeasible, unless the government subsidizes it.
3) Leakage from cisterns can cause the deterioration of load bearing slopes.
4) Cisterns and storage tanks can be unsafe for children if proper access protection is not provided.
5) Possible contamination of water may result from animal waste and vegetables.
6) Where water treatment prior to potable use is infrequent, due to insufficient resources or knowledge, health risks may result; further, cisterns can be a breeding ground for mosquitoes.
7) RWH systems increase construction costs and may have an adverse effect on home ownership. Systems may add 30% to 40% to the cost of a building.
8) RWH systems may reduce revenues to public utilities.
9) Extensive development of RWH systems may reduce the income of public water systems.
10) RWH has not been recognized as an alternative for the public sector. Governments typically do not include rainwater use in their water management policies, and citizens do not demand rainwater use in their communities.
11) Rainwater storage tanks may be a hazard to children who play around it.
12) Rainwater storage tanks may take up a valuable space.

3.12 Existing RWH in Indonesia and in the Study Area

3.12.1 Introduction

Indonesians obtain water from such sources as water piped into wells or yard plots, public taps, open wells in dwellings, open public wells, rivers, streams, springs, rainwater, tanker truck, bottled water, etc. Most urban people use groundwater from wells or water supply enterprise. Consequently, groundwater is scarce in large urban areas. The decreasing groundwater recharge is directly proportional to the increasing pavement and roof areas. In addition, high population density means large consumption of groundwater.

Historically, only dry, rural areas in Indonesia have a great, long tradition of water harvesting. The people utilized rainwater for domestic uses and their cattle. Lack of irrigation access makes Indonesians practice rainwater catching for agricultural crops, i.e. rain-fed agriculture. Since 1970s, the government has been developing irrigation mega projects funded by international sources, such as World Bank, Asian Development Bank, OECF, etc. Despite the success, these projects made farmers gradually abandon the rainwater harvesting irrigation (Widodo, 2005). According to US-EPA (2004), rainwater collection practice in Indonesia is less than 2.3% of the total population.

Recognizing the need to alter the drainage system, after Sunjoto (1988) popularized infiltration-well dimension formula, in 1980s, the government introduced a regulation requiring that all new buildings have an infiltration well. The regulation was applied to two-thirds of the territory, including DIY Province, the Capital Special Province of Jakarta (DKI), West Java, and Central Java. It is assumed if each house in Java and Madura had its own infiltration well; the 53% water deficit by 2000 would be reduced to 37%, a net savings of 16% through conservation. However, the regulation hardly had impact on rainwater conservation due to insufficient socialization, monitoring, awareness, and law enforcement.

In 1990s, Dian Desa, an NGO in Yogyakarta initiated an RWH method in Gunungkidul Regency, a dry area with serious problems of clean water. The general model for implementing roof water-collection systems was by involving the villagers. Dian Desa began its involvement in the area by considering local community participation in the development of technical skills, local lifestyle, tradition, and opinions on water consumption, project schedules that matched local time constraints, and transfer of technical skills and maintenance expertise.

The most effective and feasible areas for such systems were initially identified. The great emphasis was given to the mixing and mingling of Dian Desa's field officers with the villagers. The village head and government officials were normally requested to take part in the activities. Surveys and discussions were held to determine the feasible and most appropriate type of technological changes for each village. A very important element in this model is that the recipients chosen were 'the poorest of the poor' in the region. The funding system depended on the limited external funding and the economic status of the borrowers. Two she-goats were lent to the family that needed the Roof Water-Collection System, and when these animals bore normally four young ones, two of them were returned to the owner while the borrower kept the other two. The borrower looked after the young goats, and when they grew older, he used them as payment for his water tanks. However, this unique method has no longer been developed for many reasons, such as unserious monitoring, inconsistency, unclear regulation, etc.

3.12.2 Public Perception and Awareness

Some cities have been aware of the importance to build rainwater recharge well since 1980s, especially in Jakarta, Bandung, and Yogyakarta. Even Jakarta, Sleman and Yogyakarta have issued the rule to develop RWH. Up to now, the understood and developed RWH is rooftop RWH for groundwater.

The efforts of developing rainwater conservation have been started since 1988 through the regulations for IMB (building construction permit); however, people's understanding is still very low. In terms of water resources, Indonesian people have various perceptions and actually highly appreciate water in their tradition. Yet, only a small number of people appreciate water proportionally. Many people consider that rainwater is dirty and only a source of disease (Widodo, 2003).

(a) (b)

Figure 3.13: A failed RWH project was developed by the local Government in Prambanan: (a) The gutter for collecting rainwater is insufficient, and the water storage originally for storing rainwater is dominantly used for collecting water from the Government. (b) Rainwater storage is also abandoned by people who prefer to get water from the Government. (Photo: Widodo, 2005)

As an illustration, people living in a very dry and infertile area in Prambanan Sub-district also think that rainwater is dirty. During the dry season, they have a difficulty in getting clean water. In fact, the government has carried out a project for rainwater reservoir construction. However, it is useless since the people prefer to get water from the 'tank' supplied by the government. Despite the costly project, the government keeps distributing clean water to the people. This indicates: (1) The low awareness of the government officers and/or the people on the actual role of rainwater, and (2) The disorientation of government apparatus to get 'benefits' from the projects of water reservoir and supply.

Figure 3.13 illustrates an RWH development in Prambanan. Figure 3.13(a) shows incomplete construction of RWH; it can be seen from the gutter and the pipes. In July 2005, the writer found no water in the storage and asked one of the school developers. He said the school was waiting for water supply from the government, and the reservoir had no longer been used to catch rainwater for few months. Figure 3.13(b) also gives the same illustration. The government has built an open-reservoir, but this office did not use it anymore. Instead, they were more dependent on the water supply from the government.

The people in Prambanan are quite unlucky since the aquifer is not good enough to store water. This is different for the people in Pakembinangun, Sleman Regency. This region is a recharge zone, where people are recommended to recharge as much water as possible. In 2000, the writer found some examples of absorption wells construction funded by the Government of Sleman. They were built near and with the same construction as digging wells. Consequently, they could not function to store runoff because of the high wall. Only the rainwater falling down the wells was stored (Figure 3.14).

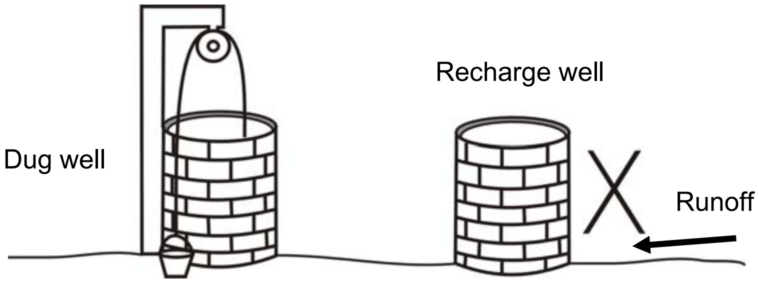


Figure 3.14: Misperception in constructing a rainwater recharge well (an example from Sleman). The recharge well was constructed as a dug well; therefore, it does not function.

3.12.3 Regulations

Sleman Regency and Yogyakarta Municipality have tried to develop RWH, especially the rooftop model by issuing the Regulation of Building Construction Permit (*"IMB*"), such as Regional Regulation ("*Perda"*) No. 4/1988 on IMB for Yogyakarta. DKI Jakarta also has Regional Regulation No. 17/1996 like Yogyakarta. The IMB regulation requires that the government agree with the proposal of IMB if the building design is completed with the plan of developing rainwater absorption well. The objective is for catching rainwater falling down the building as an effort to compensate the land use change. Unfortunately, there are rarely any evaluation and monitoring toward the implementation of IMB regulation. According to the regulation, the proposal to get IMB must be completed with the design of rainwater absorption well. Yet, most people do not make it, and hardly do they get any consequences (Widodo, 2006).

Yunus (2001) explained that only 2% - 6% of the people in Yogyakarta suburban area submit the proposal of IMB. Furthermore, Priyohadi (2005) said that IMB is a source of inefficiency as it only leads to corruption. Substantially, IMB is meant to control the development of settlement areas. In reality, it is not more than a means to gain regional income ("*PAD")* for the local government. The amount of tax for IMB depends only on the value of the building, the higher the value, the higher the tax of IMB, and vice versa.

CHAPTER 4

DATA ANALYSIS AND DISCUSSION

4.1 Population

4.1.1 General

The population growth in general is influenced by three main components: fertility, mortality, and migration (Tukiran, 2000). The mortality rate brings about a positive effect on the population growth, while the fertility rate will result in a rapid population growth. The migration, which consists of enter-migration and exit-migration, can give either a positive or negative contribution to the rate of population growth. According to the existing data, the population fertility rate in DIY, which covers four regencies and one city, including the research area, is low; on national level it is the second lowest. Such condition is related to the inhabitants' life quality in this province, which is relatively high. This fact is attributable to the educational level, the health awareness, the conducible religious life, the effectiveness of the family planning program, and the traditional values that much influence the fertility rate.

In the meantime, besides the fertility and migration, the mortality is a demographic component, which also influences the demography dynamics. The mortality rate usually differs, based on age, sex, and job/profession, even the social and economic conditions of the inhabitants. Stable social and economic conditions, which are demonstrated by, among others, good housing conditions, balanced nutrition, and high awareness of health, will also reduce the death rate. Therefore, it can be assumed that a higher mortality rate in a certain community is associated with lower social and economic conditions of that community.

4.1.2 Data Analysis

As reported by the Population Census of Statistics Central Board (BPS, 2002-b), the number of inhabitants living in DIY always tended to increase. In 1971, the number reached around 2.5 million people. In 1980 and 1990, the number reached 2.8 and 2.9 million people successively, and in 2000, it reached 3.1 million people. The rate of population growth in this province varies from regency to regency (Table 4.1). Population in DIY in general increased during recent decades (e.g. by, 0.72%/year during 1990 to 2000), but varied strongly between regencies: In 1980 – 1990, e.g. the population in Gunungkidul and Kulonprogo decreased. Based on the growth rate, Sleman had the highest rate with 1.50%/year from 1990 to 2000, followed by Bantul with 1.19%/year. As the population conditions in Yogyakarta City have been saturated, its population decreased by – 0.39% /year in the period 1990 to 2000.

The decrease in population in Yogyakarta City in that period was possibly caused by the movement of several campuses from the city to Sleman and Bantul, besides its high population density. The prevalence of many real estate developments in those two regencies is another factor causing the rate of population growth to decrease, which makes some inhabitants of Yogyakarta move to Sleman or Bantul regions. Besides, the location, land price, and extent of land became other factors that influenced some inhabitants' movement.

Table 4.1: Population number and growth of DIY Province and its districts, compared with population growth of Java Island and Indonesia

No	District/ City/ Province/ etc.	Population				Population Growth (%/year)		
		1971	1980	1990	2000	1971-80	1980-90	1990-2000
1	**Sleman**	588,304	677,323	780,334	901,377	1.56	1.43	1.5
2	**Bantul**	568,618	634,442	696,905	781,013	1.21	0.94	1.19
3	**Yogyakarta**	340,908	398,192	412,059	396,711	1.72	0.34	-0.39
4	Gunungkidul	620,085	659,486	651,004	670,433	0.68	-0.13	0.3
5	Kulonprogo	370,629	380,685	372,309	370,944	0.29	-0.22	-0.04
6	**DIY**	2,488,544	2,750,128	2,912,611	3,120,478	1.1	0.58	0.72
7	Java							1.13
8	Indonesia							1.35

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

The population density of DIY also increases as the rate of population growth increases. In 1971, it is recorded that the population density of DIY was 781 people/km^2 and in 2000, it turned up to be 979 people/km^2. Table 4.2 shows that the population density of regencies/city actually varies. Yogyakarta is the most densely populated area with the density of 10,490; 12,252; 12,679; and 12,206 people/km^2 in 1971, 1980, 1990, and 2000, successively. In the same year, Sleman was in the second position after Yogyakarta with the density of 1,024; 1,178; 1,358; and 1,568 people/km^2 successively. Bantul had a similar population growth rate to that of Sleman, i.e. 1,122; 1,252; 1,357; and 1,541 people/km^2 successively, with each number for each of the years mentioned above. The population density of Sleman and Bantul tends to increase steadily, while the population density of Yogyakarta decreased a little, especially in 1990 – 2000. Kulonprogo and Gunungkidul had a relatively similar population density during the last 30 years.

Table 4.2: Area and population density of DIY Province based on district level

No	District/City/ Province	Area		Population Density			
		Km^2	%	1971	1980	1990	2000
1	**Yogyakarta**	32.50	1.02	10,490	12,252	12,679	12,206
2	**Sleman**	574.82	18.04	1,024	1,178	1,358	1,568
3	**Bantul**	506.85	15.91	1,122	1,252	1,357	1,541
4	Kulonprogo	586.28	18.40	632	649	635	633
5	Gunungkidul	1485.36	46.63	418	444	438	451
DIY		**3,185.81**	**100.00**	**781**	**863**	**914**	**979**

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

Of the inhabitants of DIY in 1971, the age group of 0 – 14 years was 40.9% and kept decreasing to 35.1%, 28.3%, and 22.4% in 1980, 1990, and 2000 successively. On the contrary, the percentage of inhabitants of 65 years old and more increased with 4.3% in 1971, 5.8% in 1996, 7.2% in 1998, and 8.5% in 2000. It means that the number of old people is increasing steadily, especially since 1990, with the percentage of inhabitants of 0 – 14 years moves under 30%. The phenomenon is particularly related to the decreasing birth rate, but it is also influenced by the decreasing mortality rate. Therefore, it can be assumed that there is an improvement in the population prosperity and health.

Table 4.3: Percentage of population based on age range (Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002))

No	Age Range (years old)	Percentage (%)			
		1971	**1980**	**1990**	**2000**
	0 – 14	40.9	35.1	28.3	22.4
2	5 - 64	54.8	59.1	64.5	69.1
3	65 +	4.3	5.8	7.2	8.5
T o t a l		**100**	**100**	**100**	**100**

Based on the data from BPS, in DIY, the number of female inhabitants is higher than that of male inhabitants. The sex ratio shows a comparison between the number of male and female inhabitants. In some countries, at the beginning of the birth period, generally, the ratio is more than 100. It means that the number of male inhabitants is greater than that of female ones. However, the population mortality influences the ratio so that it shifts to the decreasing number of male inhabitants, specifically at older ages. Table 4.4 shows the sex ratio in DIY that were likely to increase from 1971 until 2000. The sex ratio in Sleman, Bantul, and Kulonprogo tends to increase steadily. The sex ratio in Sleman even shows a figure higher than 100, which means that the number of male inhabitants is more than that of female ones. It is assumed that the high sex ratio in Sleman is possibly influenced by a large number of people entering this regency, especially the male ones who are mostly students, due to a large number of universities in this area. Meanwhile, the sex ratio in Yogyakarta tends to fluctuate and that in Gunungkidul tends to decline.

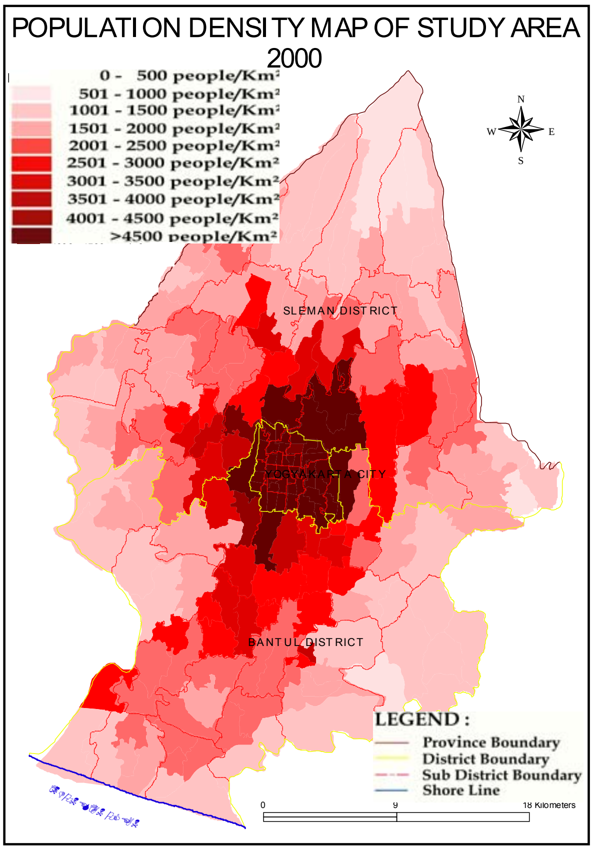


Figure 4.1: Population density of 2000 (Source: analyzed from BKKBN (1994); BPS (2002-a); BPS (2002-b); Mantra (2002))

Table 4.4: Sex ratio in DIY Province based on district/city level

No	District/City/Province	Sex Ratio (male/female)			
		1971	**1980**	**1990**	**2000**
1	**Yogyakarta**	98.9	100.7	96.2	95.8
2	**Sleman**	92.6	96.3	99.0	101.8
3	**Bantul**	90.9	94.9	96.8	99.0
4	Gunungkidul	96.6	95.8	94.5	95.1
5	Kulonprogo	94.3	94.8	96.0	97.0
DIY		**94.3**	**96.2**	**96.7**	**98.3**

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

BPS (2002-a, 2002-b) mentions that the educational level of household heads in DIY is still low. The household heads who do not have any diplomas/certificates are 24.9%, those who have primary school certificates are 28.2%, those who have junior high school certificates are 11.4%, those who have senior high school certificates are 27.5%, and the rest, those who have tertiary education certificates, including diplomas or graduate certificates, are only 7%. The data show that most of the household heads in DIY still hold only primary school certificates (28.2%). The number of family members in each family in DIY has been small, i.e. less than 4 people. This can be seen in Table 4.5. The composition of family members in this province shows that most families tend to be nuclear families. The average number of family members tends to decrease. In 1971, 1980, 1990, and 2000, the average number of family members was 4.7 people, 4.6 people, 4.0 people, and 3.4 people, respectively.

Table 4.5: Number of family members in DIY Province

No	District/City/ Province	Family Members (persons)			
		1971	1980	1990	2000
1	**Yogyakarta**	5.1	4.8	3.8	3.0
2	**Sleman**	4.2	4.5	3.9	3.1
3	**Bantul**	4.5	4.6	4.2	3.6
4	Kulonprogo	4.7	4.7	4.1	3.7
5	Gunungkidul	5.1	4.7	4.1	3.8
DIY		**4.7**	**4.6**	**4.0**	**3.4**

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

The relative small surface area of Yogyakarta has caused many educational institutions in this area to relocate to Sleman and Bantul. This relocation causes students to prefer to live in the areas surrounding their schools. According to BPS (2002-b), the greatest number of migrants entering DIY in 2000 was that of migrants entering Sleman, with 70,143 people or 40.7% of the total number of migrants entering this province. The second rank was occupied by the migrants entering Yogyakarta, with 48,986 people or 28.4%, and the smallest was the migrants entering Bantul, with 24,524 people or 14.2% (Table 4.6).

The migrants entering DIY consist of 94,066 men and 78,346 women. The number of male migrants is greater possibly because of the Javanese and regional cultures that give priority to men to be the breadwinners in their families. Therefore, there seems to be a demand in society that men have to try harder to attain high educational levels and to find jobs than women do. The arrival of the migrants is influenced more by the factor of the need for better education in Yogyakarta. The data from BPS (2002-b) also show that most of the migrants belong to the age group of 20-24 years, consisting of 63,625 people or 36.9%, followed by the age group of 15-19 years and 25-29 years, consisting of 35,633 people or 20.7% and 18, 476 people or 10.7%, respectively.

Table 4.6: Formation of migrants to DIY Province

No	District/City/Province	Male		Female		Total	
		Number	%	Number	%	Number	%
1	**Sleman**	39,411	41.9	30,732	39.2	70,143	40.7
2	**Yogyakarta**	27,086	28.8	21,900	20.0	48,986	28.4
3	**Bantul**	13,024	13.8	11,500	14.7	24,524	14.2
4	Gunungkidul	7,664	8.2	6,498	8.3	14,162	8.2
5	Kulonprogo	6,881	7.3	7,716	9.8	14,597	8.5
DIY		**94,066**		**78,346**		**172,412**	

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

The data show the origins of the migrants entering DIY. Table 4.7 provides information that Central Java is the area from which the greatest number of migrants come, followed by DKI Jakarta Province, West Java and Sumatra.. Other migrants come from East Java, Kalimantan, overseas, Bali/Western Lesser Sundas (NTB), Celebes, and Papua/Moluccas.

Table 4.7: Origins of migrants entering DIY Province

No	Origin	Number (persons)	Percentage (%)
1	Central Java	57,379	33.3
2	DKI Jakarta	27,187	15.8
3	West Java	26,307	15.2
4	Sumatra	24,054	3.9
5	East Java	17,395	10.1
6	Kalimantan	10,446	6.1
7	Overseas	2,910	1.7
8	Bali/NTB	2,832	1.6
9	Celebes	2,208	1.3
10	Papua/Moluccas	1,694	1.0
T o t a l		**172,412**	**100**

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

In terms of urbanization, the number of inhabitants who still live in the rural area tends to decrease. The rate of migration to a city in a certain area can be derived from the size of the proportion of the urban inhabitants living in that area (Mantra, 2002). Some causes of urbanization, the migration to the cities, include the community's economic facilities, and infrastructures. The provision of facilities built based on the urban characteristics in a certain rural area changes its appearance, from that of a village to that of a city. The number of inhabitants living in the urban area in DIY can be seen in Table 4.8.

Table 4.8: Urban residents in DIY Province

No	District/City/ Province	1980		1990		2000	
		Total	%	Total	%	Total	%
1	**Yogyakarta**	394,965	99.2	412,059	100	396,711	100
2	**Sleman**	107,686	15.9	400,941	51.4	738,623	81.9
3	**Bantul**	64,975	10.2	421,785	60.5	561,938	71.9
4	Kulonprogo	18,255	4.8	31,141	8.4	66,366	17.9
5	Gunungkidul	21,386	3.2	28,130	4.3	34,875	5.2
DIY		**607,267**	**22.1**	**1,294,056**	**44.4**	**1,798,513**	**57.6**

Source: BKKBN (1994), BPS (2002-a), BPS (2002-b), Mantra (2002)

From Table 4.8, it is obvious that the urban population of DIY steadily increased. In 1980, the number of inhabitants living in the urban area was still 22.1%, it increased to 44.4% in 1990, and then it grew to 57.6% in 2000. Sleman and Bantul are two regencies, which show a rapid population growth in the urban areas, too. The percentage of inhabitants living in the urban area of Sleman in 1980 was only 15.9%, it increased to 51.4% in 1990, and it increased again up to 81.9% at the end of 2000. This condition is similar to what happens in Bantul, in which there were 10.2% of urban inhabitants in 1980, increasing to 60.5% in 1990, and then increasing to 71.9% in 2000. As mentioned before, this increase in Sleman and Bantul is caused by the increasing number of tertiary educational institutions located there. Another cause is the change of certain areas from the rural into the urban status (Tukiran, 2000).

4.2 Land Use and Urbanization

4.2.1 General

Land use is the way land is developed and used in terms of the kinds of activities allowed e.g. agriculture, residences, industries, etc. (Asdak, 2007). The knowledge on land use is very important in all activities of planning and cultivating all parts related to the earth surface, either from the view of physical aspect of the land or from the social-economical aspect (Lillesand and Kiefer, 1994).

Changes in the cover, use, and management of land have occurred throughout history in most parts of the world as the population has grown and developed. Over the centuries, two important trends are evident: the total land area dedicated to human uses and increasing production of goods and services have intensified both in use and in control of the land (Smith, 1990). The major anthropogenic causes of change in land cover and land use include the population and associated infrastructure, economic factors, technological capacity, political systems, and socio-cultural factors (Berry, 1983, McGee, 1997). Moreover, they stated that the human population growth could be considered an ultimate cause for many land resources changes.

In regard to DIY, reliable data of the existing land resources is badly needed to evaluate the existing development and to determine the policy to manage the future. Moreover, the execution of almost all of the spatial development plans in DIY has never been evaluated for the lack of supportive data, so that the land use is not well organized. This fact, in turn, may endanger the environment and its own society life. The threat of water crisis is one possible impact, happening in many urban areas, including Yogyakarta and its surroundings.

As commercial centre and capital and of DIY, Yogyakarta can no longer accommodate its inhabitants. Therefore, population and its activities overflow to the nearby areas, i.e. Sleman and Bantul, especially those areas close to Yogyakarta. There is an impression that the natural resources, particularly the land resources, in those areas are not well planned.

A critical challenge for land use and management involves reconciling conflicting goals and uses of land. The goals often conflict with one another and it is difficult that land use decisions may develop stakeholders to pursue different land use goals. Conflicts often arise between those who want to have housings and those who are interested in agricultural land. Therefore, understanding how land use decisions affect the achievement of these goals can help to achieve a balance among the different goals. Sustaining ecological systems also indirectly supports other values such as ecosystems and cultural, aesthetic, recreational, and extractive uses of the land (Dale and Haeuber, 2002).

4.2.2 Methodology

4.2.2.1 Overview

In managing the land resources, reliable data on the resources in question are needed. The data needed can be obtained through several ways:

- Firstly, they can be obtained by using thematic maps.
- Secondly, they can be obtained by conducting a terrestrial survey.
- Thirdly, they can be explored directly or indirectly by carrying out remote sensing.

The data collection by using thematic maps is often restricted by the non-availability of up-to-date data; this can result in improper maps and derived information. The direct measurement takes a relatively long time, which is its weakness. The collection of satellite images, i.e. from remote sensing, is still considered the best method. Besides being up-to-date, the data accuracy and completeness can be guaranteed. With the availability of the remote sensing data, the multi-temporal data access can also probably be carried out. For this reason, this study uses data from the LANDSAT TM images of 1994, 1996, 1998, and the LANDSAT ETM image of 2000, in order to find out the land use changes, particularly the change from farmland to settlement area. The data obtained from the LANDSAT image interpretation will then be processed by using Geographic Information Systems (GIS) software that covers the Arc/Info and Arc/View. The outputs from that data processing, which are in the form of spatial and temporal land use changes, are expected to be an input for the policy makers in controlling the development in the area in question.

4.2.2.2 Data Processing

There are several types of remote sensing data (e.g. airborne data, satellite images or radar photos) and different methods to obtain data e.g. by photogrammetry. Satellites, such as LANDSAT image, have been widely used to obtain images for later interpretation. The land use interpretation of remote sensing data, for example the LANDSAT ETM image, can be tracked from its land cover, which includes all of the phenomena, which cover the land both natural and human-made. The success of this interpretation relies on the analyst's ability to identify the relevant physical characteristics of the land attributes (Malingreu, 1982, Gusmida, 2000). The choice of the remote sensing data should concern the expected information to obtain. The LANDSAT TM image has often been used to obtain land use data such as the settlement area, farmland, dry land cultivation, etc. The result of the examination shows that it is suitable to use the image of the LANDSAT TM image to record the macro land use. Meanwhile, if there is a more detailed need, the use of aerial photos will be helpful. Sutikno et al. (2002) explained that the LANDSAT TM image interpretation is good to know the land use in the area of the Merapi slope. Indratmo (1996), likewise, conducted the land use study in the region with almost the same characteristics as the region where Sutikno et al. conducted his study (2002). Based on his analysis, he and Schowengerdt (1983) mentioned that in order to obtain the land use data similar to those in the research area of this study, the method of LANDSAT TM interpretation is a better choice than the media of LANDSAT, MSS, SPOT, or the aerial photo.

Based on the advantage of the LANDSAT image explained above, this study used the LANDSAT TM image data of 1994, 1996, and 1998, while the data of the year of 2000 used the LANDSAT ETM image that has almost the same qualification as the LANDSAT TM image. Next, the LANDSAT image will be used as the interpretation media to get the type of the land use or the classification of the land use (Malingreau and Karmono, 1988). The data from the LANDSAT image are then processed by utilizing the GIS technology.

Digital image processing covers the correction and interpretation of the image with the purpose of obtaining a view of the earth surface that is similar to the real one. The image cannot be directly used, because there is a distortion caused by the sensor movement and the factor of media that the energy passes through. This image processing covers the geometrical and radio-metrical corrections. While conducting those corrections, the picture sharpening is also conducted all at once.

The purpose of the image sharpening is to increase the image quality, both for the beauty and especially for the analysis necessity. Before carrying out the interpretation, the image is sharpened so that the picture contrasts emerge. It is supported by Lillesand and Kiefer's arguments (1994) that the purpose of the sharpening is to increase the visual interpretation ability by increasing the object appearance. According to Short (1992), this sharpening technique is generally categorized into:

1) Contrast manipulation,
2) Spatial feature, and
3) Multi image manipulation.

This study, which uses the image from the LANDSAT ETM image, takes the sharpening system of contrast because it is suitable with the need of "visual" interpretation or "on screen" interpretation as well, and it is easier to carry out.

After the sharpening process, the next step is conducting the radiometric correction. This correction is an image upgrading due to the existence of radiometric mistakes that cover the errors on the optical system, the mistakes caused by the interference of electromagnetic radiation energy on the atmosphere, and the mistakes caused by the influence of the sun elevation angle. This correction is needed to improve the pixel value, which is inappropriate with the spectral reflection value of the real object (Danoedoro, 1996, Jensen and Wel, 1998).

Furthermore, they explained that the geometrical correction is needed to give an assurance on the mathematical relationship between the coordinates on the satellite imagery and its position on the earth surface. This error is caused by the distortion that emerges because there is a variation on the satellite height, uprightness, and velocity. Such condition causes the position on the satellite unsuitable with the real position on the earth surface (Jensen and Wel, 1998). Accordingly, the ground control point is needed and it is usually taken from the topographic maps. The identification and interpolation are done on the topographic map by selecting the stations that are easy to identify and have advantages on this need for correction. The selected stations include the ones on the intersection of a highway, at the end of the landing strip in an airport, etc. The ERMAPPER software can do this correction. After the correction is carried out, the coordinate system existing on the satellite image is the same as the coordinate system on the topographic map. In this study, the coordinate system that is used is the UTM (Universal Transfer Mercator) system.

In order to know the quality of output from the image LANDSAT interpretation, the accuracy test needs to be carried out for the interpretation of the output. Sutanto (1995) confirmed that the accuracy test is important to carry out if the remote sensing as the media to obtain data is used in a particular analysis. For the users, this accuracy is necessary for it will influence the degree of the data reliability.

There are some ways of conducting this accuracy test. Short (1992) mentioned that there are 4 ways of doing the accuracy test:

1) Field checking on the selected points,
2) Assumption of the conformity between the LANDSAT image and the referential map or aerial photographs,
3) Statistical analysis, and
4) Confusion matrix calculation.

This study chooses the first accuracy test, i.e. the field checking. This method is chosen because this research area passes this method. The field test is conducted to check the correctness of the interpretation result. If it is needed, the field checking will also add the data for there is a limitation of the interpretation from the image. Before conducting the field test, the researcher first determined the sample to be examined. In order to produce a good result of the refraction accuracy, the determination of the position of the sample is also important, besides its amount and type. Generally, the accuracy is considered as good if the mean of the accuracy resulted from a certain test is bigger than 80%. The output of this field test is generally used to conduct the re-interpretation, so that the more accurate interpretation data will be obtained.

4.2.3 Present Situation and Policy

4.2.3.1 Urban Development

One thing that makes Yogyakarta different from other cities is that Yogyakarta was firstly developed as the palace centre, Ngayogyakarto Hadiningrat. The existence of this palace seems to bring a physical effect of space that is quite substantial on the development of the surrounding areas. Since the Palace of Ngayogyakarto Hadiningrat was established, Yogyakarta has become the growth centre of its surrounding areas, and later it turns into the centre of activities in the middle part of Java. The development of the city and its surroundings has created slum areas with very dense population and buildings

Most of the cities in Indonesia are located in Java, supported by the infrastructure facilities that have been and are still being developed, even in the rural areas. This fact influences the form and nature of the development of land use, especially in urban areas. In Java, the biggest pressure is caused by the urban development that affects farmlands, especially those located in the outskirts of the city and along the transportation lane.

Yogyakarta has grown rapidly. As a general phenomenon prevailing in Indonesia and/or other Developing Countries, in Yogyakarta area, there is an indication of interdependent relation between the city and the outskirt areas of the city, even with its rural area. In covering its needs, the city always depends on the out-of-city area and vice versa. However, the nature of such dependency seems to be unequal, especially in the matter of fulfilling the need for land. Farmland is always sacrificed in order to fulfill the need of the city development. Apparently, the government has no tools to control such an extremely unequal development. Moreover, there have been many conflicts between the demand for urban development and the demand for farmland preservation as an economic resource, both at local and national scales. Furthermore, the food self-sufficiency has been threatened by the shrinking of farmland seized by the need for urban development (Figure 4.3). There are many claims that assert the importance of the environment policy in managing the change of the use of farmland into the non-agricultural sector, but those claims are only spoken expressions, without any real and explicit actions in the field.


(a)


(b)

Figure 4.2: (a) Dense settlement complexes such as for student housings closed to a campus area, (b) A five-story building built in Code River area (Photos: Widodo, 2004: Baiquni, 2005)

If there are no real and integrated actions, especially from the government, the urban development will always move outside. Thus, the rural areas located near the urban area are in a critical position, for in those areas the productive farmlands are located. It is known that the farmland is a vital resource for human life because it is where the food comes from, both for the present and next generations. Such critical condition is more obvious because almost all farmlands in the city and the outskirt area of the city, especially in the area of Sleman and Bantul, are the farmlands with very high production degrees due to their soil fertility and good technical irrigation facilities. This matter is also still relevant to the assumption stated by Bryant (1992) that many farmlands around many cities are food-production oriented.


(a)


(b)

Figure 4.3: (a) An early period of outskirt urban development by incoming inhabitants, (b) The rapid growth of housing development that occupies farmlands (Photos: Widodo, 2004)

Behind the increasing interest in developing the outskirt areas of the city, are as well local inhabitants as outsiders (Figure 4.3). Actually, in this case, the outsiders can be divided into two groups. The first group consists of the outsiders coming from areas outside the city and the second group consists of the outsiders coming from areas outside the country itself.

4.2.3.2 Factors Influencing Land Resources Development

The change of land necessary to be regulated is the change from farmland into non-farmland because such change will also be related to the life of rural and urban areas. The rural area, which is an agricultural area, has a very close relation to the need of many people through the production of food from the agricultural sector. The farmers in the rural area will be disturbed by such condition, considering that a number of farmers' life totally depends on the agricultural sector. In addition, the impact of the farmland decrease will also decrease the amount of food production needed not only by the rural population but also by the urban population (Figure 4.3). In the meantime, the rural sector is related to the urban life based on the optimal non-agricultural production.

The parties involved in the land conversion from farmland into non-farmland can be individuals or institutions. Before conducting a change in the land use, an individual should propose an application to the government and must pay attention to the following points:

1) The location of the requested land must be included in the planning of the sub-district or regency.
2) The requested land is relatively unfertile, i.e. not the land producing rice crops twice or three times a year.
3) The requested land does not have water from the technical or half-technical irrigation.
4) The requested land is not located in the middle part of the farmland that is still productively cultivated.

Ideally, the criteria above underpin efforts to build a strong framework to protect the existence of the fertile and productive farmland, and it is expected that such land will produce a significant result if it is cultivated with a good coordination among instances. However, the fact in the field shows a very different situation from what it should be; there are many fertile and productive farmlands turned into the area for settlement, trade, education, and/or office complex.

Moreover, besides the procedural process of obtaining the permission to change the land use from farmland into non-farmland, the government still asks for another requirement, i.e. the permission in constructing a building. This is based on the prevailing principle stating that the establishment of a building may bring about a negative impact, both on the owner and/or on other parties if it is done without a proper management. The management system of this building is explained in the procedure of obtaining the Permission to Establish a Building ("*IMB"=Ijin Mendirikan Bangunan*). The purposes of this permission are:

1) To manage the plan and the construction of a building that is suitable for the right and matches technical requirements,
2) To create a clean, healthy and neat environment,

3) To arrange the balance between the construction of a building and the development of street lanes,
4) To arrange the use of the area so that it will be in line with the development pattern and master plan of the layout,
5) To give a legal assurance to the building owner.

The procedure to get the IMB is indeed very strict. Besides the form and other administrative requirements, the applicant is obliged to attach the picture of the complete building design and he must be technically responsible. The detailed design of the building must be completed with the calculation of the detail construction, including the data of soil investigation, the ratio of the land area and the size of the building. Substantially, the process to get IMB is actually good to be a medium to establish a condition of legal order, construction order, and environmental order. However, based on IMB Registration Record of Sleman and Bantul, the detected data of 1989 – 1998 show an apprehensive number of IMB arrangements. The data gained by Yunus (2001) from 13 *kalurahan* (a political district ruled by a "*lurah"/* 'village chief') that are close to Yogyakarta shows various average IMB numbers per year. The highest number was 91.2 houses/year in *Kalurahan* Caturtunggal with the population of 49,503 people in 1996 (the population growth was 2.09%/year). The lowest number was 2.1 houses/year in *Kalurahan* Trihanggo with the population of 11,824 people in 1996 (the population growth is 1.23%/year). Even in *Kalurahan* Caturtunggal, the highest number of IMB letters was actually still much smaller than the number and growth of its population. It shows that the process of making a permission letter to establish a building still has some weaknesses.

Moreover, Yunus (2001) stated that the non-farmer group (36.62%) is the one that has more IMBs than the farmer group does (6.4%). In other words, the non-farmer group has a higher awareness to arrange IMB than the farmer group. There is a variety of public perceptions relating to IMB. The biggest part of public (54.55%) said that the arrangement of IMB is very difficult, even 28.65% stated that they do not know about IMB, and only 16.80% said that the arrangement of IMB is relatively easy. This condition has resulted in a public opinion that the arrangement of IMB is very complicated and difficult. This is related to the requirements that are relatively hard for most people to satisfy, such as the requirement of the construction design of the building and the calculation of the construction itself, which are still very unfamiliar for them. Most people are also financially incapable if they have to use the service from the professional technique staff to draw and calculate the building structure. The consequences of all those facts are that the IMB arrangement to establish a building is neglected, the government control system remains weak, and the conversion of farmland into non-farmland becomes more uncontrollable.

4.2.3.3 Orientation of Settlement Development

A house as a place to live in has several functions and dimensions later (Smith, 1990, Yunus, 1992), including:

1) Shelter function,
2) Safety function,
3) Psychological function,

4) Social function,
5) Aesthetical function, and
6) Economic function.

It is obvious that the functions, orientations, and dimensions of a house are very wide. For there is an indication of the farmland decrease because of the settlement area, people who do not have any farmlands tend to use their houses as a medium to make a living. It means that the function of the house, which, in the beginning, is only as a shelter, has changed into other several orientations, including the economic one. Generally, it can be seen in the field that more local inhabitants tend to use their houses as a medium to make a living, both as their main income and as their additional income. Meanwhile, the outsiders who build houses in the new urban area tend to use their houses not as a commercial place, such as a shop, stall, etc. This fact indicates that there is an adaptive attitude towards making a living from the agricultural sector to the non-agricultural sector, especially the local inhabitants' attitude, as one of the effects of the decrease in farmland.

In general, Yunus (2001) divided the farmers' living in 14 villages that are closed to Yogyakarta City into two groups relating to their attitudes towards the aspect of the sale of their farmlands. Group (1) were those who sell a part or the whole of their farmlands when there is a tempting offer, and group (2) were those who do not want to sell their farmlands, either a part of or the entire farmlands. The first group that consists of farmers who were ready to sell their farmlands (52%) was in fact higher than the second group that consists of farmers who do not want to sell their farmlands (48%).

The reasons why farmers sold their farmlands are varied; some of them are that:

1) The farmlands they have were so narrow that the lands will be much narrower if they are divided among and bequeathed to their children; they prefer to share their properties in the form of money, so its management will be smoother.
2) They were interested in the market price of land in their neighborhood.
3) They were influenced by their neighbors who have sold their farmlands previously.
4) The narrow land they have did not yield sufficient products for their needs.
5) The money they get from selling their farmlands would be used to buy farmlands in the rural area with a lower price, so they can get wider farmlands than the previous ones. This fact becomes an important consideration for the new land that is expected to produce more crops than the previous land and wider to be bequeathed to their children.
6) It was because there was a hope to build a house to be rented, considering the high demand for houses or rooms for rent in the related area.

In a new development area, especially the one near a college area, there is usually a very high demand for boarding houses. Bigger or better new houses can improve farmers' prestige, besides giving them a new income. Letting houses to other people will be more beneficial than cultivating farmlands producing only minimum crops. Moreover, farm operations may cause a financial loss because the production cost can be much higher than the income from the crops of the lands produce. This may even be worse if the crops fail because of pests or natural disasters. Therefore, it was plausible if farmers try to change their profession as farmers into a non-farming one. At present, the farmer profession was no longer wanted by the youth; even they will try hard not to choose this profession because for them it was of very low economic and social values. The farmers who still maintain their farms, despite their smaller number than those who want to change their profession, have several reasons that make them stay in their profession as farmers and not want to sell their farmlands, either a part of or the entire land. Some reasons for the farmers not to sell their lands, in general, are that:

1) They feel that they have only a farming competency so that if they sell their farmlands, their source of income (life-source) will end.
2) Their lands will be bequeathed to their children.
3) They will feel ashamed to sell their farmlands, as the land ownership is also a social status symbol for them.
4) There is a principle among Javanese people that it is improper to sell the lands inherited from their parents because it will degrade their honor.
5) They will not sell their lands no matter how narrow the lands are.

Despite the farmers' tendency to sell or keep their farmlands, the fact in the field shows a high rate of conversion from farmlands into non-farmlands, and it is obvious that generally they tend to leave their farmlands, either by erecting new buildings on them or by selling them to others. Such condition happens not only in the research area but also in other cities, especially in Java Island. Furthermore, the Indonesian farmers' fate depends very much on the government's policy, which does not give adequate supports to them. This is shown, for example, by the fact that the prices of fertilizer and medicines are incomparably higher than those of the crops they produce are. This results in a dilemma because if the price of the crops is raised then it will make the inhabitants who do not have any farmland suffer. On the contrary, if the low price is maintained, the farmers, as the inhabitants who supply food for others, will suffer. Apparently, the model of the incentive or subsidy system for the farmers needs to be applied in Indonesia, so that the decrease in farmland, which will bring about many impacts, will be more controllable (Prinz, 2003-c).

4.2.3.4 Regional Planning

Nationally and provincially, the regency/city should actually refer to the directives of the area development stated in the National Plan, the Provincial Plan, and the Regency/City Plan. Nevertheless, the implementation of those plans is often far from being perfect. The made violations are caused by many factors, both internal and external. Some external factors influencing the plan are:

1) A policy was changed in using the space, especially in a national or regional scale so that the use of space no longer refers to the previous plan.
2) Paradigm was changed caused by the influences from foreign countries or global world, so it affects the planning pattern of the space layout.
3) The existence of knowledge and technology developed very rapidly and radically and were based on the optimum use of the available natural resources and the minimum environmental damage.

4) A natural disaster changed the structure and pattern of the use of space (Yunus and Hardoyo, 1990).

Moreover, they explained that some internal factors that may change the implementation of the plan are:

1) The low quality of the Master Plan, which does not sufficiently accommodate the development, and the growth of the social and economic activities, and it is not sufficient to be the basis or foundation to control the arrangement of a license for the location of development. The low quality of this plan can be caused by the absence of the correct technical process and procedural instances and by the lack of supporting and arrangement systems.
2) A lack of understanding and commitment of the related agencies contributes an inconsistency between the action and its plan. The license issued by the related agency is often found not suitable or even in conflict with the available plan.
3) An indifferent attitude in a part of people towards the conduct of development activities which may be caused by many factors considering the various backgrounds of the society in terms of educational, social, and economic levels. There are many violations made by the society and they pretend as if nothing happened although the violation is done by the educated people.
4) A lack of socialization of the available plan that makes the society and many parties, even the related agencies, not know about the available plan.
5) A lack of straightness shown by the qualified agencies in controlling the use of space, especially in straightening up-action that causes the frequently worst deviation, and, in the end, it is the plan of the space layout that is actually changed instead of adjusting the application to the plan.

The arising responses relating to the deviations made depend very much on the area itself. In practice, the deviations can be categorized into some levels, such as very big, big, medium, and small. It is strongly recommended that not all of the deviations made be treated with chaos. On the contrary, it is better to face the fact that not all of the mistakes are just neglected without any meaningful responses as what often happens recently. In fact, those mistakes will bring about big impacts in later days. Thus, the monitoring and evaluation need to be done, and there should be a continual effective cooperation between the parties and the society for a certain period. It is also important to control the developed area and the urban area, besides conducting the monitoring and evaluation, by determining a clear boundary that consistently regulates the change of the land for agriculture into non-agriculture. Small towns need to be developed in order to decrease the burden of city for there are a population agglomeration and too many city activities in Yogyakarta and its surroundings.

4.2.3.5 Problems on Regional Development

There is an indication in the development process conducted in Indonesia, including in DIY and in the area of the study, that a point of departure of the program formulation is still partially oriented. Up to now, the degree of development is still based on the partial sectors. Hence, the attained result is still inadequate although there is an improvement in some related sectors. This results in a conflict among sectors, for example between the agricultural sector and the non-agricultural sector. An obvious indication is the decrease in the productive farmlands and the environment quality. This problem is not caused merely by the sectional errors but also by the fact that there is not any clear, thorough, and precise framework to accommodate all of the needs of each sector in a comprehensive context of development. The framework should not only be related to the purpose and objective of a certain activity but also cover the allocation of space and the pattern of the bond between the sector and the space.

Besides the approach that tends to be partial and a lack of integration among the sectors, another main constraint emerging in the conduct of the development in this study area is the problem of land. Because of its availability and the relatively high population growth, the land becomes a commodity with a very high economic value. As a result, landowners try to make optimum use of their lands to gain optimum economic values. This phenomenon can be seen in the field, especially in a developed area where there is always only a small open space. Then, this results in a very high ratio of the extent of the building to that of the land. This in turn will influence the balance of the water resources system in the area from which the society fulfills the need of domestic water by using groundwater. Despite those weaknesses and problems, there is also an indication that it is more difficult to get a land for the planned activities, which may result in the conversion of farmland into a place to conduct the activities. Some consequences of such condition are, for example, unplanned settlement areas that keep emerging nowadays and the inappropriate use and cultivation of land resulting in negative impacts on the general environment.

Another problem that arises due to the complexity of development is the lack of legal regulations, relating to the space and land structuring, as the existing ones are still inappropriate. In the management of space and land structuring, including the legal assurance for land, related institutions' authority and responsibility often overlap. This will be worse because a demand for land is high whereas its supply is low.

Besides, the spatial layout plan can also be a problem because it is still oriented to administrative matters, not to ecological functions or bioregion and the layout pattern. Institutions' different views regarding the model of the layout pattern that should be developed also result in several problems that are difficult to overcome. Other serious problems arise from the institutional weakness in the layout structuring and the development agents' low quality.

4.2.4 Results and Discussion

4.2.4.1 Land Use Change

4.2.4.1.1 LANDSAT Image Interpretation

The new LANDSAT TM and ETM images are corrected from the systematic distortion. Therefore, it is still necessary to conduct the non-systematic correction. This correction uses the Ground Control Point (GCP). The selection of GCP is meant to recognize both media clearly, the LANDSAT image and topographic map as its reference. This step is aimed at reducing the possibility of the position mistakes. There are 4 points used in this correction and they spread at the four edge corners.

The image sharpening is done to make the image visualization easier. The way to do so is by making the image composite and contrast sharpening. The image composite is made by selecting the spectral and composing them in a certain order of filters. For example, the TM 742 image composite means that the image is an output of the composite of band 7 of red filters, band 4 of green filters, and band 2 of blue filters. Band 7 is the top of the ground reflection, band 4 is the top of the vegetation area reflection, and band 2 is the top of the water reflection. By combining those top areas, the main objects will appear in a specific color. In order to produce the clearer image visualization, the contrast sharpening is conducted so that the pixel appearance will also contrast more.

The classification or categorization of a land use is carried out by classifying and collecting each pixel. This classification will then be examined by utilizing the training separation of the selected samples. The categories, which describe the similar objects, are then merged and given a specific name for each category. The categorization or classification in the conducted interpretation is: settlement (class 5), settlement (class 4), settlement (class 3), settlement (class 2), settlement (class 1), irrigated rice field, unirrigated agricultural field, plantation, mix forest, homogenous forest, fine sand, pyroclastic rock, and airport complex (grass, buildings, and landing strips).

The settlement area can be in the form of a village that consists of houses and their yards, schools, prayer places, graveyards, and even markets or a shopping-mall complex. Such settlements lie in both rural and urban areas. Generally, the settlement in the urban area is denser than that in the rural area. Besides the population density that influences the settlement density, the color of the imagery objects will also influence the degree of the settlement density. It is assumed that the sparser the buildings are, the lesser the population density is and the more the vegetation exists. Visually, the higher the percentage of the vegetation coverage is, the darker the color is.

The settlement category is divided into 5 classes according to the population density level. The levels, comprising the population density of more than 8500 persons/square kilometer, 8000 – 8500 persons/square kilometers, 7500 – 8000 persons/square kilometers, 7000 – 7500 persons/square kilometer, and less than 7000 persons/square kilometer, are categorized into class 5, class 4, class 3, class 2, and class 1, respectively. As an illustration, Figure 4.4 gives examples of dense settlements. To generalize the categories, fine sand, pyroclastic rock, airport (grass, buildings, and landing strips) are grouped as “others”. In addition, the “settlement” category in some discussion would be the generalization of all settlement classes. Therefore, the generalized categories of land use consist of settlement, irrigated rice field, unirrigated agricultural field, plantation, forest, and others.

The irrigated rice field (*sawah irigasi teknis*) can be easily identified on the LANDSAT image, specifically by observing the shape, pattern, size, and texture. The general shape is in orderly partitions with the similar size and having a smooth texture (Figure 4.5). The color of these farmlands can be dark or bright, depending on the condition of the farmland at that time. The dark color can be seen in the irrigated farmlands or the farmlands with young rice plants. The bright color can be seen in the dry farmlands or the harvested farmlands.

(a) (b)

Figure 4.4: (a) Dense settlement with 32,189 people/km^2 at Kraton Sub-district, Yogyakarta, (b) Settlement with more than 8000 people/km^2 at Depok Sub-district, Sleman Regency (Photos: Widodo, 2003)

(a) (b)

Figure 4.5: Irrigated rice fields (*sawah*) at early plantation (Photos: Widodo, 2004)

The unirrigated agricultural field (‘*tegalan*’) that covers the dry land cultivation is usually found in lands in where the irrigation water is scarce. Thus, it usually lies in relatively higher areas, or on the slope of hills. Other characteristics of this ‘*tegalan*’ are its shape, size, texture, and pattern. The shape of ‘*tegalan*’ is usually in the form of partitions as ‘*sawah*’-like, which usually has a smaller size than that of ‘*sawah*’. The visible texture is quite smooth and having unorganized pattern or unconformity. The color of this ‘*tegalan*’ is quite bright for its vegetation coverage is quite sparse.

Mixed plantations hereinafter referred to as plantations, consist of house yards and ‘*tegal*’, and usually have only a small number of houses. Unlike the settlement area, the distance between one house and another is rather far. The color of this plantation is usually slightly bright with relatively rough texture. The existing forests in the study area are usually identified through their size, texture, and color. The size of the forest is usually quite extensive, which is different from that of ‘*sawah*’, which has a relatively smooth-to-smooth texture. The existing color is usually quite bright to dark, depending on its density. The dense forests have a dark color, while the wide-apart forests have a brighter color, which can be found on the slope of Mt. Merapi. There are two types of forest, mixed forest and homogeneous forest. The mixed forest consists of many types of plant with a texture softer than that of the homogenous one. To simplify the land use category, the two types of forest are combined into one category, just forest.

A landscape dominated by fine sand is found along the south coast. This element is not very widely distributed compared to the total area. It is similar to the pyroclastic rocks, which are in the form of erupted volcano materials from Mt. Merapi. Adisucipto Airport complex is also interpreted by dividing its area into grass, landing strips, and buildings. This rather detailed categorization is needed to conduct the runoff analysis.

4.2.4.1.2 Field Checking

In order to validate the result of the interpretation, field checking is conducted for some samples. These samples are randomly selected for each category. Therefore, the sampling method is close to the selected-random sampling.

The field checking was done by directly observing the locations that had been previously determined as the sample points. Then, the interpretation result was adjusted with the real condition in the field by means of plotting the points in the map from the interpretation process. The locations of the sample points were identified with the help of a GPS instrument. The field checking was done in 49 (forty-nine) sample points, of which the locations had been determined. From all of the determined sample points, it was found that there were four mistakes in conducting the interpretation. This might be due to a change in the land use considering that the utilized image was the image of 2000, while the field checking was done in 2003. The mistakes also might happen because the image characteristics were similar or almost the same. Based on the field checking result, the interpretation accuracy obtained was 91.8%.

4.2.4.1.3 Temporal and Spatial Land Use Change

As the urban population grows, changes in the utilization of land inevitably occur simultaneously along with the social and economic structure. The inevitable local change occurs in the horizontal growth of the town, especially in the peripheral direction. Although the peripheral zone covers an extensive agricultural area having rural characteristics, it has very often been included in the urban boundary. To meet the housing demand of the growing population, the area for houses and other buildings has increased 1.48% annually.

Table 4.9 shows the results of the land use classification in square kilometer from the year of 1994 to 2000. Originally, there are 15 categories of the land use, namely settlement (class 5), settlement (class 4), settlement (class 3), settlement (class 2), settlement (class 1), irrigated rice field, unirrigated agricultural field, plantation, mixed forest, homogenous forest, fine sand, pyroclastic rock, airport complex (grass, buildings, and landing strips). To simplify, the categories of land use are settlement, irrigated rice field, unirrigated agricultural field, plantation, forest, and others. Figures 4.6, 4.7, 4.8 and 4.9 illustrate the land use classification resulted from the interpretation of LANDSAT images of years 1994, 1996, 1998, and 2000. It can be seen clearly from the figures and tables that those areas have witnessed a major change in land use in that decade especially in terms of agricultural lands and residential areas. Meanwhile, Figures 4.14 and 4.15 explain the trend of land use change. If there were no anticipation regarding the change, the environmental situation of the study area would be critical due to the rapid development of settlement areas that reduce agricultural lands.

Table 4.9: Land use changes: 1994 – 2000

No	Land Use	1994		1996		1998		2000	
		km^2	%	km^2	%	km^2	%	km^2	%
1	Settlement (Class5)	57.255	5.20	56.386	5.12	51.677	4.69	50.987	4.63
2	Settlement (Class4)	8.888	0.81	5.807	0.53	4.296	0.39	5.199	0.47
3	Settlement (Class3)	11.292	1.02	12.196	1.11	15.789	1.43	6.167	0.56
4	Settlement (Class2)	4.964	0.45	10.999	1.00	3.649	0.33	13.996	1.27
5	Settlement (Class1)	280.569	25.46	303.042	27.50	332.292	30.15	365.557	33.17
Total Settlement		362.968	32.94	388.429	35.25	407.702	37.00	441.907	40.10
6	Irrigated rice field	510.309	46.31	486.078	44.11	467.832	42.45	435.154	39.49
7	Unirrigated agricultural field	125.857	11.42	125.163	11.36	124.261	11.28	123.678	11.22
8	Plantation	54.485	4.94	54.166	4.92	54.144	4.91	53.495	4.85
9	Mixed forest	14.974	1.36	15.008	1.36	15.063	1.37	15.044	1.37
10	Homogenous forest	25.181	2.29	25.128	2.28	25.096	2.28	25.064	2.27
11	Fine Sand	4.085	0.37	3.942	0.36	3.890	0.35	3.654	0.33
12	Pyroclastic rock	1.277	0.12	1.222	0.11	1.154	0.10	1.153	0.10
13	Grass of airport complex	0.658	0.06	0.658	0.06	0.658	0.06	0.658	0.06
14	Buildings of airport complex	1.018	0.09	1.014	0.09	1.013	0.09	1.018	0.09
15	Landing strip of airport complex	1.150	0.10	1.158	0.11	1.156	0.10	1.150	0.10
TOTAL		1,101.97		1,101.97		1,101.97		1,101.97	

Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000

The settlement areas from 1994 – 2000 changed quite significantly. The settlement of class 1 (with the population density less than 7000 persons/square kilometer) is the settlement area with the most significant indicator of increase. This phenomenon can be seen in Table 4.11 and Figure 4.10. Meanwhile, the settlement of class 5, the second rank after class 1, also shows tendencies to increase. This settlement, which is the densest settlement, tends to lie in the urban areas.

If all types of settlements are grouped into one “total settlement” or only into “settlement”, and the categories of fine sand, pyroclastic rocks, grass, buildings, and landing strips are grouped into “others” then the simplified categories can be made as shown in Table 4.12. The data show that the changes from irrigated rice fields to residential areas are dominant. Table 4.13 shows the extent and the percentage of each category.

At the beginning of 1994, irrigated rice fields had the extent of 510.309 square kilometers or 46.31% of the total study area. Afterwards, it decreased little by little into 435.154 square kilometers or 39.49% of the total study area in 2000.

In the meantime, the extent of the total settlement of 362.968 square kilometers or 32.94% in 1994 sharply increased to 441.907 square kilometers or 40.10% in 2000. Table 4.13 shows the percentage of the changes in each category from 1994 to 2000. The settlement increased by 2.31%, 1.75%, and 3.10% for the changes in 1994 - 1996, 1996 - 1998, and 1998 - 2000, respectively. The mean of the growth was 2.39%/two years or 1.19%/year. Meanwhile, each of the irrigated rice fields decreased by -2.20%, -1.66%, and -2.97% from 1994 - 1996, 1996 - 1998, and 1998 - 2000, respectively.

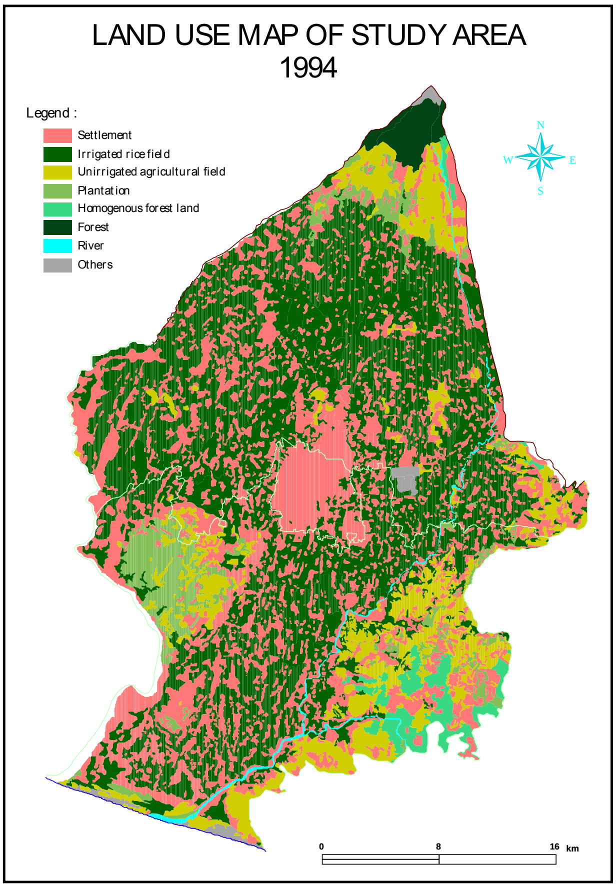


Figure 4.6: Land use map of 1994 (Source: interpreted from LANDSAT image of 1994)

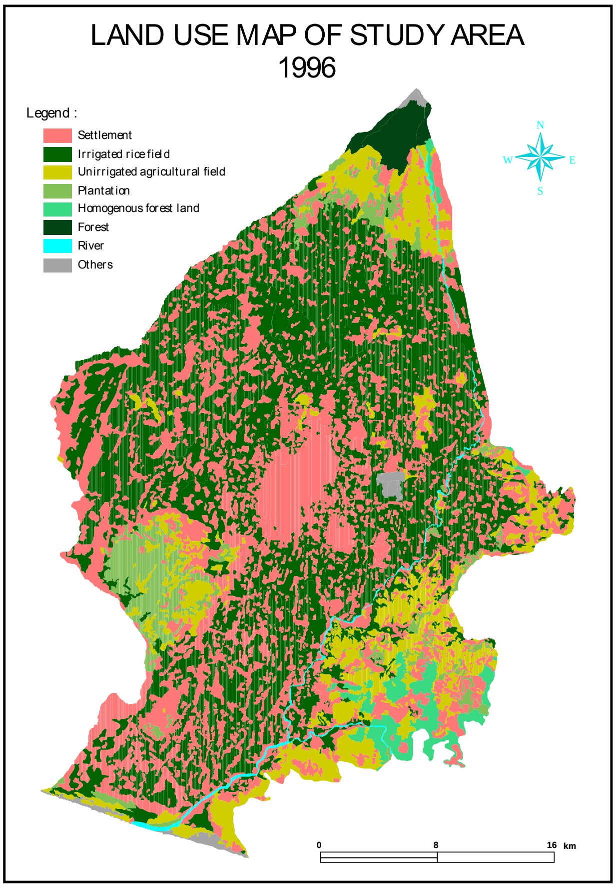


Figure 4.7: Land use map of 1996 (Source: interpreted from LANDSAT image of 1996)

Table 4.10: Land use changes in simplified categories: 1994 - 2000

No	**Land Use**	**Area (km^2)**			
		1994	1996	1998	2000
1	Settlement (Class5)	57.255	56.386	51.677	50.987
2	Settlement (Class4)	8.888	5.807	4.296	5.199
3	Settlement (Class3)	11.292	12.196	15.789	6.167
4	Settlement (Class2)	4.964	10.999	3.649	13.996
5	Settlement (Class1)	280.569	303.042	332.292	365.557
	Total Settlement	362.968	388.429	407.702	441.907
6	Irrigated rice field	510.309	486.078	467.832	435.154
7	Unirrigated agricultural field	125.857	125.163	124.261	123.678
8	Plantation	54.485	54.166	54.144	53.495
9	Forest	40.155	40.135	40.160	40.107
10	Others	8.188	7.994	7.871	7.634

(Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

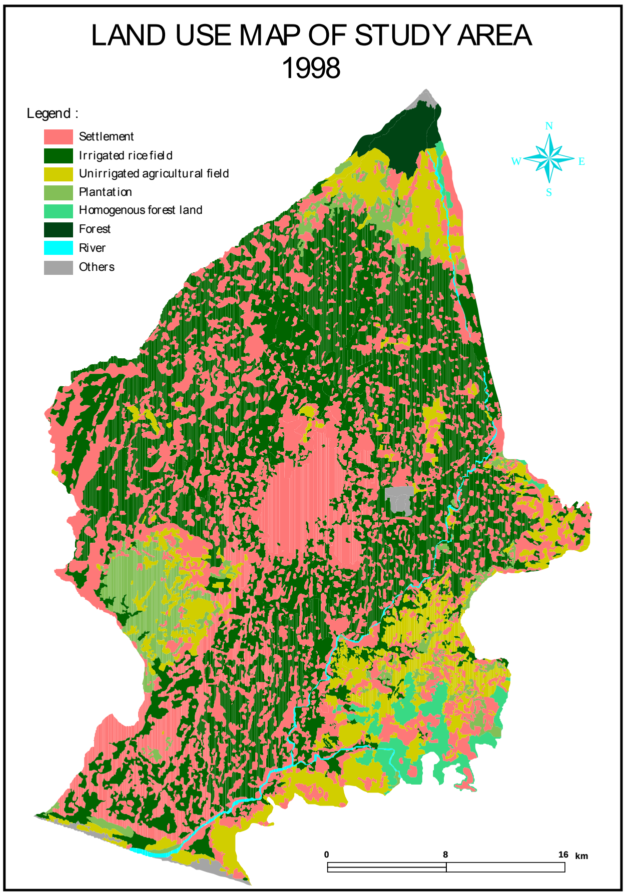


Figure 4.8: Land use map of 1998 (Source: interpreted from LANDSAT image of 1998)

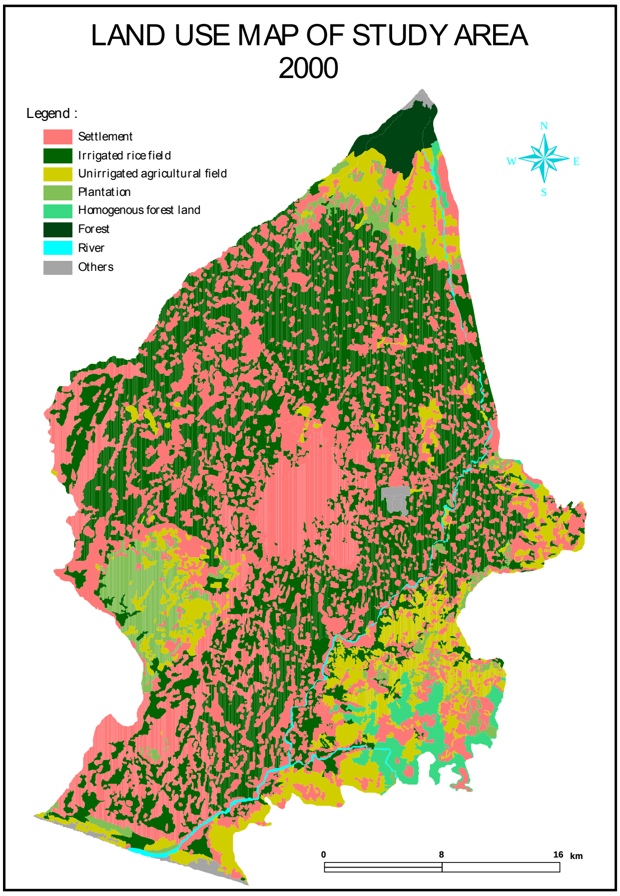


Figure 4.9: Land use map of 2000 (Source: interpreted from LANDSAT image of 2000)

Table 4.11: Development of settlement area

No	Settlement	Population Density (person/ km^2)	1994	1996	1998	2000
1	Class 5	> 8500	57.255	56.386	51.677	50.987
2	Class 4	8000 - 85000	8.888	5.807	4.296	5.199
3	Class 3	7500 - 8000	11.292	12.196	15.789	6.167
4	Class 2	7000 – 7500	4.964	10.999	3.649	13.996
5	Class 1	< 7000	280.569	303.042	332.292	365.557
	Total		362.968	388.429	407.702	441.907

(Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

On the average, the decrease per two years was -2.27% or -1.14%/year. In Figure 4.11, the graph shows clearly the change of the number of each land use category all at once. Unirrigated fields decreased by - 0.03% per year, while the plantation, forest, and others showed a relatively insignificant decrease, namely - 0.01 %/year, 0%/year, and - 0.01 %/year, respectively. It was also caused by the extent of each area that was relatively small, less than 11.22% for unirrigated farmland, 4.85% for the plantation, 3.64% for forest, and 0.69% for others (Table 4.13).

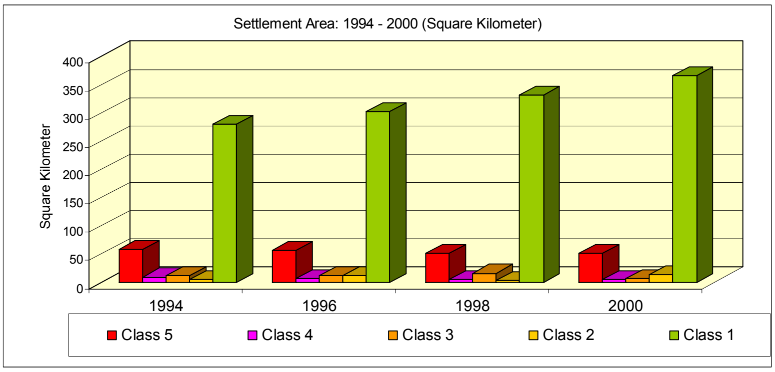


Figure 4.10: Settlement area based on LANDSAT image interpretation result (Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

Table 4.12: Land use changes in the most simplified categories: 1994 – 2000

No	Land Use	Area (km^2)			
		1994	1996	1998	2000
1	Total Settlement	362.968	388.429	407.702	441.907
2	Irrigated rice field	510.309	486.078	467.832	435.154
3	Unirrigated agricultural field	125.857	125.163	124.261	123.678
4	Plantation	54.485	54.166	54.144	53.495
5	Forest	40.155	40.135	40.160	40.107
6	Others	8.188	7.994	7.871	7.634
	T o t a l	1,101.963	1,101.966	1,101.969	1,101.975

(Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

Table 4.13: Land use changes in simplified classification

No	Land Use	Area							
		1994 (km^2)	%	1996 (km^2)	%	1998 (km^2)	%	2000 (km^2)	%
1	Total Settlement	362.968	32.94	388.429	35.25	407.702	37.00	441.907	40.10
2	Irrigated rice field	510.309	46.31	486.078	44.11	467.832	42.45	435.154	39.49
3	Unirrigated agricultural field	125.857	11.42	125.163	11.36	124.261	11.28	123.678	11.22
4	Plantation	54.485	4.94	54.166	4.92	54.144	4.91	53.495	4.85
5	Forest	40.155	3.64	40.135	3.64	40.160	3.64	40.107	3.64
6	Others	8.188	0.74	7.994	0.73	7.871	0.71	7.634	0.69

(Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

Table 4.14: Average land use changes annually

No	Land Use	Area Change (%)				
		1994-1996	1996-1998	1998-2000	Mean Biannual	Mean Annual
1	Total settlement	2.31	1.75	3.10	2.39	1.19
2	Irrigated rice field	-2.20	-1.66	-2.97	-2.27	-1.14
3	Unirrigated agricultural field	-0.06	-0.08	-0.05	-0.07	-0.03
4	Plantation	-0.03	0.00	-0.06	-0.03	-0.01
5	Forest	0.00	0.00	0.00	0.00	0.00
6	Others	-0.02	-0.01	-0.02	-0.02	-0.01

(Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

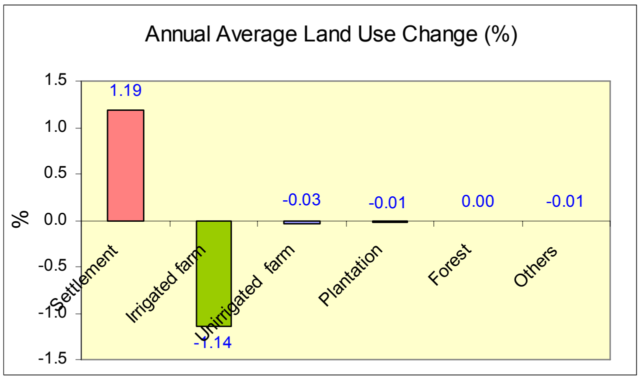


Figure 4.11: Percentage of land use change average (%/year) based on the data of 1994, 1996, 1998, and 2000 LANDSAT image interpretation (Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

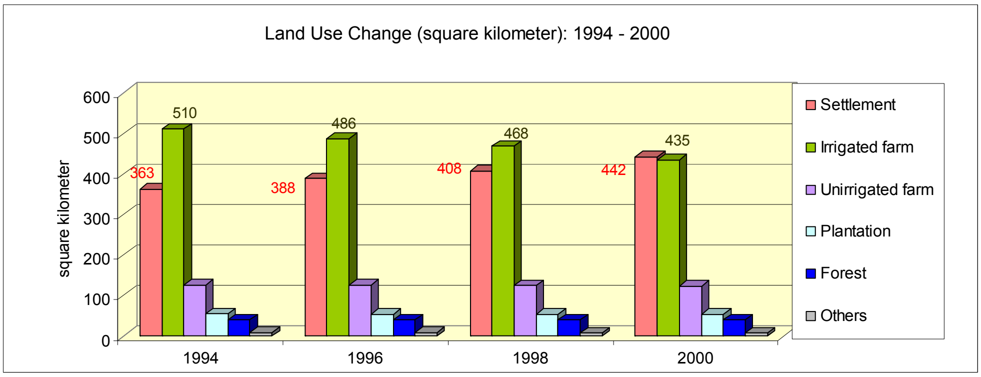


Figure 4.12: Land use change: 1994 – 2000 (Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

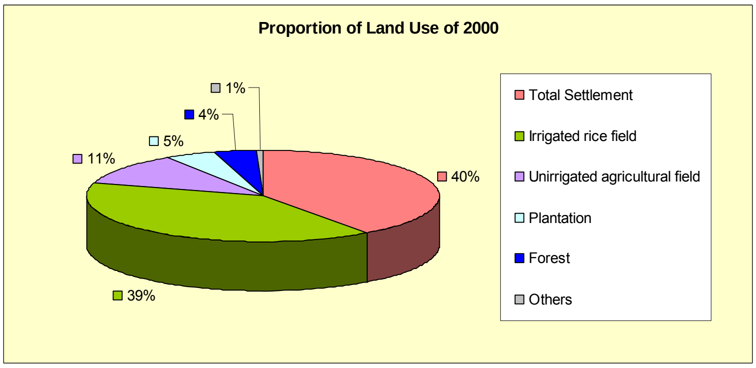


Figure 4.13: Proportion of land use in the year of 2000 (Source: analyzed from LANDSAT image of 2000)

4.2.4.1.4 Trends of Land Use Changes

Based on the data analysis on the LANDSAT images of 1994, 1996, 1998, and 2000, the trend of the land use change is predicted up to 2010. Table 4.15 and Figures 4.14 – 4.16 show interesting figures. Residential areas in 1994 were only 362.968 square kilometers; in 2010, they are predicted to increase up to 566.709 square kilometers. It means that the increase in 16 years is around 56.13%. In 2010, the settlement lands will take around 55.58% of the total area in the study area. On the contrary, the irrigated farmlands, which in 1994 were 510.309 square kilometers, will decrease sharply in 2010, with the predicted extent of 316.431 square kilometers or a decrease of 37.99%. It means that the farmlands with such extents will only take around 28.71% of the area. From the same data, it can be predicted that in the year of 2032 all of the farmlands, especially the irrigated rice fields in the study area, will be extinct due to the urban and housing seized (Figure 4.16). The prediction approach is based on the calculation using the Excel software.

Table 4.15: Trends of land-use changes up to 2010

No	Year	Land Use (km^2)					
		Settlement	Irrigated farm	Unirrigated farm	Plantation	Forest	Others
1	1994	362.968	510.309	125.857	54.485	40.155	8.188
2	1996	388.429	486.078	125.163	54.166	40.135	7.994
3	1998	407.702	467.832	124.261	54.144	40.160	7.871
4	2000	441.907	435.154	123.678	53.495	40.107	7.634
5	2002	464.274	413.915	122.880	53.325	40.110	7.475
6	2004	489.883	389.544	122.136	53.025	40.098	7.296
7	2006	515.491	365.173	121.392	52.726	40.086	7.117
8	2008	541.100	340.802	120.648	52.427	40.074	6.939
9	2010	566.709	316.431	119.905	52.128	40.062	6.760

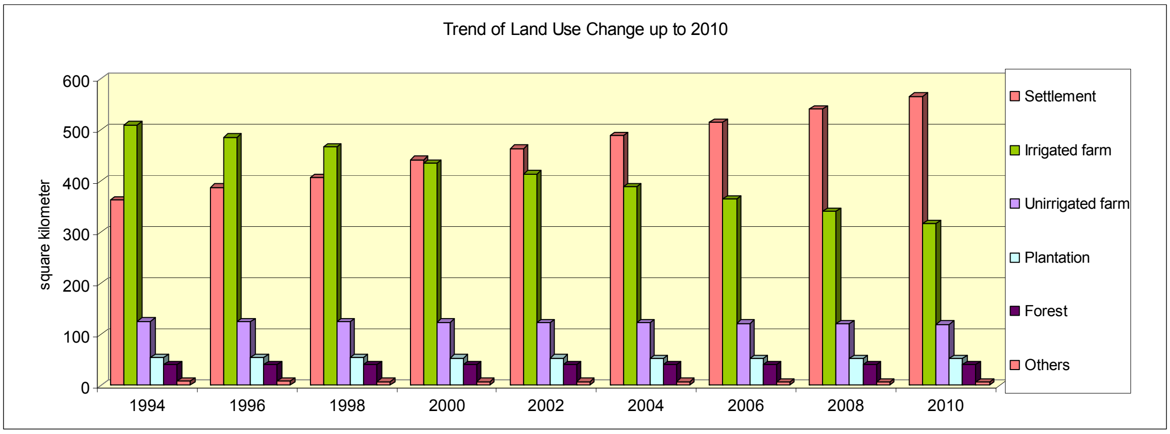


Figure 4.14: Trend of land-use changes up to 2010

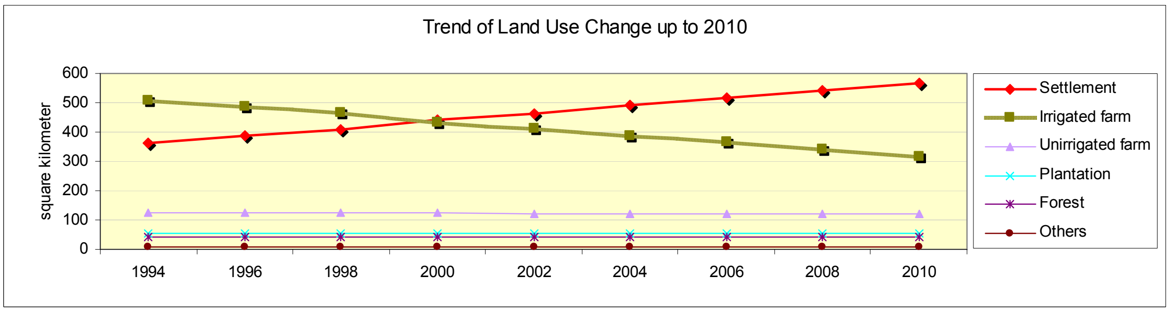


Figure 4.15: Trend of land-use changes up to 2010 (Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

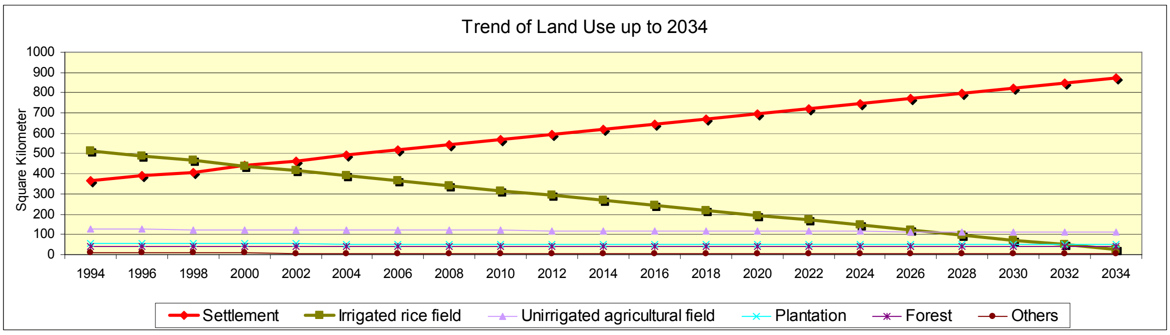


Figure 4.16: Prediction of land-use changes up to 2032 (Source: analyzed from LANDSAT images of 1994, 1996, 1998, 2000)

4.2.4.2 Pattern of Land - Settlement Development

The growth of settlement areas taken from the data of 1994, 1996, 1998, and 2000 that are analyzed from the LANDSAT image can be shown all at once in one pattern. The pattern and distribution of the amount of the change in the extent of the settlement area can be spatially known through a multi-temporal overlay on three maps of the land use. The steps in the determination of the changing pattern of the settlement area utilization can be seen in the diagram in Figure 4.17.

4.2.4.2.1 Steps in Identifying the Pattern

The steps in the determination of the aforementioned pattern are as follows:

1) Conducting the interpretation on the land use data taken from the multi-temporal LANDSAT image that has been corrected. The used LANDSAT images were the image recorded in 1994, 1996, 1998, and 2000. The interpretation process, then, results in the map of the multi-temporal land use.
2) Conducting the scoring on all of the types of land use in all years (1994, 1996, 1998, and 2000) was carried out. The use of land other than the settlement area in all years is given the score '0' (zero), while the scores of the land used for the settlement area are distinguished based on the year in which the land is used, in accordance with Table 4.16.

Table 4.16: Scoring system for settlement for each LANDSAT image (Source: Suharyadi, 2000)

No	Year of LANDSAT images	Score
1	1994	10
2	1996	100
3	1998	1000
4	2000	10000

3) Conducting the overlay on the map of land use in order to get the value or number of the change in the extent of the settlement area was conducted. The type of the overlay used in this step is the 'union' type. This step consists of three stages of process as briefly explained in the following section.

(1) The first process is conducting the overlay on the map of land use in 1994 together with that in 1996, so that it results in the value of change in the extent of the settlement area of 1994 until 1996. The polygon with the score 0 means that the area was used as a non-settlement area in 1994 up to 1996. The polygon with the score 110 means that in 1994 and in 1996 that area was used as a settlement area, whereas the polygon with the score 100 means that

there was a change in the use of that land, from the non-settlement use in 1994 to the settlement use in 1996.

(2) The second process is conducting the overlay on the map of land use in 1996 together with that in 1998. The result is that the polygon with the score 0 means that the area was used as a non-settlement area in 1996 and in 1998. The polygon with the score 1100 means that in 1996 and in 1998 the area was used as a settlement area, while the polygon with the score 1000 (one thousand) means that there was a change in the use of that land, from the non-settlement use in 1996 to the settlement use in 1998.

(3) The third process is conducting the overlay on the map of land use in 1998 together with that in 2000. The result is that the polygon with the score 0 means that the area was used as a non-settlement area in 1998 and in 2000. The polygon with the score 11,000 means that in 1998 and in 2000 the land was used as a settlement area, whereas the polygon with the score 10,000 means that there was a change in the use of that land, from the non-settlement use in 1998 to the settlement use in 2000.

4) The result of all the process above is the map of change in the extent of the settlement area in 1994 – 1996 (period 1), the map of change in the extent of the settlement area in 1996 – 1998 (period 2), and the map of change in the extent of the settlement area in 1998 – 2000 (period 3).

5) It is determined the value of change in the settlement extent in each sub-district on the basis of those three maps. Those are the map of change in the settlement extent in 1994 – 1996 (period 1), the map of change in the settlement extent in 1996 – 1998 (period 2), and the map of change in the settlement extent in 1998 – 2000 (period 3), as the results of the process mentioned above. There is a clipping on the map of change of the settlement extent based on the administrative border of each sub-district, so the map of change in the settlement extent of every sub-district can be obtained. From the map of change in the settlement extent of every sub-district, the value of change in the settlement extent of each sub-district (km^2/year) for every period can possibly be calculated.

6) The mapping was made of the data of change in the settlement extent (km^2/year) of each sub-district by entering the data of change in the extent into the administration map, in accordance with each sub-district for each period. There are three kinds of maps resulted from this step: (1) the map of the value of change in the settlement area (km^2/year) – period 1, (2) the map of the value of change in the settlement area (km^2/year) – period 2, and (3) the map of the value of change in the settlement area (km^2/year) – period 3.

Conducting the classification of the value of change in the settlement area for each period and giving the score is needed to know the pattern of change in the settlement extent of every period. The determination of the classification value is done automatically by using the Arc/View software. The classification and the score used can be seen in Table 4.17.

Table 4.17: Classification of settlement development

No	Class	The Range of Settlement Development Area (km^2/year)			Score
		Period 1	Period 2	Period 3	
1	I	0 - ≤0.09	0 - ≤0.031	0 - ≤0.132	10
2	II	>0.09 - ≤0.223	>0.031 - ≤0.149	>0.132 - ≤0.338	20
3	III	>0.223 - ≤0.385	>0.149 - ≤0.273	>0.338 - ≤0.554	30
4	IV	>0.385 - ≤0.536	>0.273 - ≤0.409	>0.554 - ≤0.705	40
5	V	>0.536 - ≤0.891	>0.409 - ≤0.575	>0.705 - ≤0.9502	50

(Source: analyzed by Arc/View from LANDSAT images of 1994, 1996, 1998, 2000)

Conducting the overlay on the three periods of map of the value of change in the settlement area of each sub-district for every period (km^2/year) gets the final result. Before the overlay is conducted, every class of change in the settlement area for every period is scored as seen in Tables 4.18 and 4.19.

Table 4.18: Classification and scoring of settlement development

No	Class	Score		
		Period 1	Period 2	Period 3
1	I	0	0	0
2	II	0	0	0
3	III	0	0	0
4	IV	0	0	0
5	V	10	100	1000

Source: Suharyadi (2000)

The highest class of change in the settlement area (class 5) for every period is scored differently in order to know the pattern of the biggest change for every period. Therefore, the area in which there is a biggest change in the settlement area during three periods orderly can be identified (Tables 4.17, 4.18, and 4.19).

Table 4.19: Total score resulted from overlay for 3 periods of settlement development area (km^2/year)

No	Total Score	Category of Development Area of Settlement
1	0	Small scale, not significant
2	10	The highest scale of period 1
3	100	The highest scale of period 2
4	110	The highest scale of period 1 and period 2
5	1000	The highest scale of period 3
6	1010	The highest scale of period 1 and period 3
7	1100	The highest scale of period 2 and period 3
8	1110	The highest scale of period 1, period 2, and period 3

Source: Suharyadi (2000), analyzed by Arc/View from LANDSAT images of 1994, 1996, 1998, 2000

4.2.4.2.2 Analysis

The areas in which the settlement growths were the highest in three periods (1994 – 2000) are, consecutively, Mlati Sub-district in Sleman and Sewon in Bantul. The settlement growth in Mlati and Sewon had the same pattern. It decreased in period 2 (1996 -1998) compared to period 1 (1994 -1996) and it increased in period 3 (1998-2000). The rate of the settlement growth in period 3 (1998 -2000) is higher than that of the settlement growth in period 1 (1994 -1996).

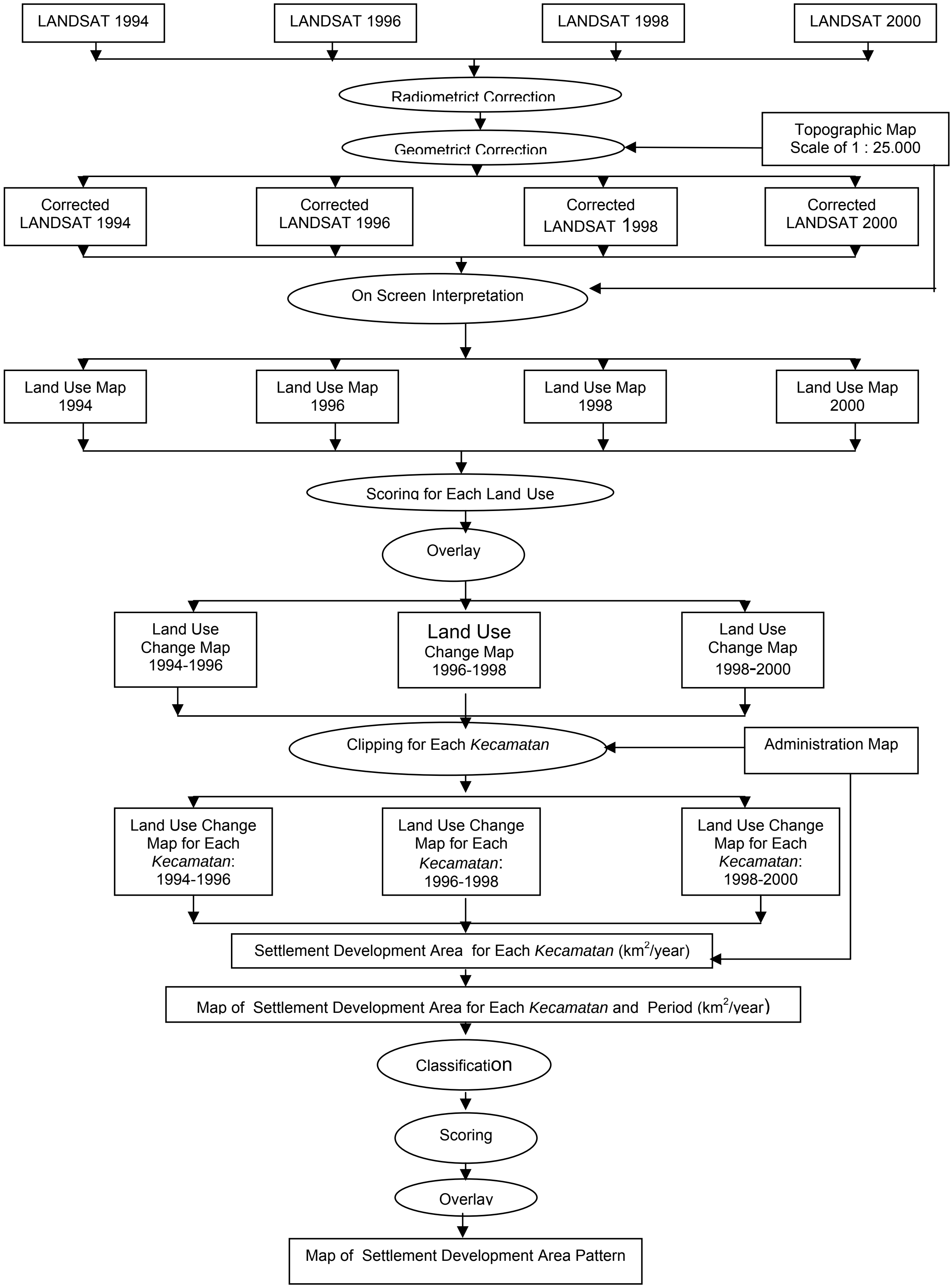


Figure 4.17: Flow diagram in identifying pattern of land – settlement development

The rapid settlement growth in that area was due to many new settlement areas built by either developers or the inhabitants themselves. Such rapid change in the land use was also caused by the factories, which were built in that area, especially in Mlati. The location of Mlati is convenient because it is near a good access, namely the Yogyakarta - Magelang Highway and the Ring Road. In addition, Mlati lies in the north side of Yogyakarta and still has vast farmlands, so it will be easier to change it from the farmland function to the non-farmland function.

Table 4.20: Development area of settlement for each Sub-district of Sleman

No	Sub-district	Period 1 (km^2/year)	Period 2 (km^2/year)	Period 3 (km^2/year)	Average (km^2/year)	Total Score
1	Berbah	0.433	0.287	0.520	0.413	100
2	Cangkringan	0.385	0.212	0.447	0.348	0
3	Depok	0.536	0.325	0.908	0.589	1000
4	Gamping	0.625	0.367	0.532	0.508	10
5	Godean	0.679	0.379	0.821	0.626	1010
6	Kalasan	0.410	0.409	0.592	0.470	0
7	Minggir	0.413	0.273	0.705	0.464	1000
8	Mlati	0.677	0.556	0.830	0.688	1110
9	Moyudan	0.418	0.366	0.848	0.544	1000
10	Ngaglik	0.435	0.382	0.950	0.589	1000
11	Ngemplak	0.367	0.239	0.450	0.352	0
12	Pakem	0.341	0.195	0.807	0.448	1000
13	Prambanan	0.171	0.119	0.108	0.133	0
14	Seyegan	0.435	0.447	0.645	0.509	1100
15	Sleman	0.379	0.335	0.790	0.501	1000
16	Tempel	0.437	0.434	0.641	0.504	100
17	Turi	0.421	0.339	0.667	0.475	0

Source: analyzed by Arc/View from LANDSAT images of 1994, 1996, 1998, 2000

Godean Sub-district had the highest rate of settlement growth in period 1 and period 3, while in period 2 it decreased and only belonged to the fourth class (class IV). The settlement growth of Kasihan Sub-district and Banguntapan Sub-district in Bantul reached its highest rate in period 1 (1994 -1996) and in period 2 (1996 -1998). In Banguntapan, the settlement growth increased in period 3 (1996 -1998); however, it was not in the highest growth category in period 3 (1996-1998) and its change was not greater than period 1 (1994 -1996). Such condition might be caused by the fact that in several areas in Banguntapan, the settlement area began to be saturated, as what is happening in Jagalan Village, for example. This village has more than 5000 people/km^2, so that it is included in class 5 and is the most densely populated area in Bantul.

Other results of this analysis are that several regions had their highest rate of settlement growth only in period 1 and some others had the rate of settlement growth, which was not too high (not in the category with the highest rate of settlement growth in all periods). There are also regions whose settlement extent was not changed (the rate of settlement growth is 0 km^2/year). These include some sub-districts in Yogyakarta. This is probably because those areas have already reached the saturated settlements (buildings), which can be seen from their population density that has reached more than 30,000 people/km^2.

Table 4.21: Development area of settlement for each Sub-district of Bantul

No	Sub-district	Period 1 (km^2/year)	Period 2 (km^2/year)	Period 3 (km^2/year)	Average (km^2/year)	Total Score
1	Bambanglipuro	0.342	0.378	0.695	0.472	0
2	Banguntapan	0.790	0.427	0.698	0.638	110
3	Bantul	0.339	0.389	0.406	0.378	0
4	Dlingo	0.028	0.028	0.043	0.033	0
5	Imogiri	0.213	0.112	0.094	0.140	0
6	Jetis	0.495	0.434	0.500	0.476	0
7	Kasihan	0.891	0.575	0.338	0.601	110
8	Kretek	0.327	0.322	0.316	0.321	0
9	Pajang	0.017	0.009	0.020	0.016	0
10	Pandak	0.407	0.381	0.466	0.418	0
11	Piyungan	0.223	0.149	0.132	0.168	0
12	Pleret	0.189	0.121	0.210	0.173	0
13	Pundong	0.415	0.231	0.291	0.312	0
14	Sanden	0.369	0.236	0.353	0.319	0
15	Sedayu	0.500	0.356	0.554	0.470	0
16	Sewon	0.590	0.480	0.783	0.617	1110
17	Srandakan	0.144	0.147	0.186	0.159	0

Source : analyzed by Arc/View from LANDSAT images of 1994, 1996, 1998, 2000

Table 4.22: Development area of settlement for each Sub-city of Yogyakarta

No	Sub-district	Period 1 (km^2/year)	Period 2 (km^2/year)	Period 3 (km^2/year)	Average (km^2/year)	Total Score
1	Danurejan	0	0	0	0	0
2	Gedongtengen	0	0	0	0	0
3	Gondokusuman	0.001	0.001	0.004	0.002	0
4	Gondomanan	0	0	0	0	0
5	Jetis	0.006	0.002	0	0.003	0
6	Kota Gede	0.090	0.089	0.025	0.068	0
7	Kraton	0	0	0	0	0
8	Mantrijeron	0.004	0	0.002	0.002	0
9	Mergangsan	0.035	0.020	0.019	0.025	0
10	Ngampilan	0	0	0	0	0
11	Pakualaman	0	0	0	0	0
12	Tegalrejo	0.080	0.031	0.062	0.057	0
13	Umbulharjo	0.296	0.193	0.248	0.246	0
14	Wirobrajan	0.016	0.010	0.003	0.010	0

Source: analyzed by Arc/View from LANDSAT images of 1994, 1996, 1998, 2000

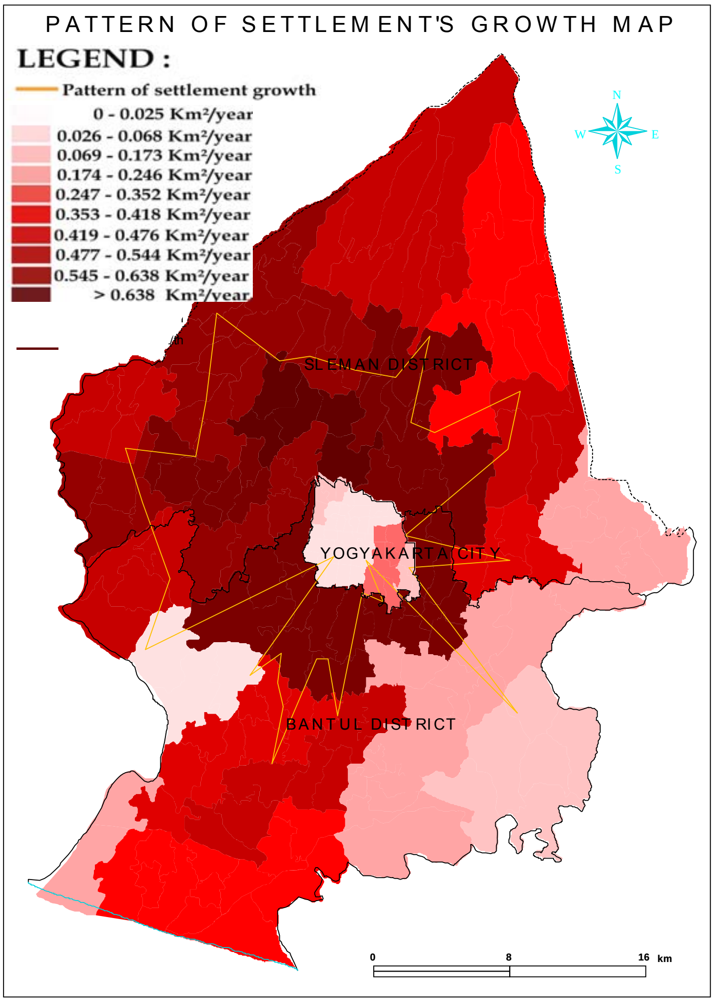


Figure 4.18: Pattern and distribution of settlement growth of 1994-2000 based on Sub-district level. Lines show the direction of the growth, which is assumed that the centre of the growth is the City of Yogyakarta (Source: analyzed by Arc/View from LANDSAT images of 1994, 1996, 1998, 2000)

It can be concluded, then, that Mlati Sub-district in Sleman and Sewon Sub-district in Bantul are the areas having the highest rate of settlement growth for the three periods. Mlati Sub-district has a more rapid average rate of settlement growth than Sewon Sub-district. This could be due to some new factory complexes in Mlati Sub-district. The direction of the settlement growth in all of the research area can be identified by taking into account the average settlement growth in three periods. Thus, the radial pattern that bulges to the North West with Yogyakarta as its centre can be obtained. To the South East direction, there are also regions with a high rate of settlement growth, precisely in Sewon Sub-district. However, the proportion between their settlement growth and the extent of the area for the settlement is not as big as that to the North West.

4.2.5 Impact of Land Resources Development

The most real impact of the development around the urban area is the decreasing farmland, especially because it is used to fulfill the need for the settlement area. This matter will influence farmers' income, and, furthermore, it will threaten the local and regional food stability. It can be seen from the data taken from the LANDSAT image interpretation that the increasing settlement area in Mlati Sub-district in Sleman, which lies in the north of Yogyakarta, from 1994 to

2000, was 0.69 square kilometer (km^2)/year, the biggest change in Sleman. The second biggest change is in Godean and Depok Sub-districts, with the change of 0.63 and 0.59 km^2/year.

The change in the use of land will also bring about an impact on the change of the inhabitants' means to earn their living. Most of them are farmers as a first work, and then have to work as non-farmers. This will influence their commitment in the agricultural sector. On the other hand, the increasing settlement area also results in the increasing demand for facilities and infrastructures. Such condition will change inhabitants' attitude, so that they develop the non-agricultural sector to earn a living.

Two groups of inhabitants directly face the impact of the decreasing farmland caused by the growth of urban area. They are:

1) The group of inhabitants who do not have farmlands anymore so that they change their profession to that of non-agricultural type, which is not easy to do,
2) The group of inhabitants who still have farmlands, which have become smaller so that it is impossible for them to base their life on revenues from agricultural production as the main source of income; therefore, they have to find other new sources for their additional income. As an illustration, in 1998, the percentage of farmers who lived in 14 villages directly bordering with Yogyakarta was 35%, while the percentage of non-farmers was 65%. The majority of local inhabitants work as farmers. The proportion of the number of farmers varies from location to location in each village. The villages lying in the north part of the city or those located in Sleman have a far lower percentage of farmers than those located in the south part of the city, or those lying in Bantul (Yunus, 2001).

The life pattern of the majority of inhabitants, especially the local inhabitants, certainly will shift from the life pattern of farmers to that of non-farmers. Indeed, there are many new sources of income in the non-agricultural sector available as a characteristic of urban life, such as running a business of stalls, letting rooms of a boarding house, working as factory workers, working as a part-time employee in stores, selling service, etc. Some people indeed seem to be flexible in adapting themselves to such condition, but some groups of inhabitants are apparently not prepared to face such change. Unemployment is a consequence that certainly will be experienced by inhabitants of those two groups and it is possible that it will result in other social problems. However, financially, non-farmer inhabitants generally may earn more money than those who work as farmers. This fact continually tempts owners of farmlands to erect buildings on their farmlands or sell them to outsiders with a hope that they will earn better incomes than those of farmers. Such condition will of course bring about a bad impact, which may remain for a long term, on the sustainability of the environment and the amount of rice production as their main food.

The existing fertile and productive farmlands, especially the irrigated rice fields, must always be the crucial consideration in managing the area surrounding the urban area. This is based on the fact connected to the policy of food self-sufficiency. From 1970s to 1990s, Indonesia succeeded in implementing the rice self-sufficiency policy, and even the country was able to help other several countries suffering from the lack of rice. However, in recent years, the rice self-sufficiency policy has been over. Up to now, Indonesia indeed imports rice from other countries to fulfill its needs. In the meantime, farmland is the main resource to produce rice, the main food for around 210 million Indonesian people. Farmland shrinkage means the loss of main source for producing the main food. The cumulative consequence of the loss of productive irrigated-farmlands in Java Island is so critical that the policy to protect farmland is badly needed and all parties must strongly support it.

Yunus (2001) stated that the development of Yogyakarta urban area dominantly moves to the northeast, comprising the area of Sleman from 1987 to 1996. Meanwhile, based on the data analysis taken from the LANDSAT image in this study from 1994 -2000, it can be seen that the direction of the change of land use from farmland to non-farmland tends to move to the north, to Sleman. This condition is parallel to the fact that there is a change in the rate of land use change to the settlement area, which certainly occupies most of the farmland. Mlati Sub-district, located in the north part of Yogyakarta, has the rate of growth of the settlement area of 0.69 km^2/year.

In order to overcome this problem, the government, through the Agency of National Development Planning (*BAPPENAS*), together with the National Agency of Land (*BPN*) and the Department of Internal Affairs (*Depdagri*), has set rules in the form of instruction, which basically controls the change of land use from agricultural use to non-agricultural use and attempts to maintain the food self-sufficiency. However, the fact in the field still shows the government's inability to reduce the speed of land use change.

The change of the urban area in the direction outside Yogyakarta and to Sleman or Bantul certainly brings positive impacts in terms of economy. However, interference disturbs the balance of water resources, besides the decrease in farmland, the resource to produce the main food. Spatially, the north part of Yogyakarta is an area that has a higher elevation than the main urban area in Yogyakarta and Bantul. The change in the land use from agricultural use to settlement use, basically, means a further sealing of the land surface, which in turn will hamper the process of rainwater absorption in the ground. The more the buildings are erected on the space of land surface, the less water can be absorbed into the ground and the more runoff water will flow to rivers. The runoff water, besides flowing to the sea finally, is also potential to cause floods. As the northern part of Yogyakarta has higher elevation, a flood is more probable downstream, in the area of Yogyakarta or Bantul. This fact has often been proved through big floods in both areas.

Besides a threat of floods in those areas, there is another problem relating to the rapid growth of the settlement area in Sleman. The problem is the declining groundwater surface in the area of Yogyakarta for there is an addition of groundwater coming from the rain and the rapid development of paving or blocking, not only in Yogyakarta but also in the area of Sleman. Most of the paving is changing the farmland, which is relatively able to absorb the rainwater better than the land full of buildings. The increasing intensity of the settlement development that generally correlates with the emergence of pollutant source may threaten the river water or the groundwater itself. It can be seen from the groundwater and river water quality, which is getting worse in Yogyakarta urban area and in the north part of Bantul.

If there are no concrete steps to control the settlement development, the food production may decrease, the river water and groundwater may be polluted, the groundwater level may decline, and the flood at the downstream areas will get worse. A suggestion that every building, either it is used for settlement or not, should have a well to absorb rainwater is crucial, besides the renovation of the drainage system, which at present is only able to discharge rainwater to the sea. The new drainage system should be able to catch the rainwater and absorb it into the ground.

4.3 Rainfall and Climatic Characterization

4.3.1 General

Wisnubroto (1994) supposed a relation between climate changes and changes of the appearance of the earth surface. The ratio between settlement area and farmland area or forests is contributing to this appearance, influencing sun radiation. This again contributes to differences in rainfall, temperature, air humidity, air direction, and speed of the wind (Kirono, 2002). The rain is the most important component that will be discussed in this study.

As mentioned before, the conservation of rainwater as the main supply of groundwater has not been managed well in most areas of DIY, especially in those of Sleman, Yogyakarta, and Bantul. The groundwater as the main source of domestic water is progressively degraded both in its quantity and in quality. The ironic condition is, that the runoff during the raining season is very high while people run short of water during the dry season. If this situation is continually neglected, it may increase the differences in water availability between the dry season and rainy season. A number of wells have to be dug deeper every year to reach the groundwater table; on the contrary, with increasing runoff water volumes the risk of floods in the rainy season rises. Another problem is the quality of groundwater that continually decreases, specifically at the area with dense population.

4.3.2 Methodology

In order to correlate rainfall with space, it needs an approach to describe, to count, and to analyze rainfall variation based on the aspects of space and time. One of the analysis methods, which are used to find the spread of rainfall based on the aspect of space, is the Polygon Thiessen method. Polygon Thiessen is considered easier to apply in the calculation of rain as the data source for the next analysis process, from which the shape is only influenced by the number and location of rain-stations without considering the amount of rainfall at each station. This is an advantage that can be used as a base in forming the model with the rain as one of the database. The rain-stations used in this research were selected based on the data validity, the data contribution on rainfall at a certain region, and the distribution of rain-stations. Data validity was determined by examining the data condition that was successfully recorded and by observing the rain data taken from the surrounding stations. Polygon Thiessen in this research was formed based on the data taken from 47 rainfall-stations located in all parts of the research area.

This stage is done by using the method of Polygon Thiessen. The advantages of using this method are it ignores the topography, the distribution of polygon will remain the same as long as there is no increment of the rainfall stations, and it is suitable for the area that has the different distance among one rainfall station and others (Seyhan, 1987).

Another method of determining the rainfall area distribution is the Isohyet Method. By using this method, it is possible to get a more detail and specific interval of rainfall caused by its discrepancy. This method is proper for the mountainous area for it considers the relief and topography, and because it is useful to record the short rainfall.

If those two methods usage are compared in this research, the explanations are:

1) The method of Polygon Thiessen will have more practical value relating to the shaping because it results in the same form of polygon, so it will be easier to record the input about rainfall, both in the form of rainfall data and planned-rainfall data; and

2) The Isohyet method will result in an irregular boundary for it depends on the amount of the rainfall at every station, thus the model resulted from the overlay process will always change.

The determining of the distribution of rainfall area at Merapi cavity is done based on the location of 47 points of rainfall measuring stations, by using the Thiessen Polygon method. This method is considered as easier to apply in measuring the rainfall as the source data for the next analysis processes, for the form is only influenced by the amount and location of the rainfall stations, without considering the amount of the rainfall at every station. This aspect is useful to be used as the foundation in forming the model with the rainfall as its one of the data sources.

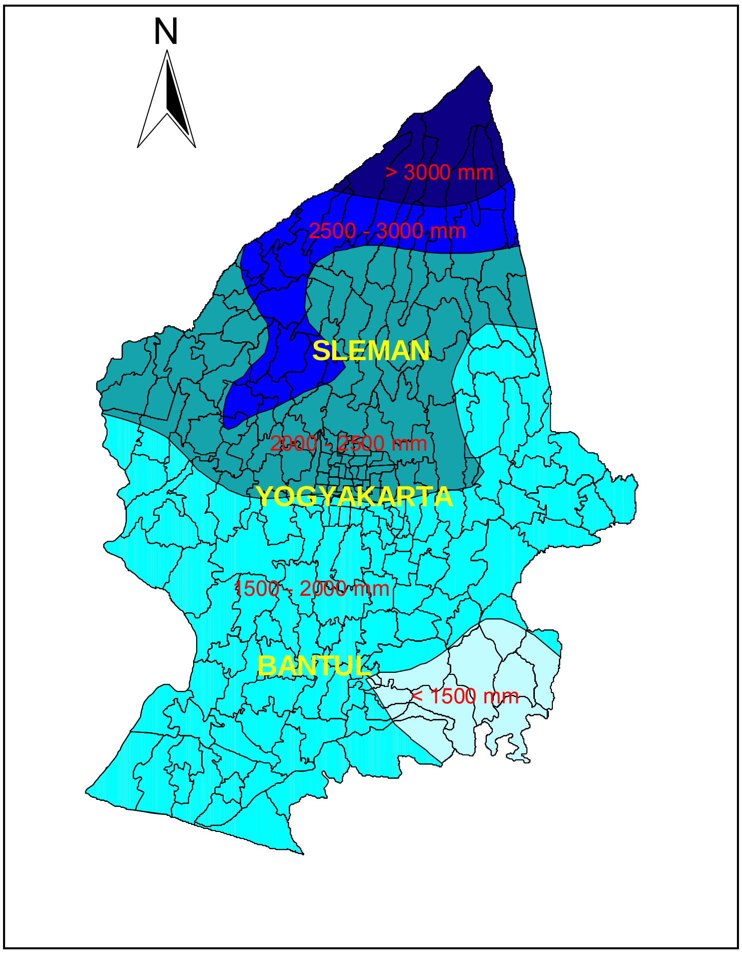


Figure 4.19: Rainfall distribution based on Isohyet's method

The rainfall stations that are used in this research are chosen based on the data validity, their contribution to the rainfall of an area, and the distribution of the rainfall stations. The data validity is determined by researching the condition of recorded data and by observing the rainfall data from the surrounding stations.

Based on the location of rainfall station and the amount of the measured rainfall at every rainfall station, the picture of the rainfall apportion in the research area can be presented in Figure 4.19. The rainfall apportion is made by using the interval of 500 mm from the average annual rainfall data of 15 years. The data of the dept of rainfall at every station is presented in Table 4.23.

Table 4.23: Annual rainfall (mm) of 47 stations at the study area

No	Station	Rainfall (mm)
1	Adisutjipto	2060
2	Angin-angin	1909
3	Babadan	2891
4	Barongan	1490
5	Beran	2555
6	Berbah/Krikilan	2022
7	Bronggang	2383
8	Brosot	1979
9	Cebongan	2842
10	Dadapan	2582
11	Dogongan	1555
12	Dolo	1957
13	Dukun	2244
14	Gandok	1996
15	Gembongan	1788
16	Godean	2528
17	Gondangan	2460
18	Jambon	2235
19	Jangkang	1986
20	Jetis	2582
21	Kalibawang	2228
22	Kalijoho	1883
23	Karangploso	1630
24	Kemput	2795
25	Kenteng	1768
26	Kolombo	2484
27	Krajan/Kalasan	1825
28	Ngepos	2471
29	Ngipiksari	3600
30	Nyemengan	1797
31	Pakem	2358
32	Patukan	2006
33	Pringpundong	1926
34	Prumpung	2283
35	Pulorejo	1815
36	SamBadan to	1848
37	Sanden	1854
38	Sapon	1870
39	Sendangpitu	2399
40	Seyegan	2353
41	Sorogedug	1773
42	Srumbung	3240
43	Tanjungtirto	1993
44	Tempel	2832
45	Terong	1472
46	Trukan	1887
47	UGM	2160

4.3.3 Description and Data Analysis

Based on the Isohyet map, it can be explained that Sleman has the average annual rainfall of more than 3,000 mm, particularly on the peak of Merapi volcano, between 2,500 – 3,000 mm in some parts of the top slope of the West side, and between 2,500 – 2,000 mm in some parts of the central slope. The average rainfall of Yogyakarta is divided into 2 parts. The first is the Northern area that has the average rainfall of 2,000 – 2,500 mm. Some parts of its Southern area the average rainfall is 1,500 – 2,000 mm. Bantul has the average rainfall between 1500 – 2000 mm, which evenly spreads almost to each sub-district, except in Eastern Bantul, that is around Dlingo Sub-district that has the average of less than 1,500 mm.

4.3.3.1 Monthly Rainfall

The condition of monthly rainfall can be found from the calculation of daily rainfall at each station during 15 years. The data of daily rainfall is then sumed up and becoming the data of monthly rainfall, and its 15-year mean is prepared. From the calculation of average monthly rainfall, it can be seen that at the research area there are generally three basic patterns covering wet months – dry months – and wet months. The first wet months occur from January to June, dry months occur from July to September, and the second wet months occur from October to December.

Table 4.24: Average monthly rainfall (mm) of 25 rainfall stations in Sleman Regency (1987 - 2001)

	Rainfall Depth (mm)												
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Adisutiptjo	386	366	310	194	65	63	38	19	14	112	209	284	2060
Angin-angin	357	313	258	169	90	74	26	32	34	152	213	245	1962
Babadan	505	565	364	232	119	90	44	36	44	125	310	462	2897
Banjarharjo	454	389	308	235	104	59	23	25	34	136	299	304	2371
Beran	415	385	362	249	143	103	50	46	41	149	316	350	2608
Berbah	386	364	298	136	89	60	45	22	16	91	194	281	1982
Bronggang	437	373	328	248	125	68	36	30	34	116	321	316	2432
Dadapan	400	388	373	281	164	104	36	43	67	173	308	324	2663
Jetis	413	391	325	272	149	104	53	31	37	170	304	384	2632
Jangkang	394	319	266	185	96	60	28	34	16	103	270	292	2062
Cebongan	452	405	376	249	117	94	42	40	43	151	339	364	2672
Dolo	342	356	266	174	81	71	27	26	26	83	226	268	1946
Kemput	453	435	390	256	150	93	24	53	39	196	366	258	2714
Godean	410	388	352	222	117	77	32	32	34	151	292	337	2444
Sendangpitu	391	407	349	309	88	61	35	19	32	164	298	279	2433
Jambon	386	368	323	242	114	83	40	35	34	132	268	308	2333
Kenteng	277	300	272	181	58	47	26	13	17	104	186	255	1732
Krajan	352	352	274	159	67	61	25	27	18	80	201	285	1900
Kolombo	546	480	369	256	142	112	41	24	48	116	293	403	2832
Ngepos	405	407	354	260	121	96	37	27	19	163	309	315	2515
Prumpung	382	367	292	240	104	82	31	36	32	162	248	317	2291
Ngipiksari	568	570	521	340	210	141	60	62	81	213	507	503	3776
Tanjungtirto	371	353	313	178	78	58	28	22	17	95	210	283	2004
Trukan	359	329	273	183	69	63	30	23	15	84	191	276	1895
UGM	417	360	298	203	85	73	36	24	16	125	240	283	2160
Average	409	388	328	227	110	80	36	31	32	134	276	319	2371

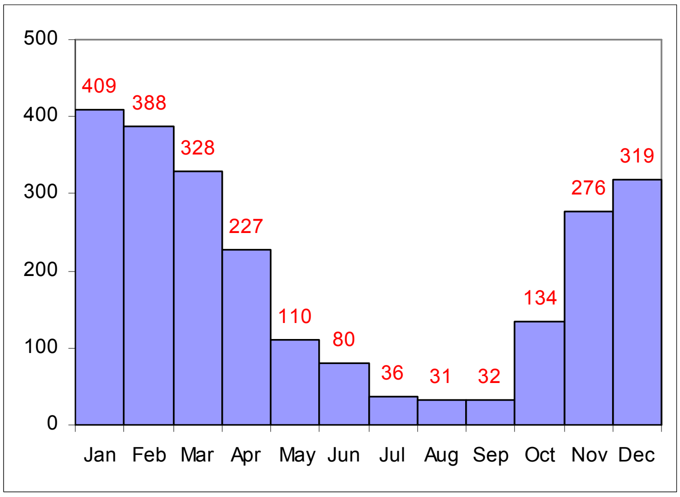


Figure 4.20: Average monthly rainfall (mm) in Sleman Regency (1987 - 2001)

The condition of monthly rainfall in Sleman can be found from the calculation on the average monthly rainfall at 26 rain-stations representing Sleman. According to the calculation result, it can be seen that the highest average rainfall happened in January with 409 mm/month, so it can be said that Sleman has the wettest month in January, while the lowest/smallest rainfall happened in August reaching 31 mm/month; thus, it can be said that the driest month in Sleman is in August. The clearer description can be seen in Table 4.24 and Figure 4.20.

Table 4.25: Average monthly rainfall (mm) of 6 rainfall stations in Yogyakarta City (1987 - 2001)

	Rainfall Depth (mm)												
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Jambon	386	368	323	242	114	83	40	35	34	132	268	308	2333
Nyemengan	348	371	326	230	40	77	46	5	8	99	274	224	2047
UGM	417	360	298	203	85	73	36	24	16	125	240	283	2160
Gandok	365	334	333	182	105	69	22	11	32	100	190	269	2012
Berbah	386	364	298	136	89	60	45	22	16	91	194	281	1982
Adisutjipto	386	366	310	194	65	63	38	19	14	112	209	284	2060
Average	381	361	315	198	83	71	38	19	20	110	229	275	2099

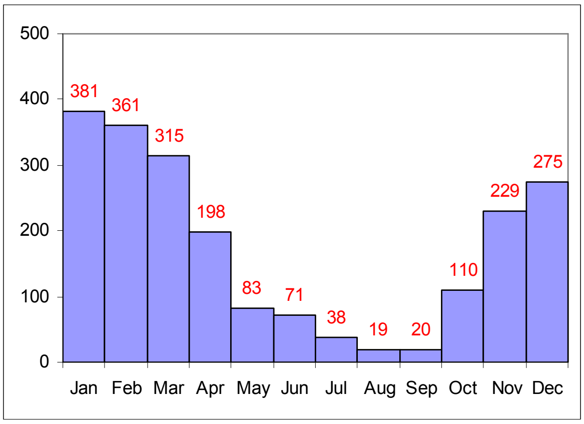


Figure 4.21: Average monthly rainfall (mm) in Yogyakarta City (1987 - 2001)

The condition of monthly rainfall in Yogyakarta can be found from the calculation of the average monthly rain observed at 6 rain-stations representing Yogyakarta. Based on the results of the calculations, it can be seen that the highest average rainfall happens in January reaching 381 mm/month, so it can be said that the wettest month in Yogyakarta is January, whereas the smallest rainfall happens in August, reaching 19 mm/month, i.e. its the driest month in Yogyakarta. Further information is given in Table 4.25 and Figure 4.21.

Table 4.26: Average monthly rainfall (mm) of 15 rainfall stations in Bantul Regency (1987 - 2001)

	Rainfall Depth (mm)												
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Brosot	337	376	290	171	42	41	23	18	74	123	285	336	2116
Berbah	386	364	298	136	89	60	45	22	16	91	194	281	1982
Sanden	447	377	247	225	92	27	56	6	132	289	260	262	2420
Terong	331	235	316	111	87	27	5	0	0	108	119	64	1404
Karangploso	328	256	210	164	50	18	2	26	6	50	176	173	1459
Sapon	366	331	271	136	37	61	21	24	46	85	220	292	1889
Kalijoho	343	314	274	153	59	81	25	16	9	88	236	280	1877
Kenteng	277	300	272	181	58	47	26	13	17	104	186	255	1732
Nyemengan	348	371	326	230	40	77	46	5	8	99	274	224	2047
Gandok	365	334	333	182	105	69	22	11	32	100	190	269	2012
Barongan	331	277	233	96	34	37	19	6	13	77	170	244	1538
Piring-pundong	360	375	249	147	51	44	18	9	29	100	268	298	1948
Trukan	359	329	273	183	69	63	30	23	15	84	191	276	1895
Dogongan	295	306	215	148	62	46	20	22	22	79	214	247	1675
Patukan	370	348	314	194	98	75	43	30	28	106	254	277	2138
Average	349	326	275	164	65	51	27	15	30	105	216	252	1876

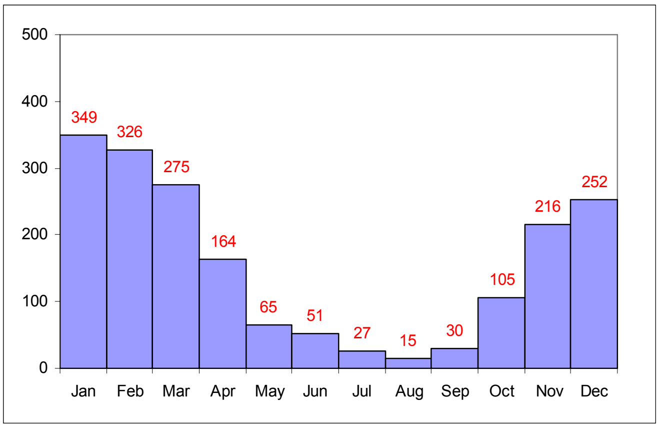


Figure 4.22: Average monthly rainfall (mm) in Bantul Regency (1987 - 2001)

The conditions of monthly rainfall in Bantul can be found from the calculation of the average monthly rain observed at 16 rain-stations representing Bantul. Based on the calculation result, it can be seen that the highest average rainfall happens in January reaching 349 mm/month, so it can be said that the wettest month in Bantul is January, whereas the smallest rainfall happens in August reaching 15 mm/month, so it can be said that the driest month in Bantul is August. A clearer description can be seen in Table 4.26 and Figure 4.22. Based on these facts, it can be concluded that in the research area, the wettest month is January, whereas the driest month is August.

4.3.3.2 Annual Rainfall

The result of analysis on the 15-year average rainfall taken from three regions included in the research area shows that Sleman has the highest average rainfall, the next is Yogyakarta, and the lowest is Bantul. The whole mean of 15-year rainfall of Sleman is 2,320 mm. The highest 15-year average rainfall is recorded in Pakem Sub-district reaching 2,971 mm and the lowest 15-year average rainfall was measured in Prambanan Sub-district reaching 1,895 mm (Table 4.27 and Figure 4.23). The high level of rainfall, especially in Pakem and Cangkringan Sub-district, is caused by the influence of Merapi volcano (orographic precipitation). Meanwhile, at the leeward side, where the air flowing down the slope will experience the heating process, there is the rain-shadow area with less rainfall. This orographic precipitation is considered as the main supplier of groundwater and surface water in the area.

The average rainfall recorded in Yogyakarta was 2,046 mm/annually within the 15 years' period. Spatially, the highest average rainfall can be found in Danurejan, Gedongtengen, Gondokusuman, and Jetis sub-districts, which is about 2,160 mm, while the lowest average rainfall can be found in Mantrijeron Sub-district with 1,797 mm (Table 4.28 and Figure 4.24).

The rainfall in Yogyakarta is still influenced by orographic precipitation, although the orographic effect is not as big as that in Sleman (Putra, 2003). The result of 15-year average rainfall analysis in Bantul indicates that the mean of rainfall in Bantul is 1,785 mm. The highest mean of rainfall happens in Srandakan Sub-district that reaches 1,926 mm while the lowest mean of rainfall was recorded in Dlingo Sub-district with 1,797 mm.

Table 4.27: Annual rainfall depth (mm) average for 15 years (1987-2001) at each Sub-district of Sleman

Sub-district	Rainfall Average of 15 year (mm)
Berbah	1963
Cangkringan	2884
Depok	2165
Gamping	2132
Godean	2408
Kalasan	1868
Minggir	2284
Mlati	2513
Moyudan	1804
Ngaglik	2289
Ngemplak	2099
Pakem	2971
Prambanan	1865
Seyegan	2430
Sleman	2406
Tempel	2642
Turi	2710
Average	2320

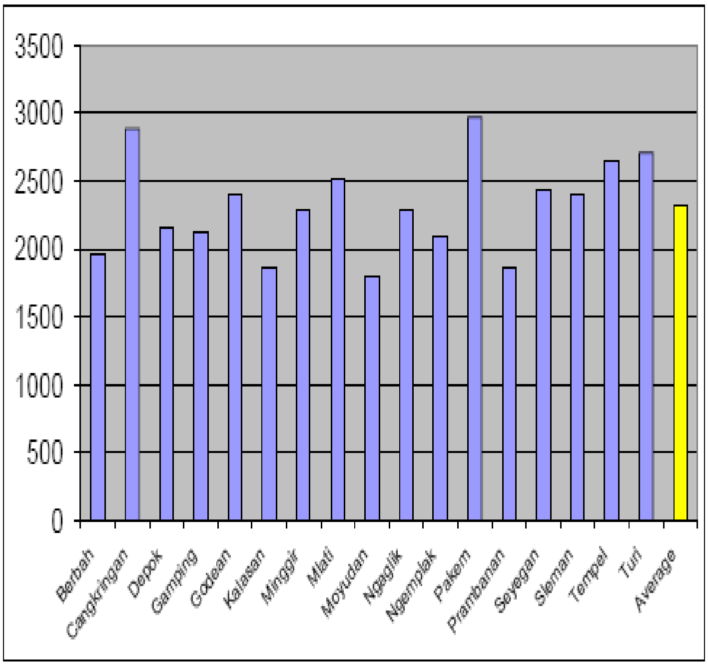


Figure 4.23: Rainfall depth (mm) average for 15 years (1987-2001) at each Sub-district of Sleman

Table 4. 28: Annual rainfall depth (mm) average for 15 years (1987-2001) at each Sub-city of Yogyakarta

Sub-district	Rainfall Average (mm)
Danurejan	2160
Gedongtengen	2160
Gondokusuman	2160
Gondomanan	2106
Jetis	2160
Kotagede	2013
Kraton	1813
Mantrijeron	1797
Mergangsan	1906
Ngampilan	2017
Pakualaman	2160
Tegalrejo	2201
Umbulharjo	2052
Wirobrajan	1940
Average	2046

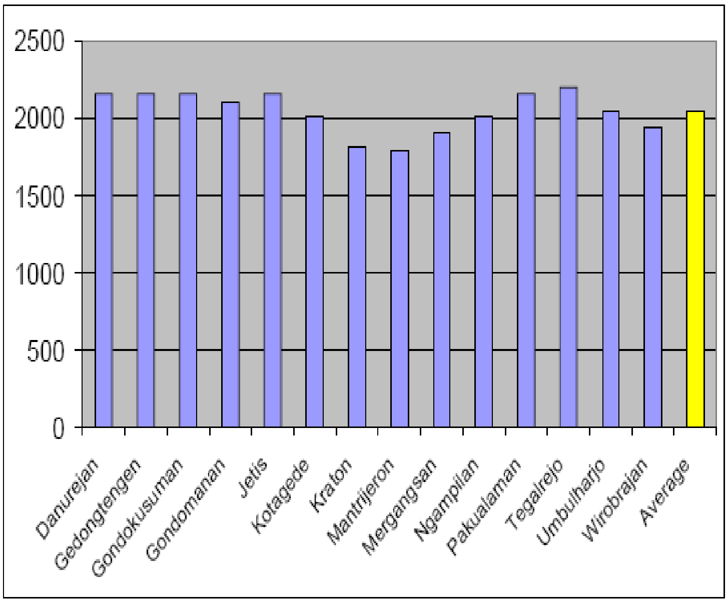


Figure 4.24: Rainfall depth (mm) average for 15 years (1987-2001) at each Sub-city of Yogyakarta

Table 4.29: Annual rainfall depth (mm) average for 15 years (1987-2001) at each Sub-district of Bantul

Sub-district	Rainfall Average of 15 years (mm)
Bambanglipuro	1898
Banguntapan	1902
Bantul	1626
Dlingo	1479
Imogiri	1528
Jetis	1611
Kasihan	1855
Kretek	1874
Pajangan	1857
Pandak	1868
Piyungan	1670
Pleret	1703
Pundong	1889
Sanden	1854
Sedayu	1916
Sewon	1888
Srandakan	1926
Average	1785

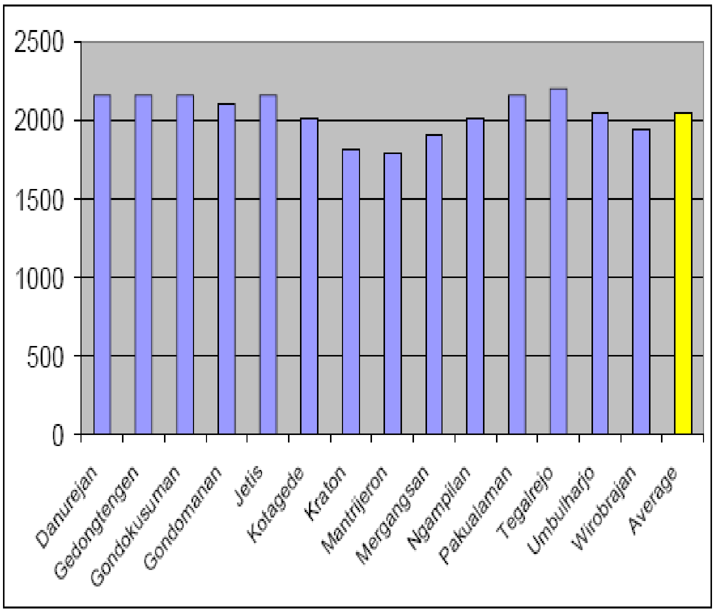


Figure 4.25: Rainfall depth (mm) average for 15 years (1987-2001) at each Sub-district of Bantul

The rain in Bantul is usually *convectional precipitation* rain. This type of rain is caused by the difference of heat accepted by the ground surface and by the air layer above the ground surface that keeps pushing the hot air to move higher until a certain height, in which the vapor forms drops and falls as rain due to the gravity. The type of convectional precipitation rain is usually characterized by rains of high intensity, relatively short period, and slightly narrow coverage areas.

4.3.3.3 Rainfall Trends

4.3.3.3.1 Trend of 15 Years

The trend analysis is used to find the direction of rainfall tendency during a certain period. Based on the results of the trend analysis, it can be seen whether the average rainfall tends to increase or decrease. In order to find the tendency, the moving average method is applied. In this research, the rainfall data used for the trend analysis come from the 15 year-data (1987-2001). Moreover, in order to see the trend condition in general, the linear analysis is used to find the direction tendency, whether it is up/increase or down/decrease.

The research on rainfall trend has often been done, both in a large scale (covering one country) and in a small scale (regency). A large-scale research of trends was done by Kirono (2005). Kirono conducted his research using three types of analysis covering qualitative, quantitative, and multi-decade aspects. The qualitative analysis on rainfall trends uses polynomial trend lines and the quantitative one uses Spearman-rank statistics while the analysis of multi-decade variation uses the 30-year moving average method.

According to the result of rainfall analysis conducted during 1975-1995, the rain happened in the rainy season and dry season tended to decrease. However, statistically, the decrease in the dry season was insignificant while in the rainy season, the decrease was significant. The rainfalls in Indonesia show the existence of multi-decade variation occurring in cycles of 30 years.

Anjalipan (2005) carried out small-scale rainfall research on "Variation of Rainfall at Urban Area and Non-Urban Area – A Case Study of Some Rain-Stations in Yogyakarta and Its Environs 2004". According to his studies, the average number of rainy days and the rain intensity was higher in urban areas in comparison to rural areas.

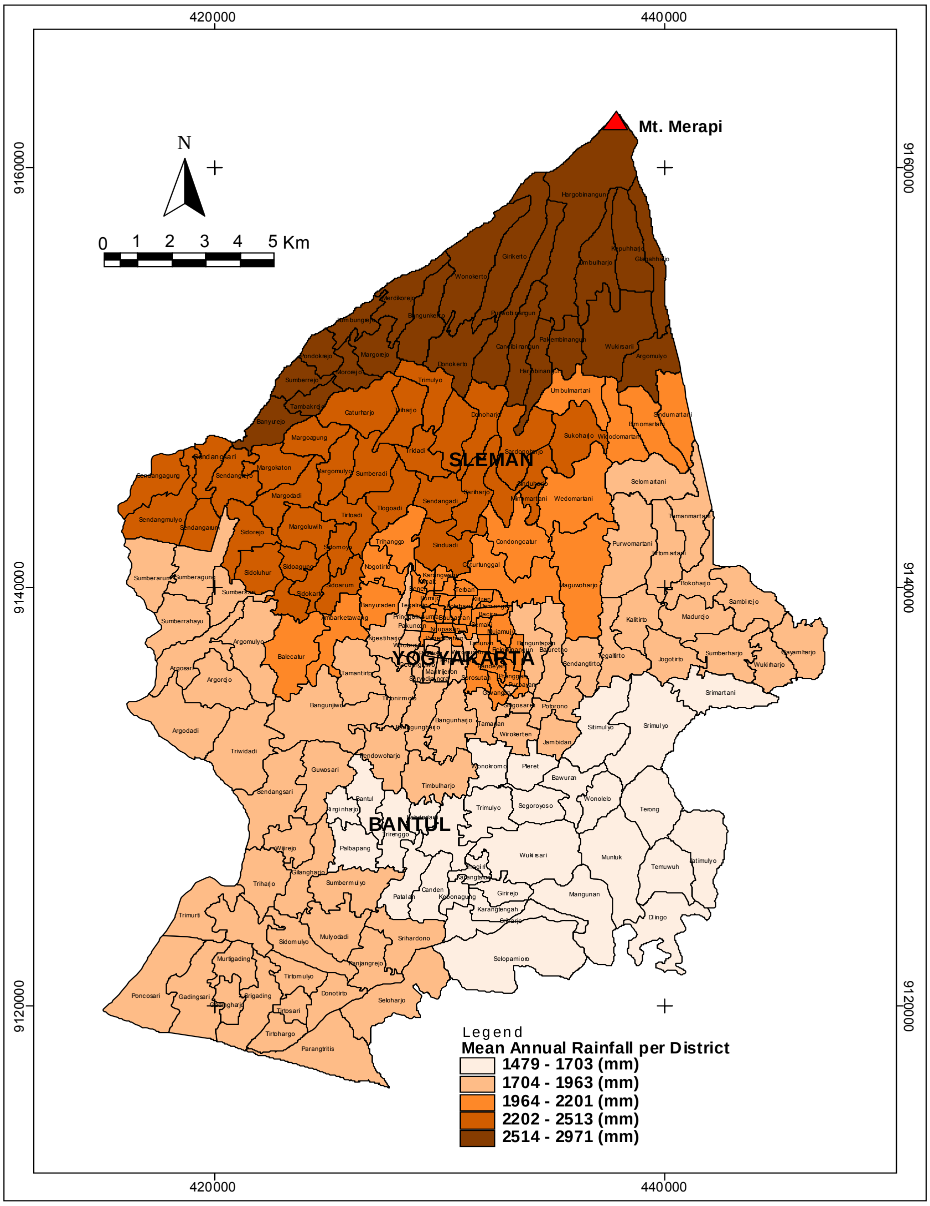


Figure 4.26: Annual rainfall map per Sub-district

The results of data analysis by the author, using the moving average, indicates that the annual rainfall during 15 years (1987 – 2001) in **Sleman** was quite fluctuating. During 1987 –

1992, the rainfall was under the annual average, while in 1999, the rainfall was above the mean value of annual rainfall.

The Polynomial line in Figure 4.27 shows that in 1987 – 1993, the polynomial line tended to go down, and from 1994 to 2001, it tended to go up with a quite clear pattern of its increasing level happening in 1997 – 2001.

The results of the same type of analysis showed the same pattern for **Yogyakarta** (Average annual rainfall 2,071 mm)**.** The results of analysis using the moving-average shows that the annual rainfall during 15 years (1987 – 2001) in was quite fluctuating. During 1987 – 1994 and in 1997, the rainfall was under the average annual rainfall, whereas in 2000, the rainfall was above the average annual rainfall. The Polynomial line in Figure 4.28 shows that during 1987 – 1994, the polynomial line tended to go down, and then from 1994 to 2001, the polynomial line tended to go up rapidly, with a quite clear pattern of its increasing level happening in 1994 – 2001.

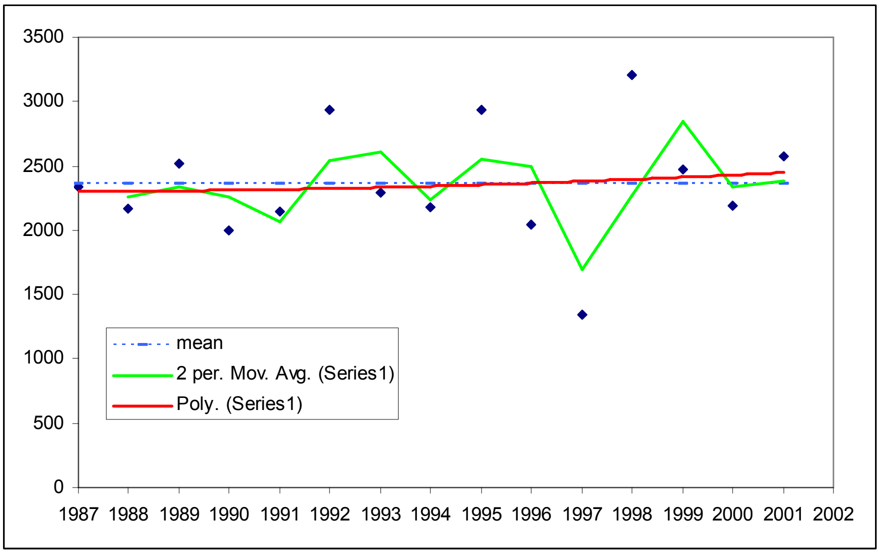


Figure 4.27: Analysis of annual rainfall trend for 15 years (1987 – 2001) in Sleman Regency using moving average method

Very similar results were achieved for **Bantul** (Average annual rainfall during 15 years 2,071 mm). Based on the moving average line, it can be seen that in 1987 – 1994 and in 1997, the rainfall was under the average, whereas in 1995 – 1996 and in 2000, the rainfall was above the average.

The Polynomial line in Figure 4.29 shows that during 1987 – 1994, the polynomial line tended to go down, and then in 1994 – 2001, the polynomial line tended to go up rapidly, with a quite clear pattern of its increasing level occurring in 1994 – 2001.

4.3.3.3.2 Rainfall Trends for Rainwater Management

The knowledge about the conditions of rainfall trends is very useful especially for planning rainwater management. The trend of rainfall at a certain location can be used for overcoming potential constraints. If the rainfall trend tends to increase, there will be much rainfall to be absorbed by the ground. This fact can cause two things; first, there will not be any water shortage because the supply, especially from the rainwater, is abundant and agricultural fields will not suffer from dryness. The second thing is there will be a surplus of rainwater supply that much rainwater becomes surface runoff and flows to the drainage channels. If the rain falls in a high intensity for a long time, it may cause floods because the drainage channels cannot accommodate the over-flown water; it means the rainwater is uselessly wasted.

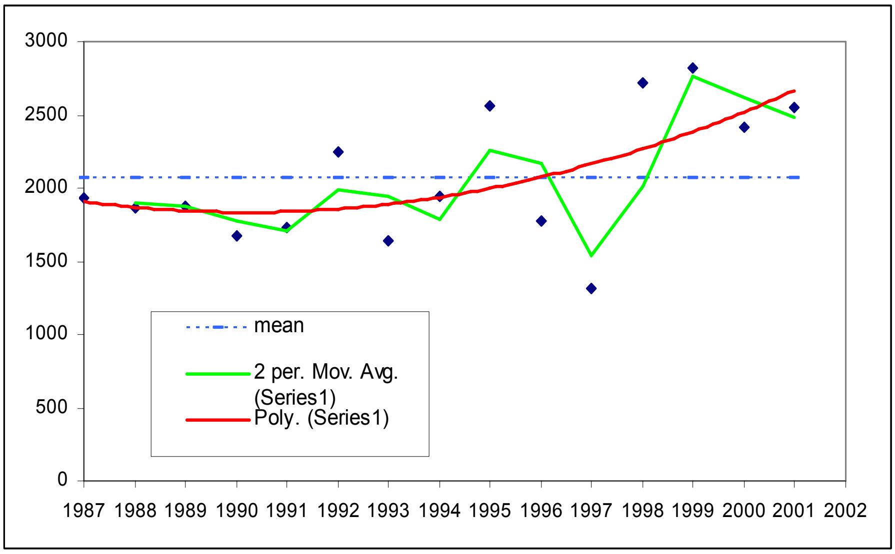


Figure 4.28: Analysis of annual rainfall trend for 15 years (1987 – 2001) in Yogyakarta City using moving average method

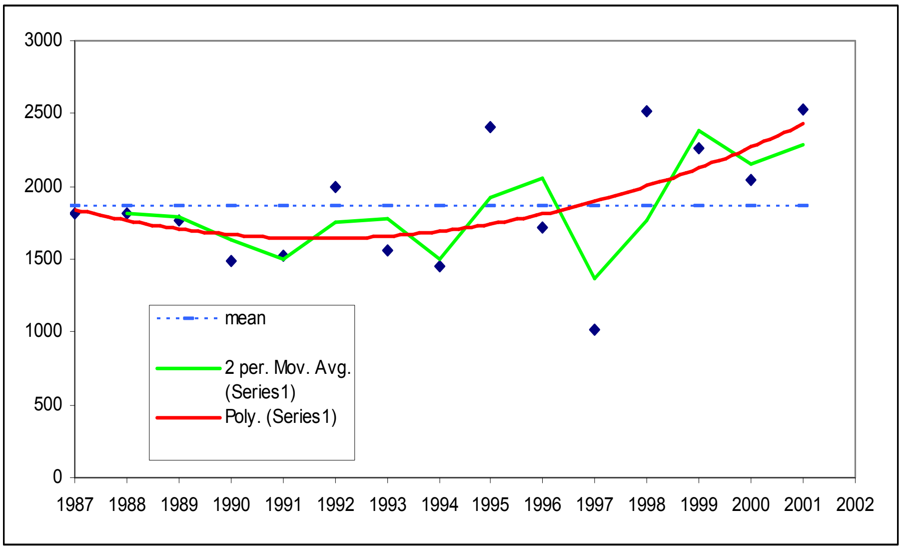


Figure 4.29: Analysis of annual rainfall trend for 15 years (1987 – 2001) in Bantul Regency using moving average method

As an illustration, there are two types of rain to be considered, they are: (1) short-term heavy rain with a quite large amount of around 100 mm during 1 – 2 hours; and (2) light/middle rain with a long duration of more than 6 hours and the amount of about 100 mm. The rainwater volume for the region of 1 square meter with the falling amount of 100 m equals 100 liter of falling rain. If the extent of the region is 25 square km or 25 million square meters; it means that the rainwater volume reaches 2.5 billion liters, falling from the sky to that region with the amount of 100 mm. For the short duration of time, the ability of the drainage will be limited only to accommodate the rainwater falling during 1 – 2 hours. Meanwhile, if the rain is falling in quite a long time with the water volume that may be accommodated by the drainage, the flooded area will not be as wide as the first region. Therefore, a careful reconsideration is needed to conduct the drainage design. It will be worse if there is a change in the beach characterized by reclamation, which will block the water and change the ecosystem, the pattern of weather and the local climate. All needs have to be carefully considered to make a more comprehensive planning and management of the flooded area.

The government is also expected to start their effort to socialize the construction of recharge wells in newly constructed or renovated houses. It is expected that at least one recharge well can be foreseen in those houses by setting 1 m^2 aside. At least, if the rain is falling, the rainwater will not directly flow to the drainage or sewage and will not flow to the river or finally be wasted to the sea. If each house has a recharge well, the rainwater can fill in shallow or even deep groundwater. Besides, for the purpose of water recharge, the surface of the well can also be used for planting various kinds of plants or flowers. Moreover, through the existence of water harvesting area and the act of making the absorption well, the seawater intrusion occurring especially in big cities like Jakarta, Semarang, and Surabaya will be retarded. The more the supply of shallow and deep groundwater in certain areas is, the larger the amount of seawater permeated to the area will be pushed back. However, with the further extraction of shallow and deep groundwater, the seawater will easily infiltrate into the aquifer that has run out of water.

4.3.3.4 El Niño and La Nina

4.3.3.4.1 General

El Niño is a natural phenomenon related to the anomaly of temperature of the sea surface of the Pacific Ocean that causes droughts in most parts of Indonesia. During the nineties, El Niño, which in Spanish means ‘little bo’, is the phenomenon of cold temperature that turns to warm temperature in a short time occurring at Christmas season. El Niño is a natural phenomenon that causes droughts, while La Nina means ‘little girl’. The natural change of La Nina is the contrary of El Niño. Up to now, the El Niño phenomenon is still as a mystery, because people still do not know the causes (Bureau of Meteorology Australia, 2001).

Based on the last 100-year experiences, the re-cycle of El Niño is taking place once every 2-6 years, and according to the records of BMG, the dry seasons that Indonesia has experienced during the last 20 years were in 1991, 1993, 1994, 1997, 2000, 2001, and 2003. The worst droughts caused by El Niño in Indonesia happened in 1991, 1994 and 1997 (Daly, 2000). The droughts started earlier and ended later than the dry season of the previous year, even the years of 1994 and 1997 were the longest droughts from the records in Indonesia. The anomaly degree or the duration is always different, and so are the early symptoms of its presence. Consequently, the long-term prediction of the presence of El Niño is still difficult (Kirono and Khakim, 1999).

According to them, the presence of El Niño can be categorized into the following forms:

1) Small anomaly with the condition that is not different from the normal condition,

2) Weak El Niño with a little drier condition than the normal condition,
3) Full El Niño in the form of longer and drier dry season if it is compared to that of the normal dry season.

According to the Meteorological and Geophysics Board analysis, the El Niño that happened in the early 2002 was a weak El Niño, which was included in category 1) or at least in category 2). However, the anticipation to face the emergence of El Niño is still necessary to be optimally strived.

In the last few years, starting in 2002-2005, in some regions of Indonesia especially in Western and Central Indonesia, there has been a series of natural disasters causing physically and none physically losses due to the extreme natural symptoms of weather and climate joined in the environment change that generally directs to the land and environment degradation. Starting with the emergence of typhoons at the end of November 2002, it was followed by the flood disaster that attacked Sumatra, Kalimantan (Borneo), and Java. Even, the capital city of the Republic of Indonesia, Jakarta, and its environs, had to face an early flood, which continued until the middle of the year. The dry season was characterized by a large number of fire disaster events and smoke pollution.

The wet condition of climate is characterized by flood or flash flood (*banjir bandang*) disaster and landslide. According to Kirono (2002), since many decades ago, certain trends are recorded by BMG such as:

1) The existence of El Niño and La Nina kept increasing. The longest El Niño was in 1991 – 1994, and El Niño with the highest intensity was in 1997-1998 and it has the faster increase than the previous record, even the latest El Niño appeared at the end of 2002. On the contrary, La Nina is less increased than the previous condition, specifically in the last 20th century.
2) The global pattern causes the change in the seasonal wind pattern in Indonesia and it has changed since 1991 until now, for example the tropical typhoon/cyclone, which appeared both in the Northern and Southern Indonesia, becomes smaller and tends to change from its normal pattern.
3) The consequence of the pattern is that the weather condition of both the rainy season and the dry season tends to change with the indication of longer dry season and shorter rainy season, or vice versa (Kirono and Khakim, 1999).

The indication caused by the population growth, the development of human technology, and the change in environment has flared. Global warming and climate change developed since the industrial revolution in 18th century, which is then aggravated by the deforestation of industrialized as well as Developing Countries.

4.3.3.4.2 Impact of El Niño and La Nina on Rainwater Management

The existence of El Niño will disturb the condition of natural climate. The presence of El Niño will lengthen the dry season and shorten the rainy season. This will disturb the hydrology cycle, which happens especially in the process of groundwater fulfillment. The little rainfall will cause several things, such as:

1) It will make the amount of groundwater supply smaller.

2) It will cause dryness in people's wells.
3) It will make the flow rate and the number of springs smaller.

This condition brings a burden for people, especially the poor who are very dependent on the natural condition to fulfill their need in the daily life. The existence of a longer dry season will disturb the process of rainwater keeping. The areas that have been known for their dry condition and in which the dwellers have got used to apply the pattern of rainwater keeping, such as Gunungkidul, Eastern Java, and Eastern Indonesia, will suffer more because the rainwater supply automatically decreases due to the long dry season and short rainy season. Even though the presence of El Niño is a bit difficult to predict, the previous symptoms can be detected, so people can prepare themselves to face it in order to minimize the impacts. From the earlier anticipation act, people can prepare to face the long dry season caused by El Niño, so they can prevent themselves from the worst condition of water shortage. One of the methods that can be used to anticipate is the method of rainwater harvesting.

4.3.3.5 Climate Types

The determining of climate type in the research area is based on the climate classification of Schmidt and Ferguson in Kirono (2005) by determining the value of Q that shows the comparison between the mean of dry months and wet months. The classification of climate according to Schmidt and Ferguson (1951) based on the score of Q is presented in Table 4.30. The counting result of the number of wet months and dry months is presented in Table 4.31.

The criteria that are used to determine wet months, humid months, and dry months are counted based on the classification from Koppen (1978) in Kirono and Khakim (1999) as follows: (1) Wet month: the rainfall > 100 mm/month, (2) Humid month: the rainfall is 60 – 100 mm/month, and (3) Dry month: the rainfall < 60 mm/month. The determining of rain type in a certain area according to Schmidt – Fergusson is based on the comparison of the number of dry months and wet months (Q). Its mathematic formula is:

$$Q = \frac{\text{Mean total dry months}}{\text{Mean total wet months}} \times 100\%$$

Table 4.31 shows that among 17 sub-districts located in Sleman, there are 14 sub-districts included in type C (fairly/quite wet), while the rest 3 have the type of climate B (wet). Table 4.32 shows that among 14 sub-districts located in Yogyakarta, there are 6 sub-districts included in type C (fairly/quite wet), while the other 8 have the type of climate B (wet).

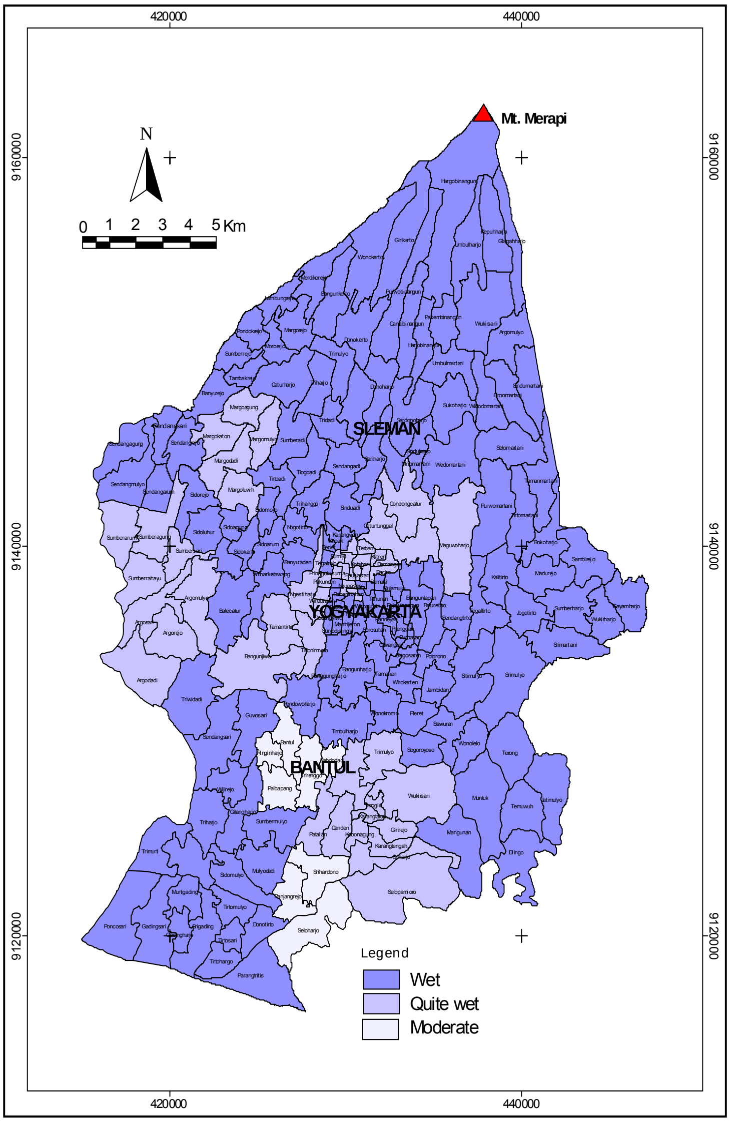


Figure 4.30: Spatial distribution of climate type in the study area (Source: analyzed from rainfall data 1987-2001 (Public Work Agency, 2002), and adapted from Kirono (2005))

Table 4.30: Climate category according to Schmidt and Ferguson

Category	Q (%)					Criteria
A	0	<	Q	≤	14,3	Very wet
B	14,3	<	Q	≤	33,3	Wet
C	33,3	<	Q	≤	60	Quite wet
D	60	<	Q	≤	100	Moderate
E	100	<	Q	≤	167	Quite dry
F	167	<	Q	≤	300	Dry
G	300	<	Q	≤	700	Very dry
H			Q	>	700	Extremely dry

Source: adapted from Kirono (2005)

Table 4.31: Climate types in Sleman Regency

No	Sub-district	Mean Annual Rainfall (mm)	Dry Months (month/year)	Wet Months (month/year)	Q (%)	Class	Season type
1	Berbah	2093	3	9	33.33	B	Wet
2	Cangkringan	2763	3	9	33.33	B	Wet
3	Depok	2252	4	8	50.00	C	Quite wet
4	Gamping	2637	3	9	33.33	B	Wet
5	Godean	2360	3	9	33.33	B	Wet
6	Kalasan	2215	3	9	33.33	B	Wet
7	Minggir	2866	3	9	33.33	B	Wet
8	Mlati	2444	3	9	33.33	B	Wet
9	Moyudan	3254	4	8	50.00	C	Quite wet
10	Ngaglik	2776	3	9	33.33	B	Wet
11	Ngemplak	2641	3	9	33.33	B	Wet
12	Pakem	2959	3	9	33.33	B	Wet
13	Prambanan	2161	3	9	33.33	B	Wet
14	Seyegan	2353	4	8	50.00	C	Quite wet
15	Sleman	2647	3	9	33.33	B	Wet
16	Tempel	2561	3	9	33.33	B	Wet
17	Turi	2901	3	9	33.33	B	Wet

Source: analyzed from rainfall data 1987-2001 (Public Work Agency, 2002), adapted from Kirono (2005)

Table 4.33 describes that among 17 sub-districts located in Bantul, there are 11 sub-districts included in type B (wet), 3 sub-districts are included in type C (fairly/quite wet), while the rest 3 have the type of climate D (moderate).

Table 4.32: Climate types in Yogyakarta City

No	Sub-district	Mean Annual Rainfall (mm)	Dry Months (month/year)	Wet Months (month/year)	Q (%)	Class	Climate type
1	Danurejan	2412	4	8	50	C	Quite wet
2	Gedongtengen	2412	4	8	50	C	Quite wet
3	Gondokusuman	2412	4	8	50	C	Quite wet
4	Gondomanan	2370	4	8	50	C	Quite wet
5	Jetis	2412	4	8	50	C	Quite wet
6	Kotagede	2738	3	9	33.33	B	Wet
7	Kraton	2140	3	9	33.33	B	Wet
8	Mantrijeron	2127	3	9	33.33	B	Wet
9	Mergangsan	2352	3	9	33.33	B	Wet
10	Ngampilan	2300	3	9	33.33	B	Wet
11	Pakualaman	2412	3	9	33.33	B	Wet
12	Tegalrejo	2731	3	9	33.33	B	Wet
13	Umbulharjo	2892	3	9	33.33	B	Wet
14	Wirobrajan	2385	4	8	50	C	Quite wet

Source: analyzed from rainfall data 1987-2001 (Public Work Agency, 2002), adapted from Kirono (2005)

Based on the discussion above, it can be seen that almost all of the Sleman areas are included in the criteria of wet-area since their rainfalls are more than 100 mm/month, and only a small part of it is included in the type of quite wet area, specifically those located in Southern Sleman. For the climate/weather types in Yogyakarta, most of the areas are included in the wet type, but in some parts of Northern and Southern Yogyakarta, the climate type is of quite wet. The climate types in Bantul are divided into 3 types: quite wet type in Western, a part of central, and a part of Eastern Bantul; medium type in central and a part of Eastern Bantul, while the rests are included in the wet type. The spatial distribution map of the climate types is represented in Figure 4.30.

Table 4.33: Climate types in Bantul Regency

No	Sub-district	Mean Annual Rainfall mm)	Dry Months (month/year)	Wet Months (month/year)	Q (%)	Class	Season type
1	Bambanglipuro	2769	3	9	33.33	B	Wet
2	Banguntapan	2446	3	9	33.33	B	Wet
3	Bantul	2089	5	7	71.42	D	Moderate
4	Dlingo	2085	3	9	33.33	B	Wet
5	Imogiri	2021	4	8	50	C	Quite wet
6	Jetis	2212	5	7	71.42	D	Moderate
7	Kasihan	2208	4	8	50	C	Quite wet
8	Kretek	2938	3	9	33.33	B	Wet
9	Pajangan	2512	3	9	33.33	B	Wet
10	Pandak	2940	2	10	20	B	Wet
11	Piyungan	1795	3	9	33.33	B	Wet
12	Pleret	2568	3	9	33.33	B	Wet
13	Pundong	2657	5	7	71.42	D	Moderate
14	Sanden	3022	3	9	33.33	B	Wet
15	Sedayu	2412	4	8	50	C	Quite wet
16	Sewon	2703	3	9	33.33	B	Wet
17	Srandakan	3140	3	9	33.33	B	Wet

Source: analyzed from rainfall data 1987-2001 (Public Work Agency, 2002), adapted from Kirono (2005)

4.4 Storm Runoff by CN (Curve Number) Method

4.4.1 General

Regarding the water resources management, surface runoff plays an important role in the hydrologic cycle in a certain watershed system together with infiltration, evaporation, and transpiration. The analysis of runoff is usually based on watershed response to rainfall. The response in general is influenced by land use, physical characteristics of the watershed (e.g. topography and type of land), and rainfall characteristics.

Vegetation can increase soil's permeability rate with its roots. Plant roots loosen the soil, creating more voids. Roots, therefore, can also form points of entry for water to seep into the soil as well as create defined routes with minimal obstructions (El-Shafei, 1994). Roots also remove water from the soil, allowing the voids to fill a new and hence allowing more water to be absorbed by the soil. The exact rate at which the runoff is reduced depends on the type of vegetation. Trees can have a much larger effect on draining near-surface soils, thereby increasing infiltration and reducing storm water runoff when compared to grass. This is because trees have a larger, deeper root structure and therefore create more passageways for water. Trees also consume a larger amount of water. The same concepts apply to larger forms of vegetation such as bush (Field, 1993).

During urbanization impervious surfaces, however, replace vegetation to a large extent and reduce or eliminate the infiltration and transpiration processes. By changing the temperature regime of an area, impervious surfaces also alter evaporation. Anyone who has seen or felt a road surface on a hot day, and compared this with the temperature of an adjacent vegetated area can attest to this simple comparison. The two primary components to imperviousness are the rooftops under which humans live, work, or shop, and a transportation system consisting of roads, driveways, and parking lots (Ward and Elliots, 1995). These impervious surfaces either eliminate or allow only a negligible amount of infiltration, converting most of the precipitation that falls on impervious surfaces to surface runoff. The runoff is in most cases diverted directly to a drainage system such as a storm sewer or drainage pipe (El-Shafei, 1994). If the impervious surface is disconnected, then the runoff flows off, contributing to floods.

Slope is another factor that can have an impact on storm water runoff. Initially, slope has little influence on the creation of surface runoff. Rainfall will seek the most direct route from the atmosphere to the lowest point in the watershed. With voids present in the soil, water will percolate vertically through the soil before moving laterally over a steep slope until it reaches a retention point. Slope, therefore, does not contribute significantly to surface runoff quantities. However, it does have a large influence on the movement and velocity once the soils' infiltration capacities are reached. Slope can accelerate the movement of surface runoff and direct it towards low-lying points where it accumulates until it is intercepted or infiltrated. A hillside's aspect does not contribute to the generation of runoff. However, it does influence where the runoff will flow (Ward and Elliot, 1995). For this reason, the aspect and slope of the topography throughout the study area are not included in the analysis.

When calculating runoff volume, traditional hydrologic methods rarely focus on assessing the long-term hydrologic impact of land use change (Pierre, 2002). Instead, such methods typically focus on "design" events. However, for effective water resources management, it is necessary to perform long-term simulations because much of the runoff from urbanized watersheds originates from smaller intensity, high frequency storms.

Some methods that have been generally used to calculate the runoff by applying the complex way are the approach of infiltration, the Rationale method, the Hydrograph method, the Cook method, and the CN method. Other methods, besides what have been mentioned, are the empirical formulations to calculate the flow rate of flood, which is based on the correlation between one or two variables that are closely related to flood (Shaw, 1994). Those formulations, for example that are based on their creators, are the formulations of Whistler, Pangliaro, Inglis, Ryues, Bransby-Williams, U.S. Geological Survey, Myer, Baird & McIlwraith, and Fanning. Usually, those formulations use the extent of the watershed area as their input data, which can be changeable.

The most popular method in calculating the size of the peak runoff is the rationale method. The characteristics of rainfall, the time of concentration, and the land use are the parameters to be used. The assumptions used in the rationale method, according to Chow (1974) are:

1) The result of the surface runoff for all of the rainfall intensity will be maximum if the intensity is equal to or longer than the time of concentration.
2) The maximum runoff resulting from rainfall intensity, with the same duration or bigger than the time of concentration is a simple part of the rain intensity. Thus, it is assumed that there is a

linear relationship between the rate of flow and the intensity. The rate of flow is equal to 0 when the intensity is equal to 0.

3) The frequency of peak runoff is equal to the rainfall intensity for the given time of concentration.
4) The relationship between the peak runoff and the extent of the watershed is equal to the relationship between the duration and the intensity of rainfall.
5) The coefficient of the surface runoff is equal to the rainfall event in various frequencies.
6) The coefficient of the surface runoff is the same as each rainfall event in a watershed.

Those assumptions, in several conditions, will decrease the validity of the result of the gained surface runoff. Besides, the resulted value of runoff is the value of the peak runoff, so it is probably not the value of the actual runoff taken from an event of rainfall. In order to decrease the use of too many assumptions, this research uses the Curve Number (CN) method. This method uses the parameters of precipitation, land use complex, the condition of soil hydrology, and the condition of soil humidity.

The SCS (Soil Conservation Service) Curve Number (CN) method was developed by the United States Department of Agriculture Soil Conservation Service (USDA, 1986). This method is widely accepted and has been applied to situations ranging from simple calculations of runoff from small watersheds to use in comprehensive hydrologic models (Arnold et al., 1995). The CN method has also been used within GIS application (Engel, 1997).

This method is used to calculate the surface runoff based on single rainfall events. The usage of CN method assumes that the surface runoff will be similar to its real condition due to the amount of potential infiltration. Therefore, there is not always a surface runoff resulting from a certain extent in every rainfall event. However, the CN method has a weakness, i.e. its parameter for determining the curve number still depends on the assumption and subjectivity of its user. The determination of the condition of soil hydrology is still limited to the condition of the soil texture with only several variations, although it is still possible to conduct the infiltration approach. The determination of the curve number also still depends on the subjectivity in determining the condition of hydrology and the conservation in a land use complex.

The calculation of runoff in a certain period relating to the current land use will help the analysis process of determining the runoff portion that can be exploited and the runoff as the component of surface water. Most of the predictions on the actual runoff caused by the rainfall can be accommodated by this method correlating to the existing land use. Water balance model, which includes precipitation, runoff, evapotranspiration, infiltration, and the land use data, will give an overview on how to manage the rainwater in order to have sustainable water resources in a region.

4.4.2 Methodology

The SCS-CN methodology is based primarily on the curve number, which is a constant representative of the major runoff-producing watershed characteristics: hydrologic soil groups, land use, surface treatment, and hydrologic surface condition of native pasture (e.g. good, fair, and poor) (Mishra et al., 2003). Curve Numbers provides a table of curve numbers used by the SCS method.

In the past, the SCS-CN methodology has been used for a variety of purposes. The main reason why the methodology was created was to evaluate the hydrological status of a watershed. The method can also be used to calculate annual runoff by using annual rainfall (Mishra et al., 2003). Determining pollutant load for micro urban watersheds is another use for the SCS-CN methodology.

There are many advantages of the SCS-CN methodology. The SCS-CN methodology is a simple conceptual method for estimating surface runoff based on average rainfall amounts. It requires basic data, and it is recommended for small sub-watersheds. Sub-watersheds are the primary unit of analysis when allocating a curve number and produce accurate results when the watersheds are uniform in land use. It is well adapted to showing differences in runoff due to changes in land use, soil type, and soil cover, thus limiting data needs to these three factors (Mishra et al., 2003). A composite method of applying the SCS-CN methodology is based on watersheds that are not homogenous in land use. This method uses a weighted curve number versus a general curve number. A weighted curve number is calculated by taking the percentage of the watershed that is a particular land use and multiplying the curve number for that land use by that percentage (Arsyad, 1999). For instance, if 20 percent (20%) of a watershed has a land use with a corresponding curve number of 90, and the remaining 80 percent (80%) has 78 as a curve number, the composite curve number for the watershed would be (90 x 0.2) + (78 x 0.8) = 80.4.

The basic assumption of the SCS curve number method is that, for a single storm, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall. This relationship, after algebraic manipulation and inclusion of simplifying assumptions (USDA-SCS, 1986), where CN represents a convenient representation of the potential maximum soil retention, S (Ponce and Hawkins, 1996) is:

$$Qv = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where: Q_V = runoff depth (mm)
P = rainfall depth (mm) and $P \geq 0{,}2S$
S = potential infiltration (mm)

$$S = \frac{25400}{CN} - 254$$

CN = curve number value

Although usually considered to be a model for predicting surface runoff, "direct flow" (Q) also includes subsurface flow or interflow (USDA, 1986). The method was developed to predict the initial or "quick" response of a watershed outlet to a storm event. In general-watersheds, total outlet response may be the sum of base flow or water flowing directly in through the sides and surface runoff. Conceptually, the SCS method could be applicable to such watersheds, with possible modification of the following:

1) Curve Number (CN) value is used to estimate potential maximum soil retention (S). Values are tabulated in Table 4.36 for various land covers and soil textures.

2) Fraction of potential maximum retention (S) is associated with initial abstractions (*Ia*). Initial abstractions are water losses (such as plant interception, infiltration, and surface storage), which occur prior to runoff and are thus subtracted from the total rainfall available for soil retention or quick response (USDA, 1986). The standard assumption is that Ia = 0.2S (USDA, 1986). The "0.2" was based on watershed measurements with a large degree of variability and other researchers have reported using values ranging from 0.0 to 0.3 (USDA, 1986, Ponce and Hawkins, 1996). The original estimates of *Ia* were determined by subtracting rain that fell prior to the beginning of watershed outlet response from the total rainfall (USDA, 1993).
3) Accounting for watershed wetness prior to the storm event of interest (antecedent moisture condition, AMC); curve number can be adjusted to estimate less runoff under dry conditions and more runoff under wet conditions (USDA, 1993).

Subarkah (1990) gave the CN method as an alternative in the calculation of runoff if there is not any data of flow in a certain area. Subarkah presents the CN value that is directly adopted from the U.S. SCS. The CN method is used to calculate the surface runoff by using the data of single rainfall, soil texture, and land use. However, it is also affirmed that the method has to be calibrated before being applied in the areas outside the United States of America. Thus, a conclusion can be drawn, i.e. the examination towards the runoff resulting from the application of CN method is needed to conduct, by using the comparison resulting from the runoff that uses the real data, in this case it covers the data resulting from the AWLR (automatic water level recorder).

Arsyad (1999), in his book entitled “Conservation of Land and Water”, gave a method for calculating the runoff using the CN method adopted from the U.S. SCS. The CN values, which are presented, are the values directly adopted from the table presented by the U.S. SCS. The CN method that is intended to calculate the runoff on the farm area has been adopted to apply to the settlement area, which is indicated by the existence of the land use complex in the form of settlement area, industrial area, shopping complex, and even highway. It is an analogue for paved-building areas.

Asdak (2007) presented the calculation of the runoff thickness taken from the watershed of Jatigede, West Java conducted by EXSA and ECI based on the amount of rainfall applying the CN method. That research used the land use complex in the form of farmland that has a good contour and has a planted-soil with a good category. The CN values used were directly taken from the table of CN value based on the land use complex from the U.S. SCS. It is also stated that the runoff value resulting from the calculation based on the CN method that has been conducted has the difference level up to 10% of the runoff value resulting from the observation (using the AWLR data). The flow of study methodology can be seen in Figure 4.31.

The data used in the calculation of the surface runoff using the Curve Number covers:

1) The daily rainfall data in 1998, 1999, 2000, 2001 as the input for the curve number model that is used and the input to determine the condition of the previous soil humidity (AMC),
2) The AWLR (automatic water level recorder) data in 1998, 1999, 2000, and 2001, as a calculation-base of the river flow rate on the selected watershed,
3) The map of land use resulting from the LANDSAT TM image interpretation in 2000 to be converted into the form of land use complex using the U.S. SCS method,

4) The semi-detailed map of soil in the scale of 1: 50,000 in order to know the spatial distribution of the soil texture and it is used as the parameter in determining the condition of the soil hydrology.

The previous water content influences the volume and the speed of the flow. Considering the important influence of that factor, the U.S. Soil Conservation Service arranges three kinds of condition of the previous water content coverage (Arsyad, 1999).

The determination of the AMC is done by using the data of 5-day rainfall before the calculation day. For example, the runoff calculation will be held on 6^{th}, thus the AMC is counted by adding up the rainfall occurring on date 1, 2, 3, 4, 5. The adding result then is classified based on the SCS classification (Table 4.34).

The condition of the soil hydrology is determined by using the soil texture as its parameter. The soil texture data are gained from the semi-detailed soil map, i.e. the soil map with the scale of 1: 50,000 that consist of clayey soil, clay, and sand. Arsyad (1999) stated that the classification of the soil hydrology condition is done by using the classification of the U.S. SCS method (Table 4.35).

The land use complex is determined based on the land use in the study area which then is classified based on the land use complex that applies at the U.S. SCS method by considering the condition of hydrologic factor of every land use extent (Arsyad, 1999, Chow, 1974). Arsyad also stated that the use of farmland is often divided into given treatments or actions, such as the planting based on contour or the terrace making. This division shows its potential influences on the surface flow. The condition of hydrology reflects the level of the land cultivation that is divided into bad, average (medium), and good.

The curve number value is determined using the classification table of the curve number value. In that table, the curve number value is determined on AMC II, then the recorded values are converted in the equivalent table of the curve number value at the condition of AMC I and III for the extent at the condition of AMC I and III. Meanwhile, the steps taken in order to determine the speed of the potential infiltration are following the certain formula. Then, runoff depth of the research area is calculated by using weighted average system.

Table 4.34: AMC condition

AMC	**Characteristics**	**Rainfall prior to 5 days (mm)**
AMC I	Dry soils but not to the wilting point	< 35
AMC II	Average soil moisture conditions	35 – 53
AMC III	Wet soils with high runoff potential	> 53

Source: SCS (1972), USDA (1986), Arsyad (1999)

Calibration is a process to adjust the CN method into the scope of a research area. This calibration is done by comparing the curve number based on the US SCS assumption with the curve number that is considered as in accordance with the assumption existing in the research area. Here, some variables that influence the curve number value are adjusted to the condition of the watershed in the area through trial and error process, until the time when the curve number value is considered as very close to the result that is regarded as true. After that stage has finished, the optimization of the surface runoff is done by comparing it to the surface runoff resulting from the AWLR (automatic water level recorder).

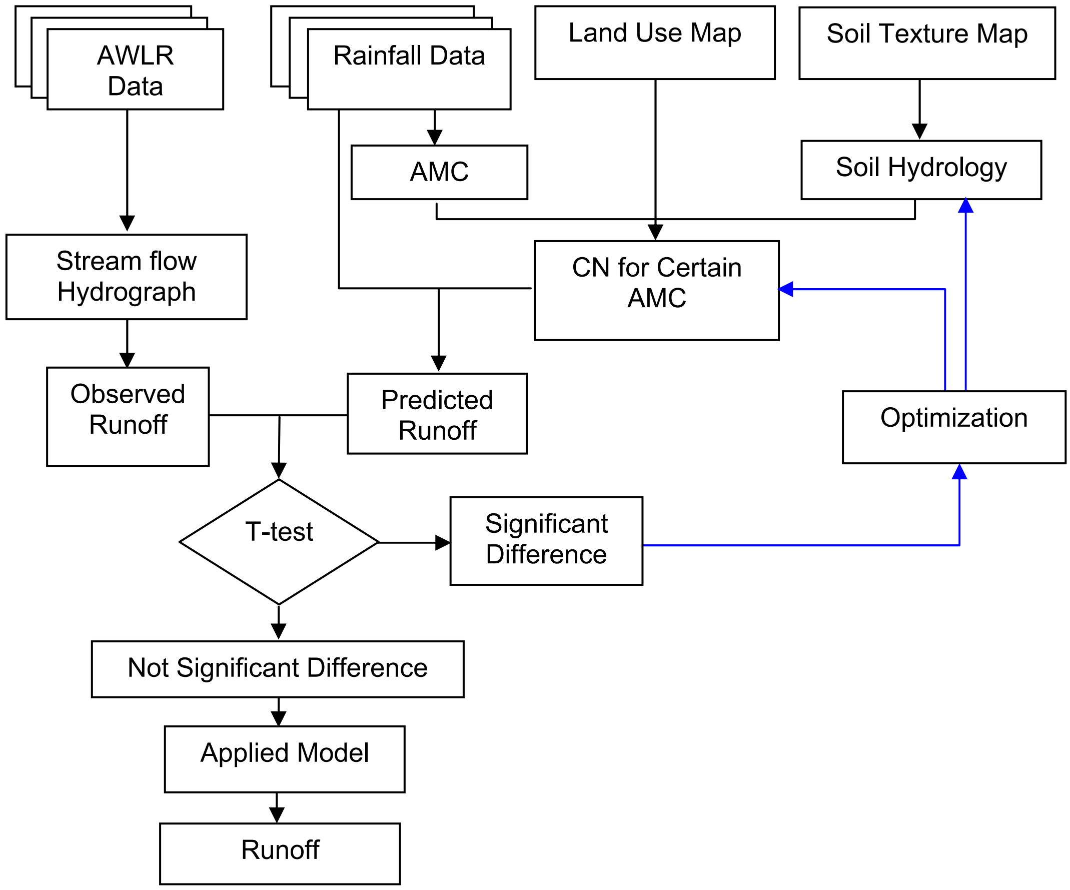


Figure 4.31: Flow of work for the runoff analysis by CN method

Table 4.35: Characteristics of hydrologic soil groups

Soil Group	Characteristics	Minimum Infiltration Capacity (in/hr)
A	Sandy, deep, well-drained soils, deep loess, aggregated silty soils	0.30–0.45
B	Sandy loams, shallow loess, moderately deep and moderately well-drained soils	0.15–0.30
C	Clay loam soils, shallow sandy loams with a low permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05–0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water-logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00–0.05

Source: SCS (1972), USDA (1986), Arsyad (1999)

4.4.3 Data Analysis and Results

The CN method is used for calculating the runoff in Sleman, Yogyakarta, and Bantul. Before conducting the runoff calculation, the CN value to be used is first examined based on the runoff flow-rate debit resulting from the AWLR at five stations of AWLR (Padokan, Papringan, Pogung, Gadjah Wong, and Pulo). The differed-test can be applied on the runoff resulting from the use of the CN method by using the actual runoff applied together with the method of the flow hydrograph. It is assumed that the runoff resulting from the flow hydrograph based on the AWLR data is the most correct result, so it is possible that there will be a change in the CN value by referring to the resulted runoff. The way of trial and error is done in order to get the result of the predicted runoff, which is not very different from the runoff resulting from the observation process.

The assumption is that the curve number value resulting from the observation is the correct value so that it can be compared to the curve number from the prediction. Consequently, the tentative curve number value can be considered as true if it approaches or even is the same as the comparing curve number. The determination of the curve number value is done by using the range value remaining at the two complex of the land use assumed as having the same characteristics. For example, the dry land cultivation and the fallow land are possibly to be classified in their classification, but, from the view of runoff, they are the same in fact.

4.4.3.1 Land Use Complex

The CN value is gained by referring to the use of land in the research area and adjusting them to the available table of the CN method based on the land use complex. The changing of the land use data into the land use complex is done by using several ways, i.e. 1) examining references of several previous research studies, 2) using the consideration on the land use type, specifically that of the vegetation which is considered as being dominant, and 3) using the element of the position of the land use.

The data resulting from the interpretation of the ETM-LANDSAT image allow 10 types of the land use, covering the forest, homogenous forest, mix plantation, wet land cultivation, dry land cultivation, settlement area, airport complex buildings, sandy-land and pyroclastic to distinguish. Those types of land do not exist in the classification of the land use complex, thus the adjustment step is necessary to conduct. This step is meant to ease the research process if the t-test gives an insignificant result, which means that it requires optimization.

The forest resulting from the interpretation is adjusted to the type of leguminous trees densely planted along the contour of the slope, while the homogenous forest is adjusted to the type of leguminous trees planted uphill. It is assumed that the contour-planted forest results in less runoff than the homogenous one, in spite of the fact that the location of the contour-planted forest is on the steeper part of Merapi Mountain while the homogenous forest lies on the lower slopes and it is usually a plantation-forest.

Mixed cropping is found on dry farmland, which is planted with various types of annual plants or the combination of permanent and annual plants, so that it is difficult to differentiate them (Maryono, 2005). The mixed cropping resembles the contour-planted leguminous trees, which contribute to soil and water conservation. The assumption taken is that the farmlands in Sleman District, Yogyakarta Municipality, and Bantul District already use the terrace system, apply irrigation and drainage system. Correspondingly, the wetland cultivation resembles the paddies practicing a good contour and terrace system.

Sawah is a wet farmland, which is planted with seasonal crops, i.e. paddy and *palawija* (crops planted as second crop in dry season). The use of land as a *sawah* takes the biggest portion in the research area. The deviation in determining the CN value is possible to occur on the assumption that the *sawah* has been planted, the *sawah* is planted with *palawija*, and/or the *sawah* has just been watered.

Tegalan is a dry farmland, which is planted with seasonal plants, including paddy, which are permanently planted (Sandy, 1987 in Maryono, 2005). Similar to the use of land as a *sawah*, the deviation in determining the CN value occurs because there is a different assumption between the seasonal crops or *palawija* and *sawah.*

The fallow land (*bera)* on slopes resembles critical land near the Peak of Merapi Mountain. Fallow land is usually uncultivated land containing pyroclastic material.

Settlement area is considered as an area containing a small part or almost entirely area of the impervious part by buildings. This consideration is taken because the settlement areas existing in Sleman and Bantul usually only result in big runoffs that cause the blocking, the hardening of the house yard, or the designing of the roof-placement that only leaves a small opened-room.

In this research study, there are 5 types of settlement area, but in fact, it is difficult to divide them into those 5 categories. It is caused by the small size/grade of the resolution of the LANDSAT TM image in presenting their appearances on the earth surface (1 pixel = 30m x 30m). With such resolution, the appearance of several houses on a land use cannot be interpreted in details. To overcome the problem, then, it is through conducting the approach based on the amount of the dwellers and the extent of the settlement area in order to get the population density in a certain settlement area. The determination of the curve number value, temporarily, is still assumed on an extent of house with the comparison of its extent of building and its total extent of land.

The airport building, also included the landing strip is categorized as an area that has 98% part containing impervious material. It is assumed that the use of such land will give 98% of the amount of rain as the runoff for any condition of the soil hydrology.

4.4.3.2 AMC Conditions

The determination of the AMC conditions in the research area is done based on 47 rainfall stations, which accommodate the daily rainfall data in 2000. Generally, the condition of AMC I mostly existed during the dry seasons and in the dry areas, in South and East Bantul, however, it may occur in the wet-months. Table 4.37 is an example in identifying AMC.

To match the curve number value including the condition of AMC II with the curve number value (CN) of AMC I and AMC III the following ways can be chosen to conduct:

1) Using the resemblance table of the curve number for AMC I and AMC III.
2) Using the mathematical formulation as follows: (Asdak, 2007, Arsyad, 1999)

$$\text{CN I} = \frac{4{,}2 \text{ x CN II}}{10 - (0{,}058 \text{ x CN II})}$$

$$\text{CN III} = \frac{23{,}7 \text{ x CN II}}{10 + (0{,}13 \text{ x CN II})}.$$

4.4.3.3 Soil Hydrology

The soil texture is the main component in determining the group of the soil hydrology in a certain area. The usual approach conducted to support the determining of the soil hydrology is the infiltration value that is done to overcome the selection of the group of the soil hydrology, which is considered as not too detailed. However, there are some difficulties arising during the measurement of the infiltration value, those are the fact that the measuring is needed to conduct when the soil is not saturated with water and the infiltration value is the value gained at the time of measuring so that it is better to conduct the infiltration through the laboratory test. However, the determination of classes of the soil hydrology that only uses the soil texture data is regarded as quite valid considering that there are not any data of infiltration.

The soil texture in the research area covers 10 types, adding by one extent of area that is considered as having no soil texture because it consists of limestone (Figure 4. 32). In some locations, the data of the soil texture are not available (Figure 4.33) because the existing lands are used as settlement area, thus the determination of the real soil as a sample is difficult to conduct. The way to overcome such problem is by conducting a fast survey on the soil texture on the field or using the extrapolation, the consideration on the river stream flow, the topography in the research area, and the characteristics of the soil granules.

The grouping of the soil hydrology classes in the research area changes after it passes the optimization phase and calibration of the CN components. The groups of the soil hydrology that are used in the stage of calculating the amount of runoff are Group B to Group D. The changing of these groups is caused by the increasing classes of every soil hydrology group that each of them increases one class. This fact is as the result of the optimization and the calibration of CN method based on the runoff resulting from the AWLR. Special for Group D, these classes of group cannot be increased because they are considered as the highest class.

4.4.3.4 CN Based on Land Use Complex

In general, the CN value of every land use complex has been shown in details by the U.S. SCS. The problem that will possibly emerge is the validity of the CN value if it is applied in the areas outside the United States of America. The method of the statistical test with the comparing-test is considered as the best way to overcome that problem. The test is done by comparing the runoff resulting from the application of the CN method with the runoff resulting from the measuring of the AWLR. The significance level of those two compared data becomes the evaluation-base for the validity of the CN values, whether they are valid to be applied in the research area or not.

The optimization is done through the way of trial and error conducted on the CN values; therefore, it can produce the CN value that results the runoff with a high significance level compared to the actual runoff from the AWLR method. Calibration also can be conducted trough the way of trial and error, on the components of the CN method for determining the AMC and the soil hydrology group.

The first CN value is shown in Table 4.38 in which the type of the land use complex, which is not exactly the same as the table of U.S. SCS. The resemblance of the land use type is done because there are many similarities of the criteria of both vegetation and non-vegetation.

Using the CN value, then, it is possible to calculate the runoff using the rainfall data, which have the same time with that of the runoff resulting from the AWLR (automatic water level recorder) for the same five watersheds. If it is viewed from the side of the differed-test result and the calculation on the relative-deviation, it can be said that there is still a significant difference between the runoff resulting from the observation and the predicted runoff. The optimization is necessary to conduct in order to change the CN value so that the runoff result will be considered as non-real different. The optimization using the way of trial and error that results in the CN value of the land use type is shown in Table 4.39.

4.4.3.5 Field Verification

The CN Method was developed using three basic data, comprising land use complex, soil texture, and rainfall data. In this study, the land use complex, which is interpreted from LANDSAT TM images, can be categorized into ten (10) types of land use covering forest, homogeneous forest, mixed farms, wetlands, uplands, settlements, civil structures or buildings, sand areas, and uncultivated lands (pyroclastics).

The land use complex of settlements is divided further into some class categories in order to have more detailed runoff. The applied method classifies the settlement areas based on the percentage of water resistant areas against the total settlement area. In general, any settlement does not merely consist of buildings, but it varies from area that is fully covered by buildings to area that is not yet developed.

In order to have best assumption of field parameters, the classification of the settlement follows the SCS method. It is categorized into five (5) classes, with slight modifications applied, according to the general condition of the study area and the population density as the supporting data (Table 4.40). The five (5) classes of CN method for land use complex for the settlement are:

1) Settlement for class 1 assuming that the population density is less than or equal to 7500 persons/square kilometer with CN value:
   a) Settlement with soil hydrology A, the value of CN = 61
   b) Settlement with soil hydrology B, the value of CN = 75
   c) Settlement with soil hydrology C, the value of CN = 83
   d) Settlement with soil hydrology D, the value of CN = 87
2) Settlement for class 2 assuming that the population density is between 7501 – 8000 persons/square kilometer with CN value:
   a) Settlement with soil hydrology A, the value of CN = 77
   b) Settlement with soil hydrology B, the value of CN = 85
   c) Settlement with soil hydrology C, the value of CN = 90
   d) Settlement with soil hydrology D, the value of CN = 92
3) Settlement for class 3 assuming that the population density is between 8001 – 8500 persons/square kilometer with CN value:
   a) Settlement with soil hydrology A, the value of CN = 81
   b) Settlement with soil hydrology B, the value of CN = 88

c) Settlement with soil hydrology C, the value of CN = 91

d) Settlement with soil hydrology D, the value of CN = 93

Table 4.36: Runoff curve figures for hydrologic soil-land use complexes (for watershed condition II and $I_a = 0.2S$)

No	Land use/Characteristic/Hydrologic Condition	Hydrologic Soil Group			
		A	B	C	D
1	Settlement				
	Land area: **Paving average (%)**				
	- ≤ 500 m^2 65	77	85	90	92
	- 1000 m^2 38	61	75	83	87
	- 1300 m^2 30	57	72	81	86
	- 2000 m^2 25	54	70	80	85
	- 4000 m^2 20	51	68	79	84
2	Asphalt parking area, roof, asphalt road, etc	98	98	98	98
3	Road:				
	- asphalt with drainage system	98	98	98	98
	- gravel	76	85	89	91
	- soil	72	82	87	89
4	Commercial area (85% impervious)	89	92	94	95
5	Industrial area (85% paving)	81	88	91	93
6	Open space, meadow, park, golf area, grave, etc:				
	- good condition: > 75% grass cover	39	61	74	80
	- medium condition : 50%-75% grass cover	49	69	79	84
7	Fallow, straight row	77	86	91	94
8	One season plant, straight row:				
	- poor terraced	72	81	88	91
	- good terraced	67	78	85	89
	- poor contoured	70	79	84	88
	- good contoured	65	75	82	86
	- poor terraced and contoured	66	74	80	82
	- good terraced and contoured	62	71	78	81
9	Grain:				
	- poor terraced	65	76	84	88
	- good terraced	63	75	83	87
	- poor contoured	63	74	82	85
	- good contoured	61	73	81	84
	- poor terraced and contoured	61	72	79	82
	- good terraced and contoured	59	70	78	81
10	Leguminosa:				
	- poor terraced	66	77	85	89
	- good terraced	58	72	81	85
	- poor contoured	64	75	83	85
	- good contoured	55	69	78	83
	- poor terraced and contoured	63	73	80	83
	- good terraced and contoured	51	67	76	80
11	Meadow/pasture for herding:				
	- poor terraced	68	79	86	89
	- good terraced	49	69	79	84
	- poor contoured	39	61	74	80
	- good contoured	47	67	81	88
	- poor terraced and contoured	25	59	75	83
	- good terraced and contoured	6	35	70	79
12	Grass for production	30	58	71	78
13	Forest:				
	- poor	45	66	77	83
	- fair	36	60	73	79
	- good	25	55	70	77
14	Farmer settlement	59	74	82	86

Source: USDA (1986), Arsyad (1999)

4) Settlement for class 4 assuming that the population density is between 8501 – 9000 persons/square kilometer with CN value:

a) Settlement with soil hydrology A, the value of CN = 89

b) Settlement with soil hydrology B, the value of CN = 92

c) Settlement with soil hydrology C, the value of CN = 94

d) Settlement with soil hydrology D, the value of CN = 95

5) Settlement for class 5 assuming that the population density is more than 9000 persons/square kilometer with CN value:

a) Settlement with soil hydrology A, the value of CN = 93

b) Settlement with soil hydrology B, the value of CN = 94

c) Settlement with soil hydrology C, the value of CN = 95

d) Settlement with soil hydrology D, the value of CN = 98

Table 4.37: AMC condition at Adisutjipto rainfall station (January – March 2000)

Date	Jan (mm)	a	b	Feb (mm)	a	b	Mar (mm)	a	b
1	0	36	2	2	76	3	17	39	2
2	0	35	2	3	77	3	8	56	3
3	5	21	1	13	54	3	56	64	3
4	28	5	1	21	66	3	4	118	3
5	45	33	1	13	39	2	14	121	3
6	15	78	3	14	52	2	25	100	3
7	100	93	3	7	64	3	34	107	3
8	61	193	3	25	69	3	0	132	3
9	0	248	3	17	81	3	0	76	3
10	33	221	3	59	77	3	0	72	3
11	34	209	3	0	123	3	0	58	3
12	0	228	3	0	109	3	13	34	1
13	1	128	3	0	102	3	0	13	1
14	1	69	3	13	76	3	0	13	1
15	5	69	3	1	72	3	0	13	1
16	11	42	2	8	14	1	0	13	1
17	2	18	1	0	23	1	26	13	1
18	5	20	1	21	23	1	0	26	1
19	3	24	1	23	44	2	2	26	1
20	1	26	1	24	54	3	16	28	1
21	6	22	1	0	76	3	35	44	2
22	15	17	1	0	68	3	4	79	3
23	3	31	1	0	68	3	0	57	3
24	7	28	1	0	46	2	3	57	3
25	0	32	1	0	24	1	19	59	3
26	36	31	1	3	0	1	7	61	3
27	1	61	3	0	3	1	25	33	1
28	26	47	2	36	3	1	68	55	3
29	0	70	3				20	122	3
30	48	64	3				56	139	3
31	0	112	3				14	176	3

Source: calculated from the rainfall data taken from Public Work Department of Yogyakarta Province (2002)

Note: a = total rainfall for prior to 5 days
b = AMC condition

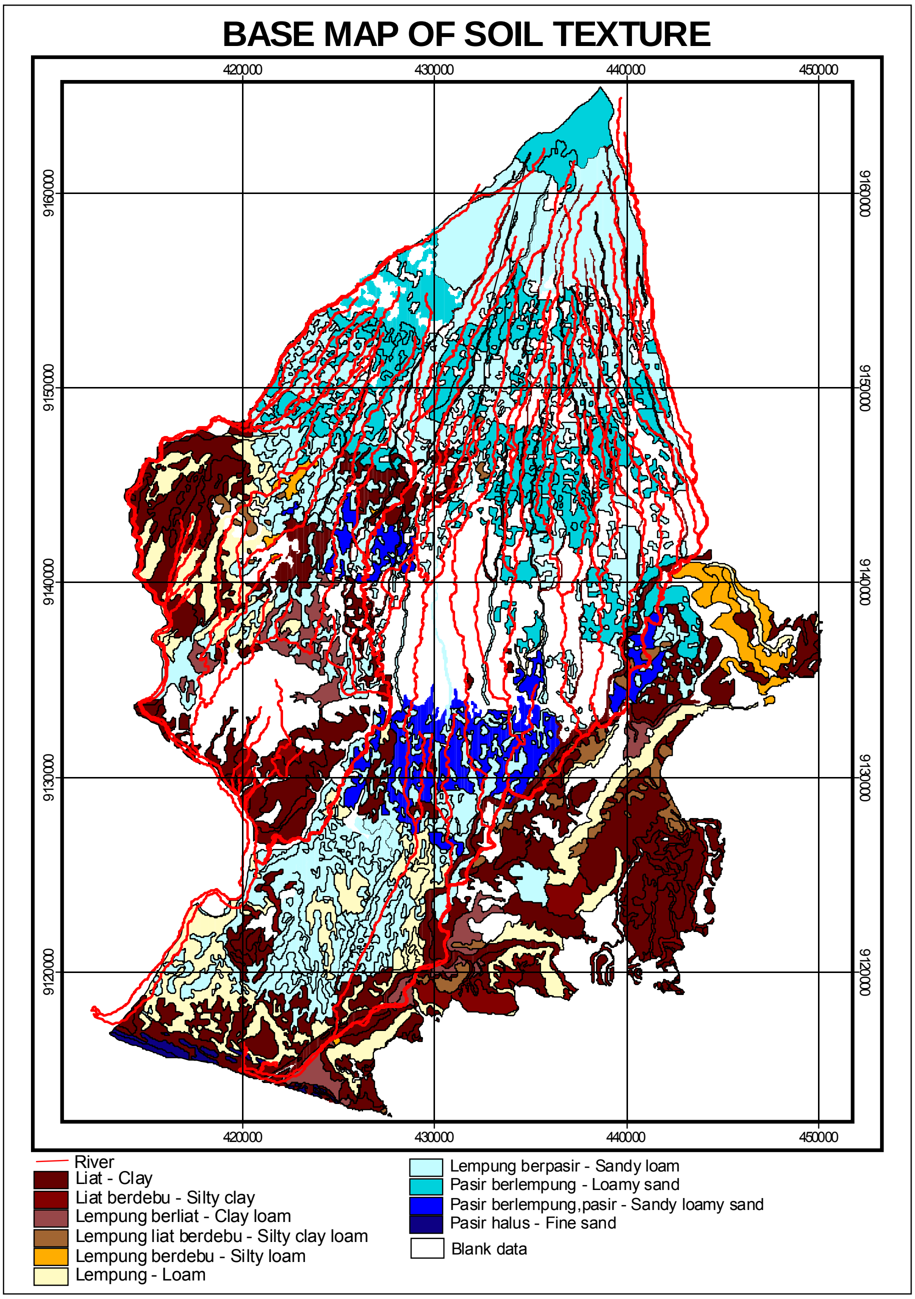


Figure 4.32: Base map of soil texture (Source: adapted from Bappeda, 2000)

The aim of using the assumption for the population density is to decrease the problem of determining class category of the settlements based on the rate of building density. These problems come to the result that the CN values of the study area cannot be determined accurately. The spatial resolution rate of the LANDSAT TM image is 30 meters x 30 meters per pixel, so it is not ideal as a basic tool for the determination of the settlement class. Another problem is the possibilities of the existence of clouds and unclear vegetation coverage of part of the study area. Due to the lack of accurate data, it needs such a method that is able to give classification, and no basic data is spoiled.

The applied method has used the appropriate population density of annual LANDSAT TM image. This method assumes that there is a relation between the rate of population density and the rate of building density. In general, the existing settlements in this study area have only the first floor (one-story buildings). In this study, the population density is defined as the value of the total population of a certain region to be divided by the total area of the housings, not by the total area. A region, for example Kasihan Sub-district, generally consists of housings and non-housing including paddy fields, uplands, etc. Therefore, the calculated population density for closed estimation of building population rate will differ from the population density calculated by the local Statistics Board office.

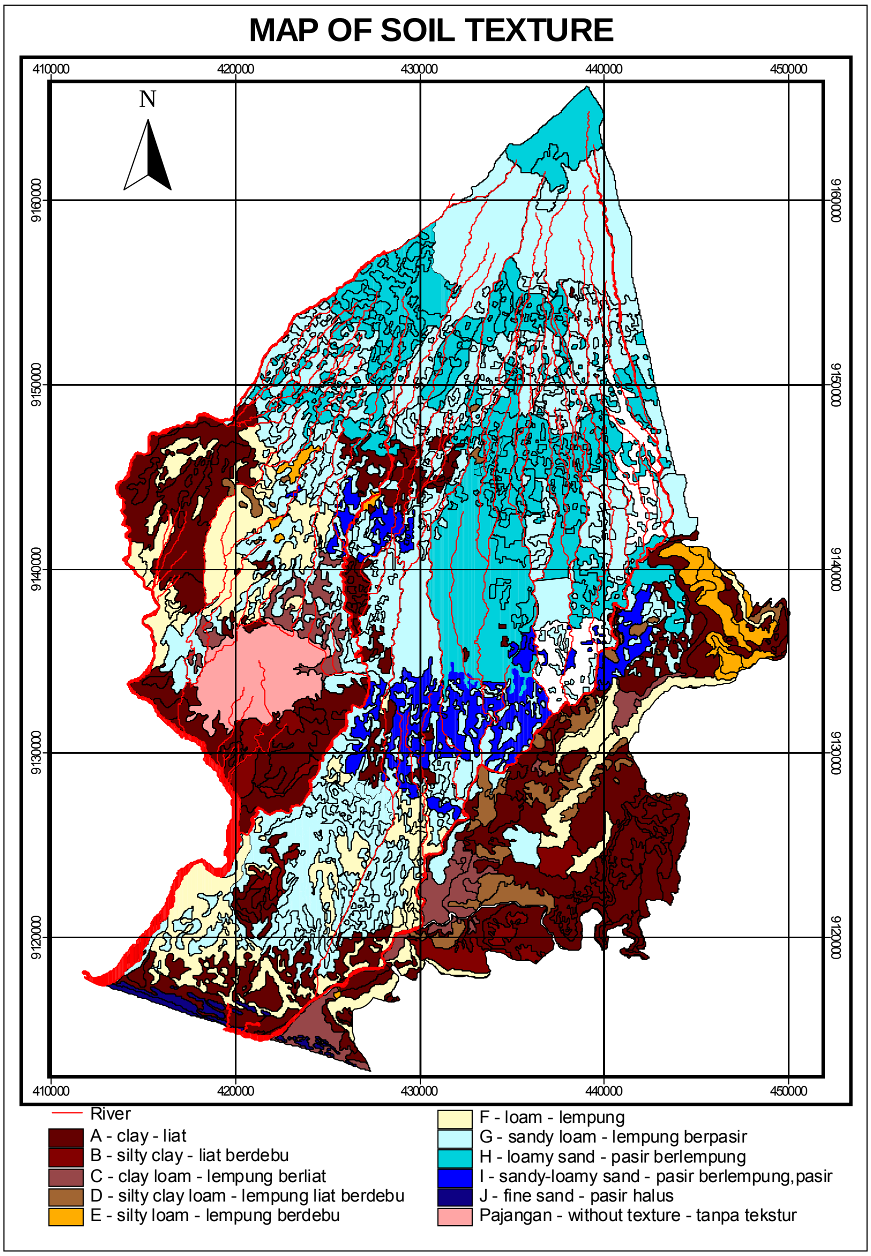


Figure 4.33: Map of soil texture after being revised and completed (Source: adapted from Bappeda, 2000)

Table 4.38: First assumption of CN value

No	Land Use	Soil Hydrology			
		A	B	C	D
1	Settlement (Class 1)	51	68	79	84
2	Settlement (Class 2)	54	70	80	85
3	Settlement (Class 3)	57	72	81	86
4	Settlement (Class 4)	61	75	83	87
5	Settlement (Class 5)	77	85	90	92
6	Irrigated rice field	59	70	78	81
7	Unirrigated agricultural field	62	71	78	81
8	Plantation	51	67	76	80
9	Forest	25	55	70	77
10	Piroclastic	77	86	91	94
11	Fine sand	77	86	91	94
12	Airport buildings	89	92	94	95
13	Landing strip	98	98	98	98
14	Grass	49	69	79	84
15	Homogenous forest land	36	60	73	79

Source: Mutreja (1982), Arsyad (1999)

Table 4.39: Optimization of CN based on land use complex

No	Land Use	Soil Hydrology			
		A	B	C	D
1	Settlement (Class 1)	61	75	83	87
2	Settlement (Class 2)	77	85	90	92
3	Settlement (Class 3)	81	88	91	93
4	Settlement (Class 4)	89	92	94	95
5	Settlement (Class 5)	93	94	95	98
6	Irrigated rice field	59	70	78	81
7	Unirrigated agricultural field	62	71	78	81
8	Plantation	51	67	76	80
9	Forest	55	70	77	83
10	Pyroclastic	80	86	91	94
11	Fine sand		6		
12	Buildings	98	98	98	98
13	Landing strip	98	98	98	98
14	Grass	39	61	74	80
15	Homogenous forest land	58	72	81	85

Table 4.40: CN values based on settlement classification (class 1, 2, 3, 4, 5), population density (persons/square kilometer), and soil hydrology (A, B, C, D)

Soil Hydrology	Settlement Classification				
	Class 1	Class 2	Class 3	Class 4	Class 5
	≤ 7500	7501 – 8000	8001 – 8500	8501 – 9000	> 9000
A	61	77	81	89	93
B	75	85	88	92	94
C	83	90	91	94	95
D	85	92	93	95	98

The population density according to Board of Statistics version is the total population divided by the total area of the region, covering housing area and non-housing area. Such value, indeed, is not relevant to be used as the value of population density for assumed factor relating to the rate of building density in this study. The classification of population density for every Class is determined by using field samples taken from the site with smallest value of a region, which is assumed as Class-1 housing and the calculated population of that region. Then, another field sample is taken to represent the Class-5 housing as well as the recorded population density.

This method has some weaknesses in its application due to the relationship between the housing class and the total population, e.g.:

1) The population density does not always represent the class of existing housing. This condition can be found in Kotabaru village. In that region, the population density shows the Class-1 housing category. However, in reality, the housing class is Class 5. The condition is due to the large number of public facilities and other auxiliary structures for the houses, so the population living in those houses is highly dense.
2) Determining the class of a region is difficult in the close class categories. For example, a certain region is determined as Class 3, but the difference between Class 3 and Class 4 categories is small, so an observer will get different values from the others. If the determination is based on the percentage of the extent of the housing area, the difficulty will occur in a housing block having various values of the extent and the coverage, and it will not be efficient if it is theoretically computed.
3) In some villages, such as Tamanan village of Banguntapan Sub-district and Pendowoharjo village of Sleman Sub-district, the inconsistency of Class of residence is due to relatively the same total population in the increasing extent of housing areas. During the initial analysis, this condition is assumed because housing is developed while the owners reside in other village or due to the development of public facilities and government and public offices. New housing might be developed by newcomers, but the data of such people are frequently not directly registered as local residents, so a difference will occur between the real situation and what is recorded in the statistical records.
4) Such problem is solved by implementing checks and field tests in areas that had an uncertain class of settlement. Those uncertainties could be identified by observing the consistency of class changing for each interpreted year. For example, Bangunharjo village was interpreted as a settlement of Class 5 in the year 1994, but in 1996, it was interpreted as of Class 3. That condition is impossible to be visually observed, so it needs a visual recheck on site.

Field verification on the settlement classification was carried out on July 1 to July 4, 2004. It was done to 37 villages of the total 153 villages in the whole study area. The study area comprises 11 villages in Sleman of 54 villages, 4 villages in Yogyakarta of the total 45 villages, and 22 villages in Bantul of 54 villages. The total of site verification of the classified data is 24.2 %.

The field check was carried out in two ways, i.e. 1) checking the data of total population or density of population in the related villages, and 2) observing the settlement blocks following the criteria of comparison between the extent of land area and the structures on it. The percentage follows the average of the existing comparison of structures and land

The criteria used for determining settlement classification of a region are (El-Shafei, 1994, Yunus, 2001):

1) Class 1 settlement covers the extent of watertight area <=40% of total extent of land.

2) Class 2 settlement covers the extent of watertight area >40% to 55% of total extent of land.
3) Class 3 settlement covers the extent of watertight area >55% to 70% of total extent of land.
4) Class 4 settlement covers the extent of watertight area >70% to 85% of total extent of land.
5) Class 5 settlement covers the extent of watertight area >85% of total extent of land.

Generalizing the class of a certain bigger areas will ease the digitization of base maps and the analysis of their land use complex. The generalization was done by examining the whole area thoroughly first, and then estimating the percentage of its watertight area. For example, a photo of field check is presented Figure 4.34. Visually, we can see in Figure 4.34 (a) that the settlement area is a densely populated area of Class 5.

(a)

(b)

Figure 4.34: (a) Settlement of Class 5 in Kraton Sub-city, Yogyakarta, (b) Settlement of Class 1 in Pajangan Sub-district, Bantul (Photos: Widodo, 2004)

An example of Class 1 settlement is in Pajangan Sub-district (Figure 4.34 (b)). The settlement is visually seen as a cluster, and this cluster can be grouped into Class 3 settlement. Nevertheless, in the LANDSAT TM image, such object may be seen as an area with dense vegetation. Actually, the portion of the housing area in comparison with the vegetation area is very small. The settlement area is categorized as Class 1 settlement because in each cluster of housing still can be found in relatively vast space of non-watertight area. That space is usually utilized for household purpose, for rinsing cloths and drying rice, a front yard or a family garden, etc.

The field check results of 37 villages among 153 villages of some sub-district/sub-city are wholly presented in Table 4.41. Referring to Table 4.41 of the field checks, practically, the computation using population density only does not assure that it can show the actual physical condition. The above check was done using the latest condition to be completed with interviews with authorized local government officials. The result is also valid for former conditions; it means that the condition when it was checked is analogized with the newest interpretation of the year 2000 satellite imagery and then it is used as a reference for estimating the condition in the preceding years.

Table 4.41: Field verification for settlement classification

No	Location			Settlement Classification							
				1994		1996		1998		2000	
	Village	Sub-district	District	Original	Verific.	Original	Verific.	Original	Verific.	Original	Verific.
1	Jambidan	Banguntapan	Bantul	2	1	1	1	1	1	1	1
2	Potorono	Banguntapan	Bantul	3	1	2	1	1	1	1	1
3	Tamanan	Banguntapan	Bantul	5	1	3	1	2	1	1	1
4	Wirokerten	Banguntapan	Bantul	5	3	5	3	5	3	3	3
5	Karangtalun	Imogiri	Bantul	5	2	2	2	1	2	5	2
6	Sumberagung	Jetis	Bantul	5	2	4	2	3	2	2	2
7	Trimulyo	Jetis	Bantul	5	3	5	3	5	3	5	3
8	Ngestiharjo	Kasihan	Bantul	5	2	5	2	5	2	2	2
9	Tirtonirmolo	Kasihan	Bantul	4	2	2	2	1	2	1	2
10	Bangunharjo	Sewon	Bantul	5	1	3	1	3	1	1	1
11	Panggungharjo	Sewon	Bantul	5	1	5	1	1	1	1	1
12	Kotabaru	Gondokusuman	Yogyakarta	1	5	1	5	1	5	1	5
13	Ngupasan	Gondokusuman	Yogyakarta	5	5	5	5	4	5	5	5
14	Karangwaru	Tegalrejo	Yogyakarta	5	1	3	1	1	1	1	1
15	Giwangan	Umbulharjo	Yogyakarta	5	1	1	1	1	1	1	1
16	Sendangtirto	Berbah	Sleman	4	1	4	1	4	1	1	1
17	Banyuraden	Gamping	Sleman	2	1	1	1	1	1	1	1
18	Nogotirto	Gamping	Sleman	5	4	5	4	5	4	4	4
19	Trihanggo	Gamping	Sleman	3	1	1	1	1	1	1	1
20	Sidoarum	Godean	Sleman	2	2	1	3	1	3	1	3
21	Sidokarto	Godean	Sleman	4	4	3	4	3	4	2	4
22	Sidomulyo	Godean	Sleman	3	1	1	1	1	1	1	1
23	Tirtomartani	Kalasan	Sleman	2	1	1	1	1	1	1	1
24	Sendangadi	Mlati	Sleman	5	5	5	5	5	5	5	5
25	Sinduadi	Mlati	Sleman	4	3	4	3	3	3	5	3
26	Sumbersari	Moyudan	Sleman	1	1	2	1	2	1	1	1
27	Donoharjo	Ngaglik	Sleman	3	1	2	1	1	1	1	1
28	Minomartani	Ngaglik	Sleman	4	1	2	1	2	1	1	1
29	Sariharjo	Ngaglik	Sleman	1	1	5	1	1	1	1	1
30	Sinduharjo	Ngaglik	Sleman	5	3	5	3	4	3	3	3
31	Umbulmartani	Ngemplak	Sleman	5	5	5	5	5	5	5	5
32	Harjobinangun	Pakem	Sleman	5	1	4	1	3	1	1	1
33	Sumberharjo	Prambanan	Sleman	3	4	2	4	1	4	1	4
34	Pendowoharjo	Sleman	Sleman	5	1	5	1	5	1	3	1
35	Tridadi	Sleman	Sleman	5	4	5	4	5	4	4	4
36	Trimulyo	Sleman	Sleman	1	1	2	1	1	1	1	1
37	Mororejo	Tempel	Sleman	5	4	2	4	1	4	1	4

Source: Field verification on 1- 4 July 2004

For example, the field check shows a Class 3 settlement; it is not possible that in the preceding years the settlement was categorized in the higher Class (Class 4 or 5). However, if in the preceding years the area accommodated the settlement of a class lower than the test result, the result is valid. The basic idea is that it is almost impossible that in the preceding years the settlement class is higher than in the latter years.

4.4.3.6 Runoff Resulting from CN Method

The land use data is gained based on the interpretation of the LANDSAT-TM image in 2000 and it is divided into 10 types of land use. The overlay uses the help of software ARC-Info in order to get the smooth overlay result because if it uses the ARC View, it will result in a rough overlay. The components used in the tabular data are area (m^2), legend (type of land use), soil hydrology group, soil texture, Polygon-Thiessen area, and sub-district for the administrative area.

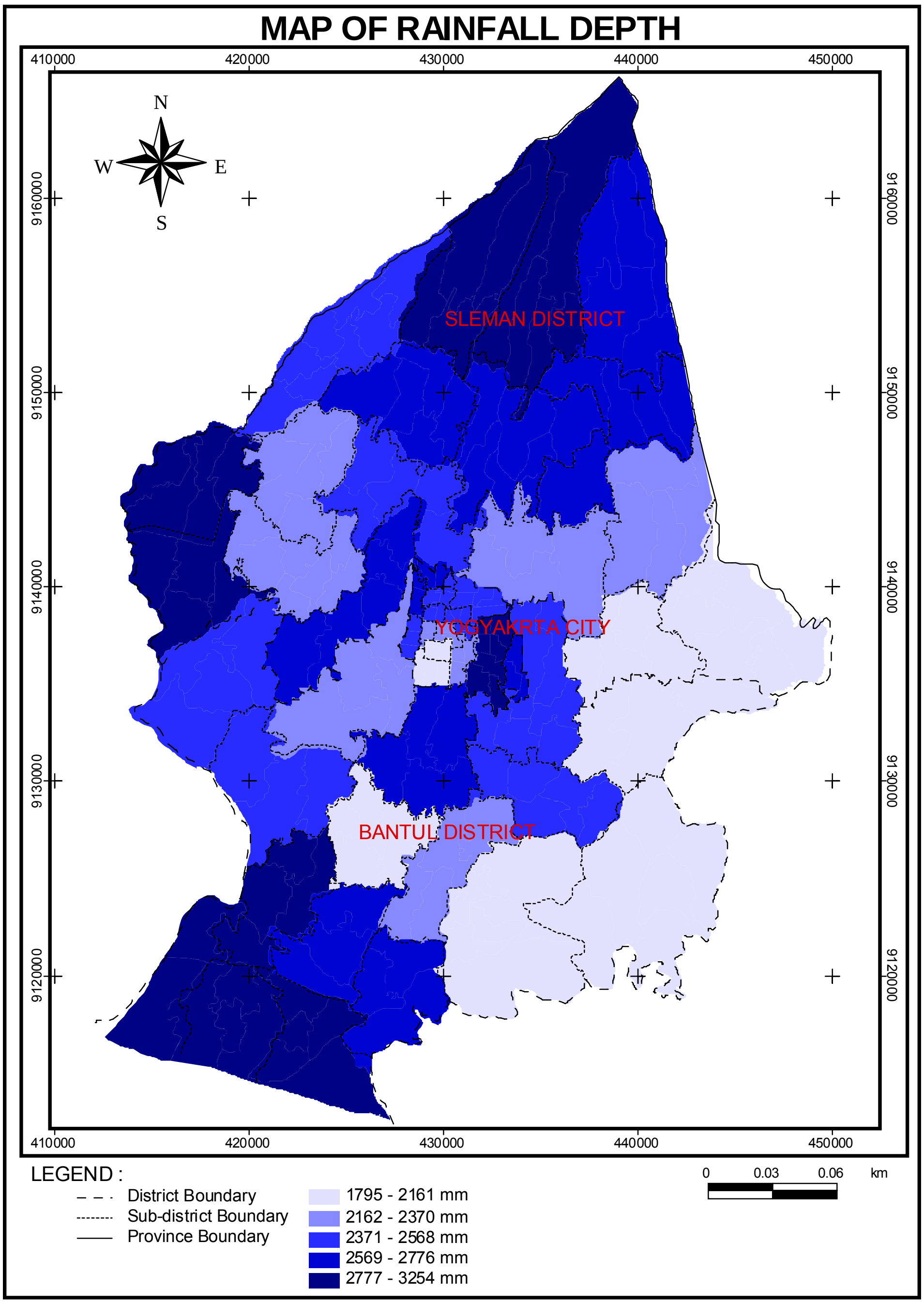


Figure 4.35: The map of rainfall depth in mm (rainfall data of 2001)

The tabular data, then, are used as a base-model of the runoff calculation. In the model table, it is added with the tabular data, i.e. the condition of AMC which is calculated based on the daily rainfall, CN value based on the land use complex, CN value resembling based on its AMC condition, the potential infiltration value (S), the rainfall data (P), and the runoff value (Qv). The result of CN calculation based on sub-district level can be seen in Table 4.43 and Figure 4.36.

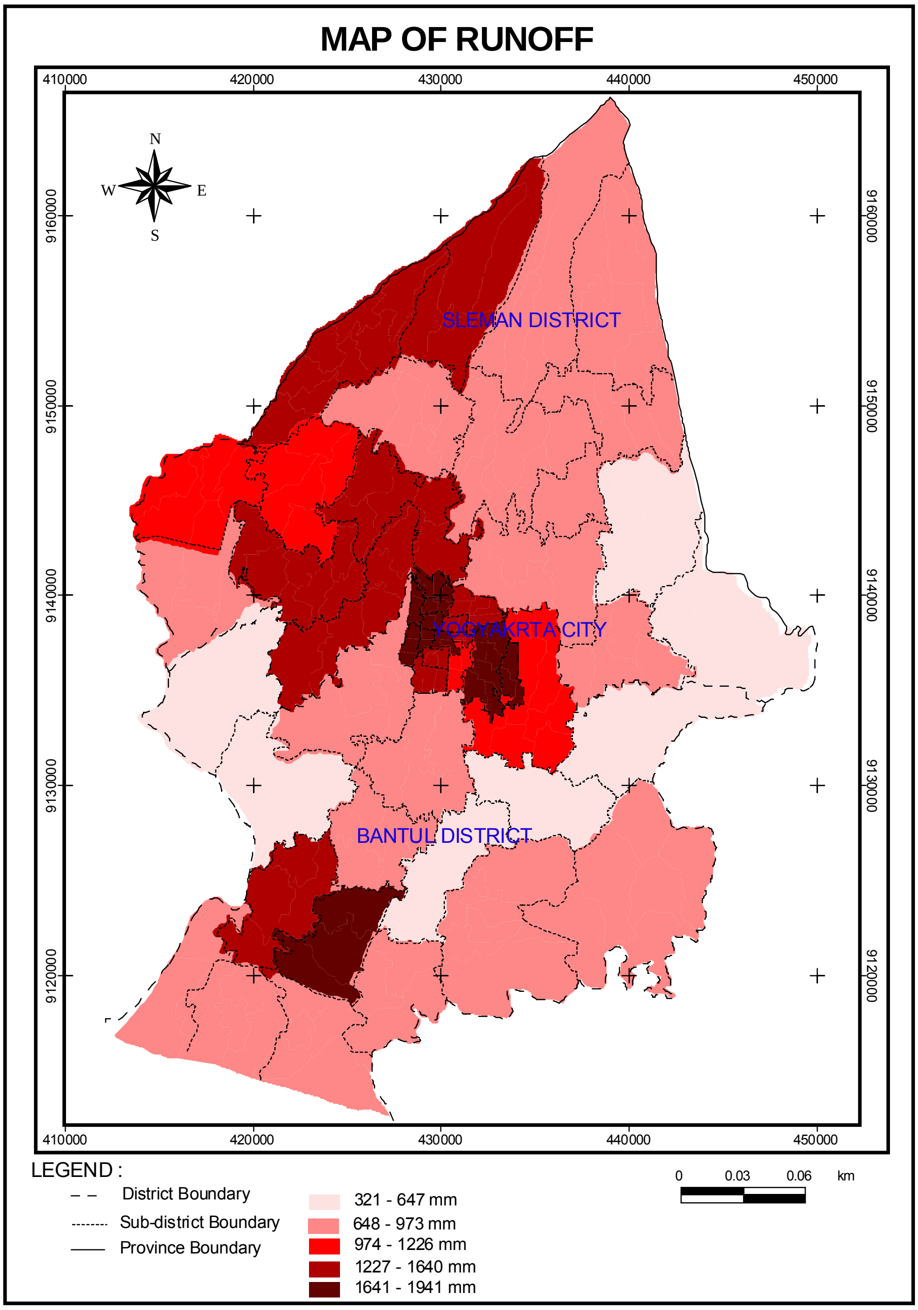


Figure 4.36: The map of runoff depth in mm resulting from CN analysis (rainfall data of 2001)

Table 4.42 shows the rainfall within 48 sub-districts of DIY in the year 2001 (mm) and Table 4.44 the ratio of runoff/rainfall for the same sub-districts. The same feature is given as a map in Figure 4.37. The made models then are used for making the runoff calculation easier on several different models or on several different times. The runoff calculation using the CN method is adequate to use if the input of the rain data is the single rain data. The input of the rainfall data, which is considered as valid, is that taken from the result of the automatic rainfall recording, so it is the data of per rainfall event. Asdak (2007) and Subarkah (1990) said that daily rainfall could be used for this calculation if there is no single rainfall data.

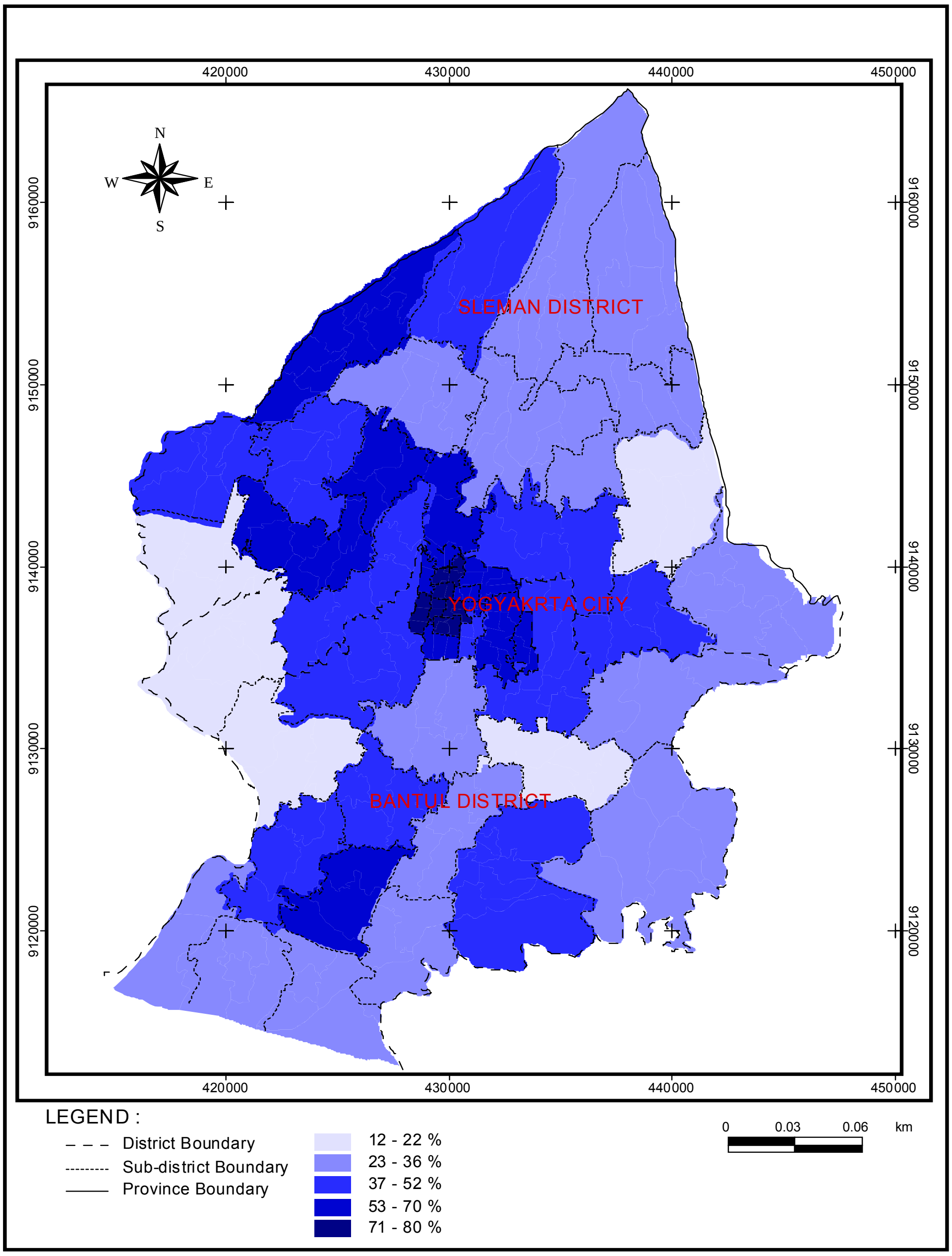


Figure 4.37: The ratio of runoff/rainfall map (rainfall data of 2001)

The calculated runoff per mapping unit is the runoff value on a point lies on certain area. However, in relation with the runoff value, it is necessary to see the proportion between the extent per mapping unit and the total extent of the area. The method of weighted-balance is considered as able to make the runoff value produced from certain mapping unit be in proportion with the total runoff value. Land use of such river that has no reference data from US SCS is considered as the same as impervious area, which has CN = 100.

Table 4.42: Rainfall within 48 Sub-districts in the year 2001 (mm)

No	Sub-district	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Bambanglipuro	480	657	329	70	66	23	31	0	77	479	306	250	2769
2	Banguntapan	561	346	406	270	106	110	12	0	1	209	291	135	2446
3	Bantul	451	266	333	125	20	31	18	0	29	271	306	239	2089
4	Berbah	656	277	371	190	78	77	27	0	2	128	217	72	2093
5	Cangkringan	307	349	430	278	110	138	55	3	11	490	482	111	2763
6	Danurejan	395	212	471	339	29	116	5	0	0	302	404	139	2412
7	Depok	447	247	460	325	47	92	29	1	1	226	280	98	2252
8	Dlingo	331	329	365	171	97	78	13	0	0	218	302	181	2085
9	Gamping	451	258	589	285	84	122	0	0	0	267	494	86	2637
10	Gedongtengen	395	212	471	339	29	116	5	0	0	302	404	139	2412
11	Godean	447	267	441	222	71	72	5	0	0	224	500	111	2360
12	Gondokusuman	395	212	471	339	29	116	5	0	0	302	404	139	2412
13	Gondomanan	394	229	457	325	29	109	7	0	0	292	384	143	2370
14	Imogiri	299	206	254	35	72	74	7	0	0	434	333	308	2021
15	Jetis Bantul	470	329	319	85	37	32	8	0	0	333	327	272	2212
16	Jetis Kota	395	212	471	339	29	116	5	0	0	302	404	139	2412
17	Kalasan	385	269	468	244	88	94	44	11	0	258	264	91	2215
18	Kasihan	394	309	421	252	39	78	16	0	0	241	310	150	2208
19	Kotagede	798	327	396	290	105	129	5	0	2	245	310	129	2738
20	Kraton	385	320	384	249	30	69	19	0	0	240	277	166	2140
21	Kretek	554	530	349	90	59	29	76	0	241	444	324	243	2938
22	Mantrijeron	385	325	380	245	30	67	20	0	0	237	271	167	2127
23	Mergangsan	418	313	414	287	49	94	14	0	0	271	323	168	2352
24	Minggir	654	243	473	233	98	140	54	2	0	357	515	97	2866
25	Mlati	369	232	485	219	104	111	5	0	0	305	494	120	2444
26	Moyudan	1536	136	262	192	31	503	48	0	0	200	259	85	3254
27	Ngaglik	395	331	536	272	151	165	43	3	10	386	292	192	2776
28	Ngampilan	391	256	435	302	29	97	11	0	0	276	352	150	2300
29	Ngemplak	419	321	466	266	103	107	34	12	0	437	369	106	2641
30	Pajangan	468	322	392	192	44	61	58	0	162	327	320	166	2512
31	Pakem	311	334	455	364	141	145	38	3	18	563	472	114	2959
32	Pakualaman	395	212	471	339	29	116	5	0	0	302	404	139	2412
33	Pandak	575	367	352	126	62	21	88	0	372	403	339	234	2940
34	Piyungan	230	351	381	163	103	81	26	0	0	100	252	107	1795
35	Pleret	450	373	417	266	126	118	9	0	0	266	352	191	2568
36	Prambanan	364	314	431	180	105	145	50	1	0	163	290	117	2161
37	Pundong	421	683	310	54	74	29	9	0	0	511	306	261	2657
38	Sanden	596	449	360	101	54	32	101	0	334	421	334	240	3022
39	Sedayu	482	283	468	212	35	144	48	0	3	320	350	67	2412
40	Sewon	497	373	428	317	99	124	11	0	0	308	351	195	2703
41	Seyegan	354	274	487	187	109	51	14	0	0	259	496	122	2353
42	Sleman	320	291	514	271	137	79	14	5	6	465	462	84	2647
43	Srandakan	648	394	374	103	47	39	132	0	415	402	343	243	3140
44	Tegalrejo	480	263	545	328	80	120	2	0	0	299	500	116	2731
45	Tempel	288	345	477	261	99	60	18	0	9	454	458	92	2561
46	Turi	295	347	481	343	176	173	51	4	22	518	395	97	2901
47	Umbulharjo	558	342	469	364	111	149	6	0	1	325	383	183	2892
48	Wirobrajan	431	312	448	271	55	86	14	0	0	258	365	146	2385

Table 4.43: Runoff (mm) resulting from CN analysis for 48 sub-districts in the year of 2001

No	Sub-district	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Bambanglipuro	351	607	102	0	0	0	12	0	31	409	129	46	1687
2	Banguntapan	418	214	162	99	8	21	0	0	0	31	84	15	1053
3	Bantul	177	289	96	16	0	1	0	0	0	77	154	92	901
4	Berbah	450	121	140	55	5	13	0	0	0	6	62	4	857
5	Cangkringan	63	101	109	83	12	4	1	0	0	185	192	4	753
6	Danurejan	264	129	356	240	1	32	0	0	0	241	265	30	1557
7	Depok	208	85	202	167	2	10	0	0	0	91	105	6	878
8	Dlingo	36	218	191	34	0	5	0	0	0	74	154	16	728
9	Gamping	245	128	328	143	17	37	0	0	0	133	280	24	1336
10	Gedongtengen	317	166	426	284	7	60	0	0	0	277	336	69	1941
11	Godean	436	183	216	56	0	37	0	0	0	69	377	4	1379
12	Gondokusuman	240	112	321	217	0	21	0	0	0	226	234	16	1388
13	Gondomanan	310	182	402	267	9	51	0	0	0	262	317	71	1871
14	Imogiri	114	108	46	3	0	24	0	0	0	246	197	122	861
15	Jetis Bantul	136	175	65	19	1	11	0	0	0	85	94	60	647
16	Jetis Kota	317	165	425	283	7	59	0	0	0	276	335	68	1937
17	Kalasan	71	131	148	31	3	26	0	0	0	0	74	1	485
18	Kasihan	118	242	174	92	7	8	0	0	0	57	175	21	893
19	Kotagede	671	247	236	226	11	89	0	0	0	146	218	65	1908
20	Kraton	288	284	297	195	18	17	0	0	0	196	244	101	1640
21	Kretek	224	259	73	2	1	1	2	0	38	132	64	17	813
22	Mantrijeron	284	288	258	179	19	15	0	0	0	146	170	93	1453
23	Mergangsan	216	217	201	145	13	26	0	0	0	138	182	70	1208
24	Minggir	374	42	207	86	0	39	0	0	0	141	311	0	1200
25	Mlati	210	137	340	182	2	1	0	0	0	303	436	0	1613
26	Moyudan	123	72	233	65	0	12	0	0	0	35	137	0	677
27	Ngaglik	119	103	286	74	7	60	1	0	0	146	171	7	973
28	Ngampilan	305	214	373	247	12	42	0	0	0	243	298	82	1817
29	Ngemplak	73	109	86	70	1	1	1	0	0	198	190	2	730
30	Pajangan	96	100	60	14	0	0	0	0	26	40	67	2	405
31	Pakem	51	96	138	124	30	12	3	0	2	163	199	9	826
32	Pakualaman	250	119	338	229	0	25	0	0	0	232	247	20	1461
33	Pandak	359	390	195	0	0	0	0	0	64	142	215	59	1423
34	Piyungan	21	148	174	19	7	7	0	0	0	2	89	1	467
35	Pleret	26	99	90	19	3	6	0	0	0	13	62	4	321
36	Prambanan	132	129	181	55	1	35	0	0	0	8	83	1	625
37	Pundong	141	404	64	1	2	3	0	0	0	252	50	37	954
38	Sanden	277	213	79	0	0	0	0	0	53	96	82	9	808
39	Sedayu	126	73	96	36	0	15	0	0	0	70	55	0	473
40	Sewon	156	181	133	105	2	44	0	0	0	87	148	21	877
41	Seyegan	216	143	245	73	0	0	0	0	0	101	446	1	1226
42	Sleman	58	52	172	92	5	5	0	0	0	214	241	2	841
43	Srandakan	272	165	82	0	0	0	17	0	94	67	76	5	777
44	Tegalrejo	333	168	381	219	36	42	0	0	0	222	347	41	1788
45	Tempel	87	86	379	222	4	0	0	0	0	356	500	2	1637
46	Turi	93	224	285	270	42	2	0	0	0	310	231	19	1476
47	Umbulharjo	370	230	285	246	9	80	0	0	0	191	234	55	1701
48	Wirobrajan	343	278	365	221	38	35	0	0	0	215	326	91	1913

Table 4.44: Ratio of runoff/rainfall

No	Sub-district	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
		(x 100 %)												
1	Bambanglipuro	0,73	0,92	0,31	0,00	0,00	0,00	0,39	0,00	0,40	0,85	0,42	0,18	0,61
2	Banguntapan	0,75	0,62	0,40	0,37	0,07	0,19	0,00	0,00	0,00	0,15	0,29	0,11	0,43
3	Bantul	0,39	1,08	0,29	0,13	0,00	0,03	0,00	0,00	0,00	0,28	0,50	0,39	0,43
4	Berbah	0,69	0,44	0,38	0,29	0,07	0,17	0,02	0,00	0,00	0,05	0,29	0,06	0,41
5	Cangkringan	0,21	0,29	0,25	0,30	0,11	0,03	0,02	0,02	0,03	0,38	0,40	0,03	0,27
6	Danurejan	0,67	0,61	0,76	0,71	0,05	0,28	0,00	0,00	0,00	0,80	0,66	0,22	0,65
7	Depok	0,47	0,34	0,44	0,52	0,05	0,11	0,02	0,00	0,00	0,40	0,38	0,06	0,39
8	Dlingo	0,11	0,66	0,52	0,20	0,00	0,06	0,00	0,00	0,00	0,34	0,51	0,09	0,35
9	Gamping	0,54	0,50	0,56	0,50	0,20	0,30	0,29	0,00	0,00	0,50	0,57	0,28	0,51
10	Gedongtengen	0,80	0,78	0,91	0,84	0,24	0,51	0,00	0,00	0,00	0,92	0,83	0,49	0,80
11	Godean	0,98	0,69	0,49	0,25	0,00	0,52	0,00	0,00	0,00	0,31	0,75	0,04	0,58
12	Gondokusuman	0,61	0,53	0,68	0,64	0,00	0,18	0,00	0,00	0,00	0,75	0,58	0,12	0,58
13	Gondomanan	0,79	0,79	0,88	0,82	0,29	0,47	0,00	0,00	0,00	0,90	0,83	0,50	0,79
14	Imogiri	0,38	0,53	0,18	0,08	0,00	0,32	0,00	0,00	0,00	0,57	0,59	0,40	0,43
15	Jetis Bantul	0,29	0,53	0,20	0,22	0,04	0,34	0,02	0,00	0,00	0,26	0,29	0,22	0,29
16	Jetis Kota	0,80	0,78	0,90	0,84	0,24	0,51	0,00	0,00	0,00	0,91	0,83	0,49	0,80
17	Kalasan	0,18	0,49	0,32	0,13	0,03	0,27	0,00	0,00	0,00	0,00	0,28	0,01	0,22
18	Kasihan	0,30	0,78	0,41	0,37	0,18	0,10	0,00	0,00	0,00	0,24	0,56	0,14	0,40
19	Kotagede	0,84	0,75	0,60	0,78	0,11	0,69	0,00	0,00	0,00	0,59	0,70	0,50	0,70
20	Kraton	0,75	0,89	0,77	0,78	0,62	0,25	0,00	0,00	0,00	0,82	0,88	0,61	0,77
21	Kretek	0,40	0,49	0,21	0,02	0,02	0,02	0,02	0,00	0,16	0,30	0,20	0,07	0,28
22	Mantrijeron	0,74	0,89	0,68	0,73	0,63	0,22	0,00	0,00	0,00	0,62	0,63	0,56	0,68
23	Mergangsan	0,52	0,69	0,49	0,51	0,27	0,27	0,00	0,00	0,00	0,51	0,56	0,41	0,51
24	Minggir	0,57	0,17	0,44	0,37	0,00	0,28	0,00	0,00	0,00	0,39	0,60	0,00	0,42
25	Mlati	0,57	0,59	0,70	0,83	0,02	0,01	0,00	0,00	0,00	0,99	0,88	0,00	0,66
26	Moyudan	0,08	0,53	0,89	0,34	0,00	0,02	0,00	0,00	0,00	0,18	0,53	0,00	0,21
27	Ngaglik	0,30	0,31	0,53	0,27	0,04	0,36	0,02	0,00	0,00	0,38	0,59	0,04	0,35
28	Ngampilan	0,78	0,84	0,86	0,82	0,40	0,44	0,00	0,00	0,00	0,88	0,85	0,55	0,79
29	Ngemplak	0,17	0,34	0,18	0,26	0,01	0,01	0,03	0,01	0,00	0,45	0,52	0,02	0,28
30	Pajangan	0,20	0,31	0,15	0,07	0,00	0,00	0,00	0,00	0,16	0,12	0,21	0,01	0,16
31	Pakem	0,16	0,29	0,30	0,34	0,22	0,08	0,07	0,02	0,09	0,29	0,42	0,08	0,28
32	Pakualaman	0,63	0,56	0,72	0,67	0,00	0,22	0,00	0,00	0,00	0,77	0,61	0,15	0,61
33	Pandak	0,62	1,06	0,55	0,00	0,00	0,00	0,00	0,00	0,17	0,35	0,63	0,25	0,48
34	Piyungan	0,09	0,42	0,46	0,12	0,07	0,09	0,00	0,00	0,00	0,02	0,35	0,00	0,26
35	Pleret	0,06	0,26	0,22	0,07	0,03	0,05	0,00	0,00	0,00	0,05	0,17	0,02	0,12
36	Prambanan	0,36	0,41	0,42	0,31	0,01	0,24	0,01	0,04	0,00	0,05	0,29	0,01	0,29
37	Pundong	0,33	0,59	0,21	0,02	0,02	0,10	0,02	0,00	0,00	0,49	0,16	0,14	0,36
38	Sanden	0,46	0,47	0,22	0,00	0,00	0,00	0,00	0,00	0,16	0,23	0,25	0,04	0,27
39	Sedayu	0,26	0,26	0,21	0,17	0,00	0,11	0,00	0,00	0,00	0,22	0,16	0,00	0,20
40	Sewon	0,31	0,48	0,31	0,33	0,02	0,36	0,00	0,00	0,00	0,28	0,42	0,11	0,32
41	Seyegan	0,61	0,52	0,50	0,39	0,00	0,00	0,00	0,00	0,00	0,39	0,90	0,01	0,52
42	Sleman	0,18	0,18	0,34	0,34	0,04	0,06	0,00	0,00	0,01	0,46	0,52	0,03	0,32
43	Srandakan	0,42	0,42	0,22	0,00	0,00	0,00	0,13	0,00	0,23	0,17	0,22	0,02	0,25
44	Tegalrejo	0,69	0,64	0,70	0,67	0,45	0,35	0,00	0,00	0,00	0,74	0,69	0,35	0,65
45	Tempel	0,30	0,25	0,79	0,85	0,04	0,00	0,00	0,00	0,00	0,78	1,09	0,03	0,64
46	Turi	0,32	0,65	0,59	0,79	0,24	0,01	0,00	0,00	0,00	0,60	0,59	0,19	0,51
47	Umbulharjo	0,66	0,67	0,61	0,67	0,08	0,54	0,00	0,00	0,00	0,59	0,61	0,30	0,59
48	Wirobrajan	0,80	0,89	0,81	0,82	0,69	0,41	0,00	0,00	0,00	0,83	0,89	0,63	0,80

4.5 Water Balance

4.5.1 General

Water balance compares water availability and water demand of a defined area. Water availability in an area regards to the amount of rainfall and inflowing surface water. The Meteorological Water Balance takes into account rainfall, air temperature, and evapotranspiration. This meteorological water balance was developed by Thornthwaite and Mather (1957). Meteorological water balance uses the data of monthly average rainfall, potential evapotranspiration, and actual evapotranspiration. A water-surplus area is an area where water or rainfall is more abundant than the potential evapotranspiration subtracted by water storage or humidity. Water demand takes into account the water needs of crops, humans (domestic and industrial demand) and domestic animals, but should consider the water needs of ‘nature’

4.5.2 Methodology

The water availability in the research area is calculated using rainfall and evapotranspiration approach, assuming the rainfall as the water input and the actual evapotranspiration as the actual water loss. Water availability is calculated from an area by runoff multiplied by area dimension. The runoff value is calculated based on CN analysis using the coefficient of land use in each sub-district. Then, the runoff percentage is used for defining the amount of runoff in each rainfall in every month, i.e. from the ratio of runoff to rainfall of the same year. Considering the availability of data, the calculation uses the data of 2001 to define the water availability.

Domestic use is the use of water by individuals for drinking, showering, cooking, watering yards, and other sanitation activities (Sutikno et al., 2002). Domestic use is calculated using the standard of the report of Public Work Department of Yogyakarta Province (2003) i.e. domestic use in urban areas is 150 litres/person/day, while domestic use in rural areas is 80 litres/person/day.

Each sub-district in Sleman, Bantul, and Yogyakarta is classified as a rural area, small city, medium city, or big city based on the classification made by BPS (2005). Therefore, the standard domestic use for calculating the water demand in this research is 80 litres/person/day for rural areas, 100 litres/person/day for small cities, and 150 litres/person/day for medium and big cities.

Meanwhile, the water demand of agriculture sector is calculated based on Public Work Department of Yogyakarta Province (2005), i.e. water demand of rice-field irrigation is 2177,23 m^3/hectare/month, and water demand of dryland-crops irrigation is 544,25 m^3/hectare/planting. The water demand of industry is calculated 0.7 m^3/day for a large industry and 0.35 m^3/day for a small industry (Nippon Koei, Co. Ltd, 2003).

The water demand of livestock is based on Indra Karya (2003). The water demand of livestock is divided into water demand of four-legged livestock and water demand of poultry. Each animal in a certain group has its own water demand (Table 4.45). The standard water demand of cows, buffalos, and horses is e.g. 40 litres/day/animal. The water demand of industry in Bantul and Sleman is overlooked considering the very small number of industrial activities in the area (BPS, 2005). Meanwhile, the water demand of industry in Yogyakarta is taken into account considering that there are a large number of industries in this area.

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Table 4.45: Standard water demand of livestock

Livestock Type	Water Demand (litre/day/animal)
Cows/ buffalos/ horses	40.0
Goats/sheep	5.0
Pigs	6.0
Poultry	0.6

Source: Indra Karya, 2003

Table 4.46: Water balance for each sub-district of Sleman

No	Sub-district	Water Availability	Water Demand of Domestic	Water Demand of Farmland	Water Demand of Livestock	Difference	Remark
		(m³/year)					
1	Moyudan	70957990	1264397	6897384	105258	62690952	Surplus
2	Minggir	45330376	1288961	7010054	88046	36943315	Surplus
3	Seyegan	30076987	2373851	7450938	102529	20149670	Surplus
4	Godean	26603808	3314237	6892485	95121	16301966	Surplus
5	Gamping	37780470	3989687	5525745	71835	28193203	Surplus
6	Mlati	23698979	3959411	4820331	98337	14820901	Surplus
7	Depok	48857432	6508242	2762872	43115	39543202	Surplus
8	Berbah	28416790	1553075	6040109	113665	20709940	Surplus
9	Prambanan	63414360	1654472	7308875	136740	54314273	Surplus
10	Kalasan	61948723	3126554	8273921	204815	50343433	Surplus
11	Ngemplak	67877568	1760249	9630864	200007	56286448	Surplus
12	Ngaglik	69505488	2658952	8744197	195870	57906468	Surplus
13	Sleman	56396045	3240269	7793848	110550	45251377	Surplus
14	Tempel	29954480	1757366	8357199	149916	19690000	Surplus
15	Turi	61273118	1252680	2464051	99387	57457000	Surplus
16	Pakem	93368678	1189718	8278820	262092	83638049	Surplus
17	Cangkringan	96830383	807614	5354290	228956	90439523	Surplus
Total		**912291674**	**41699732**	**113605984**	**2306237**	**754679722**	**Surplus**

4.5.3 Data Analysis

Based on the water availability and water demand of each regency/city, Sleman has a water surplus of 754.679.722 m^3/year. Yogyakarta has a water deficit of 4.381.657.838 m^3/year, while in Bantul the water surplus is 706.685.901 m^3/year.

According to the water balance calculation for Sleman, the meteorological water availability in each sub-district of Sleman is still larger than the water demand, so there is a water surplus

(Table 4.46). Among the sub-districts in Sleman, Mlati Sub-district has the lowest water surplus, while Cangkringan Sub-district has the highest one.

Based on the water balance calculation for Yogyakarta, the meteorological water availability shows a water deficit (Table 4.47). Umbulharjo Sub-district has the highest water deficit, while Pakualaman Sub-district has the lowest one.

According to the water balance calculation for Bantul, the meteorological water availability in each sub-district of Bantul is still larger than the water demand, so there is a water surplus (Table 4.48). Among the sub-districts in Bantul, Bambanglipuro Sub-district has the lowest water surplus, while Dlingo Sub-district has the highest one. The water balance in Bantul indicates a surplus based on the ideal condition when all the rainfall subtracted by runoff becomes groundwater and reserve water. The water demand in Bantul does not include the demand of industry, fishery and tourism.

Table 4.47: Water balance for each sub-district of Yogyakarta

No	Sub-district	Water Availability	Water Demand of			Difference	Remark
			Domestic	Industry	Livestock		
		(m3/year)					
1	Mantrijeron	1776470	1955560.5	974717211	2074	-974,898,375	Deficit
2	Kraton	688758	1188075	0	399	-499,716	Deficit
3	Mergangsan	2661097	1884823.5	243679303	752	-242,903,782	Deficit
4	Umbulharjo	9624717	4160781	1218396514	5698	-1,212,938,275	Deficit
5	Kotagede	2519856	1675788	974717211	2655	-973,875,798	Deficit
6	Gondokusuman	3768509	2910510	243679303	457	-242,821,761	Deficit
7	Danurejan	928620	1186596.75	0	368	-258,345	Deficit
8	Pakualaman	592628	636249.75	0	93	-43.714	Deficit
9	Gondomanan	557189	833404.5	243679303	201	-243,955,719	Deficit
10	Ngampilan	395888	1054594.5	0	678	-659,385	Deficit
11	Wirobrajan	839872	1599630.75	0	577	-760,335	Deficit
12	Gedongtengen	463104	1072662	0	557	-610,115	Deficit
13	Jetis	820080	1559280	243679303	1343	-244,419,846	Deficit
14	Tegalrejo	2783561	2111214.75	243679303	5714	-243,012,671	Deficit
Total		**28420349**	**23829171**	**4386227449**	**21567**	**-4,381,657,838**	Deficit

4.6 Piped Water Supply (PDAM)

4.6.1 General

The economic crisis that has attacked Indonesia for almost eight years also unconsciously threats the clean water supply. The limited funds and the increasing operational costs in fact influence the operational activity of the Local Drinking Water Company or Public Water Supply Company (PDAM) as the body that manages the piped drinking water. According to PDAM (2001), 80% of 303 PDAMs spread all over Indonesia were at that time in a critical condition. Those PDAMs face serious difficulties in financing their risen operational costs, specifically due to the increasing price of spare parts, chemical substances, and electricity. Besides these financial problems, PDAM also has to face the efficiency problem that makes it unable to serve the public optimally.

Table 4.48: Water balance for each sub-district of Bantul

No	Sub-district	Water Availability	Water Demand of			Difference	Remark
			Domestic	Farmland	Livestock		
		(m3/year)					
1	Srandakan	43143600	1074159	2052559	81149	39935733	Surplus
2	Sanden	51092350	1248118	4830128	100494	44913610	Surplus
3	Kretek	56647462	914427	4369649	44258	51319128	Surplus
4	Pundong	40282522	1208333	4232485	67421	34774283	Surplus
5	Bambanglipuro	24505104	1580304	5702098	101317	17121385	Surplus
6	Pandak	37137204	1781967	4541104	60850	30753283	Surplus
7	Bantul	26136524	3247168	5545340	50231	17293785	Surplus
8	Jetis	38430624	1842630	5765782	43263	30778950	Surplus
9	Imogiri	62801905	1673072	5432669	67888	55628275	Surplus
10	Dlingo	75717818	1086269	2508140	120595	72002814	Surplus
11	Pleret	51908525	1259506	4212891	65132	46370996	Surplus
12	Piyungan	43198802	1121368	6784713	80169	35212553	Surplus
13	Banguntapan	39723619	4391443	6902282	60842	28369052	Surplus
14	Sewon	49921166	4252925	6392817	76407	39199017	Surplus
15	Kasihan	42935880	4348464	3296832	55694	35234890	Surplus
16	Pajangan	70160160	891710	1283462	137627	67847361	Surplus
17	Sedayu	66301056	1633704	4702762	33806	59930785	Surplus
Total		**820044320**	**33555563**	**78555714**	**1247141**	**706685901**	**Surplus**

The PDAMs in all regions of Indonesia are the result of the transition function of the Drinking Water Management Institution that previously was under the management of Department of Public Works. At present, the organization and management of PDAM are fully under the responsibility of regency/city government in which the PDAM is located. In general, the coverage of PDAM service is still focused on supplying the urban area. The main task of PDAM is to serve the public in supplying drinking water that should meet the health requirements. However, most of the drinking water consumers of PDAM in Indonesia complain since the water they consume is still far from what they expect in terms of quality, quantity, and continuity. Even the data from the Health Service of Bantul (2001) and PDAM (2002-b) show that 80% of the water taken from the people's wells in Bantul is not proper to consume for it contains high pollution substances. Nevertheless, PDAM still cannot fulfill the people's need for clean water since there are many constraints to deal with. According to Bantul PDAM (2002-a), Puser Bumi (2003), and PDAM (2001), the PDAMs in Indonesia in general, and particularly those in the research area, face problems of various aspects, such as:

1) The operational aspect that covers: the high level of water loss (around 40%), incomplete equipment to detect the water loss, the wide service area that makes the water loss detection more difficult, the water quality that has not fulfilled the requirements of the drinking water standard, bad water treatment system, low service-quality due to the unavailability of 24-hour service the untested, broken or even missing water meters, and the water-meter inaccurateness at the central production,
2) The marketing aspect that includes: the poor service quality towards customers, the narrow service coverage, insignificant number of customers from the industrial sector, the growth of

packaged-drinking water industry, and the low level of people's awareness about the importance of clean water,

3) The human resource aspect that consists of the poor quality of human resources working at PDAM that makes it difficult to apply the professional working system, and the less optimal development of the existing human resources, and
4) The financial aspect that covers: the low profit rate of PDAM and even frequent loss, the very high cost of water resources, the large amount of debt that makes the financial crisis worse, the limitedness of investment from the funding sources, the manual bookkeeping system that potentially leads to inefficiency, the high rate of operational cost, especially the cost of energy; the low rate of PDAM income due to the small number of customers, and the selling price of water that is still below the production cost.

Many PDAMs in the research area depend on wells, especially deep wells, while other small units depend on springs. Around 72% of water is taken from deep wells, 10% is from shallow wells, and around 18% is from springs (PDAM, 2003).

The data of population in the middle of 2002 show that the population living in Yogyakarta cover 501,399 people, 856,618 people in Sleman and 780,217 people in Bantul. Table 4.49 shows that the number of families living in Yogyakarta is 79,502 in which each family has 4.99 family members; in Sleman, there are 226,477 families in which each family has 3.99 family members, and in Bantul, there are 192,842 families in which each family has 4.05 family members. On the other hand, the average income of the families living in Yogyakarta was the highest among those three regions, which is Rp. 3,821,600/month (about 329.448 Euro/month). While in Sleman, each family earns Rp. 1,500,700/month (about 129.371 Euro/month), and in Bantul, each family can earn Rp. 1,056,500/month (about 91.077 Euro/month for 1 Euro = Rp. 11,600).

According to the standard of the Public Works Department, the ability of families to pay for water is estimated around 4% of their income. This income indicates that the people can afford the clean water price between Rp. 1,000 to Rp. 1,800/cubic meter (about 0.086 – 0.155 Euro/cubic meter). The water price of PDAM at this moment is still very low with the range of Rp. 500 to Rp. 1500/cubic meter (about 0.043 – 0.129 Euro/cubic meter) that is used for the domestic need.

Table 4.49: Population and PDAM customer profiles (Year 2002)

No	Description	Yogyakarta	Sleman	Bantul
1	Area (km2)	32.5	574.82	506.85
2.	Population (person) in 2000	396,711	901,377	781,013
3	Population growth (%)	-0.39	1.5	1.19
4	Population density (prs/km2)	12,206	1,568	1,541
5	Family number (unit)	79,502	226,477	192,842
6	Family member (person)	4.99	3.98	4.05
7	PDAM customers (unit)	34,611	17,918	9,995
8	Distribution density (m)	969	5,664	7,121
9	Income (Rp./family/month)	3,821,600	1,500,700	1,056,500

Source: BPS (2002-a), PDAM (2003), Puser Bumi (2003)

4.6.2 Data Analysis

4.6.2.1 PDAM Service in KartaManTul Area

The three PDAMs still depend on groundwater as the water resources taken through wells, especially deep wells. PDAM of Sleman in 2001 has 18 units of well with the capacity of 180 liters/second, and 2 units take water from spring with the capacity of 80 liters/second. PDAM of Yogyakarta uses 28 units of well with the capacity of 529 liters/second, and 1 unit uses spring with the capacity of 75 liters/second. PDAM of Bantul uses 17 wells with the capacity of 131 liter/second, and 5 units take water from spring with the capacity of 29 liters/second (Table 4.50).

The existing problems relating to the deep wells are the decrease in the production capacity caused by clogging and in the groundwater capacity of wells, as well as the water quality that is influenced by the substances of Mn and Fe. Moreover, as deep wells are still the main water resources, PDAM has to spend a large amount of money to pump up the water using electrical energy to distribute water to the customers because not all the service areas can be served through the gravitation distribution system.

Table 4.50 shows the high amount of water loss. PDAM in Sleman suffers water loss of around 40%, the leakage in PDAM of Yogyakarta is around 35%, and PDAM in Bantul suffers water loss of around 40%. This leakage is caused by: (1) the physical leakage on the installation or utility of the old pipes, (2) the broken or expired water-meter that can malfunction and lead to inaccurate recording, (3) the unrecorded connection of illegal pipes, and (4) the existence of wasted water particularly during the draining process.

Table 4.50: Production system of PDAM

No	Description	Yogyakarta	Sleman	Bantul	Total
1	Well (unit)	28	18	17	63
2.	Spring (unit)	1	2	5	8
3	Well debit (liter/second)	529	180	131	840
4	Spring debit (liter/second)	75	80	29	184
5	Total debit (liter/second)	604	260	160	1,024
6	Pumping system liter/second)	599	190	185	927
7	Gravity system (liter/second)	75	55	21	132
8	Operational production (hour)	24	23	20	22
9	Complete treatment (unit)	4	11	8	23
10	Simple treatment (unit)	-	1	4	5
11	Water loss (%)	35	40	40	target 20

Source: PDAM (2003), Puser Bumi (2003)

Table 4.51: PDAM service profile

No	Description	Yogyakarta	Sleman	Bantul	Total
1	Population (person)	396,711	901,377	781,013	2,079,101
2.	Population serviced (%)	32.6	17.0	11.55	18.42
3	Population serviced (person)	129,328	153,235	90,208	372,771
4	Population serviced (family)	25,918	38,502	22,274	86,694
5	Customer: commercial, industry	1,604	256	45	1,905

Source: BPS (2002-a), PDAM (2003), Puser Bumi (2003)

At present, most people living in Sleman, Yogyakarta and Bantul have not had the water access from PDAM. Based on the data in 2001, the majority of people, around 81.58%, still fully depend on the non-PDAM water resources especially from wells, while only 18.42% of the people can access the water from PDAM. Figure 4.38 explains the spatial distribution of the service level provided by PDAM. It can be seen from the figure that the service distribution of PDAM has not spread throughout the three areas; many areas still have not been served. The data used for describing this service distribution are taken from the data of PDAM bill. The data cover the customers' name, type, and address.

Despite being the customers of PDAM, people generally still use wells as their resources to get clean water. Even, they often use the water from PDAM only for non-cooking or non-drinking matters. Many people use water from wells for cooking and drinking, while the water from PDAM is used for doing the laundry, watering plants, and other cleaning activities. Nowadays, much of the water from wells is in a critical condition in terms of quantity or quality; therefore the society becomes more interested in getting the access to PDAM water. However, because PDAM has to face the limitedness of fund and other technical factors, many people cannot get the service from PDAM.

Table 4.51 shows that the PDAM water is used more for domestic sector rather than for industrial or commercial sectors. Industrial sector takes only 1.5% of PDAM water in Sleman, while in Yogyakarta, it takes 4.6%, and in Bantul, it takes 0.5%. The average amount of PDAM water used for industrial need is only 3.10%. The low level of the use of PDAM water in industrial sector is caused not only by the insufficient service of PDAM itself but also by the small number of industries in those three areas. However, if the industries take water from wells as their main water resources, a threat towards the sustainability of groundwater resources must be anticipated.

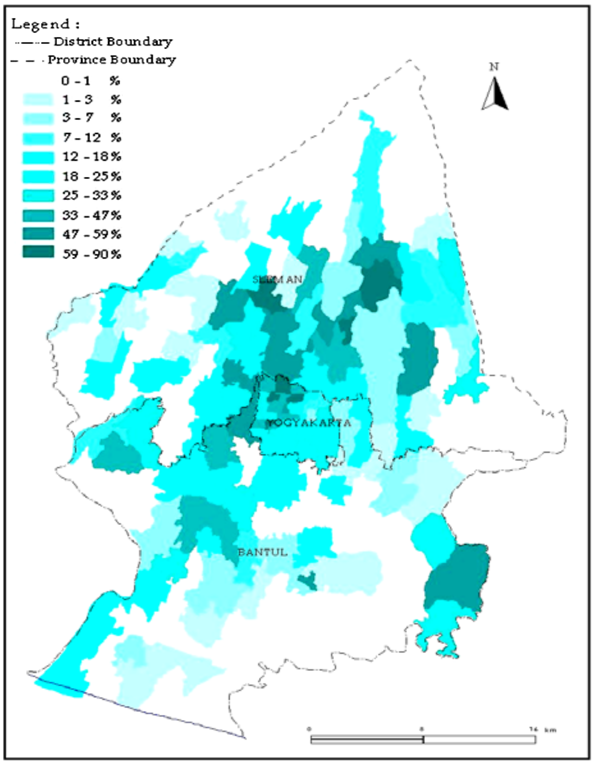


Figure 4. 38: Spatial distribution of PDAM service (Source: analyzed from the list of PDAM (2002; 2003; 2004)

4.6.2.2 Water Quality and Public Perception

Based on the survey and study on the quality of water from people's wells conducted by Bapedalda of DIY in 2001 – 2003 and Puser Bumi (2003), it is shown that, in general, people prefer using water from wells instead of utilizing water from PDAM as their main water resources to fulfill their domestic needs. The quality of water from wells is generally better than that from PDAM. The quality of PDAM water is regarded as not fulfilling the people's expectations.

Physical parameters as color, turbidity, temperature, and total dissolved solid, and the chemical parameters such as smell, taste, pH, electrical conductivity, Fe, Mn, organic content, Cl, and NH_4 show that the quality of the water from wells is generally better than that of the PDAM water. Although some samples of water taken from wells show that the parameter content is still in the tolerable limits of the clean water standard stated in the Health Minister Regulation No. 416/1990, according to many studies, biologically, the quality of shallow well water is far below the standard of drinking water, especially in the urban dense-areas. Some parts of the areas have E Coli of 400 ppm in the well water. NO_3 is another parameter that recently is a trend in some parts of urbanized areas (Kapedal, 2001, Hendrayana, 2005, Bapedalda, 2001, 2002, 2003, 2005-a).

The quality of PDAM water in the west part of Sleman, Yogyakarta, and Bantul is still in trouble, particularly relating to the high content of Fe and Mn, turbidity, and even its unpleasant smell. The turbidity of water taken from the wells is quite low, between 0.4 – 0.78 NTU, compared with the turbidity of PDAM water that varies between 0.6 – 12.4 NTU. Some data of pH from PDAM water are in fact lower than that of water from the people's wells, which in average is normal. For example, the pH of PDAM water located in Kraton Sub-district is 5.64 while Sedayu Sub-district has the pH of 5.89 and Godean Sub-district has the pH of 5.73. The content of Fe taken from the water of shallow-well shows a much lower figure than that of PDAM. As an example, the Fe figure of PDAM water is around 0.5 – 1.5 milligram/liter. Nevertheless, the PDAM water is rather smelly and 'yellowish', has a high content of Chloride and the turbidity of 12.4 NTU.

In general, the water quality of PDAM indeed has not fulfilled the quality standard of drinking water; however, a large amount of it has fulfilled the requirements of clean water quality. The content parameters of PDAM water dominantly causing problems are Fe, Cl, and pH. This condition brings up a perception in the society that the water quality of their wells is better than that of PDAM. However, some of the wells have a continuity problem, especially during the dry season, which then makes their wells often run out of water. Some people that use PDAM water also consider that the quality of water from PDAM has not met their hope since it seems to be dirty and turbid. Another complaint is about the fluctuating flow of water; sometimes it is stuck, even completely stopped. The people's perception can be seen in Table 4.52 and 4.53.

Table 4.52: Public perception on dug-well water use

No	District	Water availability & continuity (%)	Perception on good quality of dug well water (%)	Complaint on dug well water (%)
1	Yogyakarta	88.00	92.38	10.38
2	Sleman	93.73	98.06	3.74
3	Bantul	92.96	93.58	10.99

Source: Puser Bumi (2003)

Table 4.53: Public perception on PDAM water use

No	District	Water availability & continuity (%)	Perception on good quality of PDAM water (%)	Complaint on PDAM water (%)
1	Yogyakarta	85.00	8.47	90.06
2	Sleman	95.00	23.12	49.31
3	Bantul	95.00	39.89	39.38

Source: Puser Bumi (2003)

4.6.2.3 Development of PDAM

As the population grows and industries are increasing rapidly, the need for clean water also continually increases. The production capacity of PDAM all over Indonesia is only able to fulfill 43% of the water needs of the people living in urban areas with 64.4 million people in 2000 (BPS, 2002-a). At the end of 2020, it is estimated that the people living in the urban areas will reach 150.2 million people, and they will consume 125 liters of water per day per capita, and also the target of the service coverage shall reach 70%, which means that the production capacity must be increased at least up to four times. Immediately, PDAM has to get a proper way to handle these problems in order to prevent a worsening of the present conditions through the application of strategic planning and management. The society's expectations are actually high i.e. PDAM should supply clean, cheap, healthy water, and able to fulfill the people's needs in accordance with the health standards and other technical standards. The already developed program shall be executed in the form of either short-term program or long-term program.

The long-term program covers, e.g.:

1) Increasing the service towards the customers by increasing the quality, quantity, and continuity of the water supply for the customers,
2) Decreasing the water leakages in all service areas, e.g. by fixing or replacing water-meters,
3) Fixing up the water treatment system,
4) Minimizing the operational cost by increasing the management efficiency and conducting an integrated supply system,
5) Increasing the company's income by expanding new connections and conducting the re-classification of the customers,
6) Optimizing the human resources available at the company,
7) Changing the accounting system from the manual system to the computerized system, and
8) Establishing cooperation with many parties based on mutual interests and profits.

4.6.2.4 Discussion

The long-term program is expected to establish the integrated and comprehensive master plan. The core of the target of this program is to make PDAM become the institution that supplies healthy clean water with affordable price for the people by still concerning the sustainability principle of water resources and the environment in general. For instance, this program may consist of: (1) Developing the alternative water resources other than the groundwater. Because the sustainability of groundwater has been more critical, the water resources in the surface water and rainwater become the alternative resources to work on. The water of Progo River, which is still relatively proper to be consumed, can be used as the alternative resource. Rainwater which all this time has been wasted, can be collected in certain units as a new alternative water resources, and (2) Developing an integrated model of PDAM service that covers Sleman, Yogyakarta, and Bantul in order to establish an efficient service management. The gravitation system of water supply can be more developed rather than the pumping system, especially in Bantul, by utilizing the water resources from the higher region, such as from Sleman.

Since the demand for water is high and the water supply is still very limited, there is a potential to involve private parties' investment in the drinking water business. The privatization in the clean water sector has been opened following the privatization of the electrical grid, telecommunication, and transportation infrastructures. The Law on Water Resources No. 7/2003 urges the strong privatization rate on the management of water resources. This privatization is also open for the foreign investors through the issuance of the Deregulation Package No. 2/1995. With this privatization act, PDAM is expected to be able to increase the quantity, quality, continuity, and efficiency in supplying clean water. In spite of this, however, the privatization principle still faces a challenge i.e. the anxiety about the loss of spirit that water resources socially is a very important part of people's needs, especially for poor people. Therefore, this privatization has to face a very hard refusal from various elements in the society.

The privatization of clean water in Jakarta in fact fails to increase the service quality although the price of water tends to keep growing. The people cannot trust their expectations into private enterprises or to the overseas help for getting clean water. Therefore, the solution to overcome the water crisis during the economic crisis highly depends on the people as the customers. During the crisis, it will be better if the "save water action" is sounded again. At least, there will be a new paradigm, which prevents the impulsive exploitation on water.

If the people already have the awareness on the importance of water, they will be likely to preserve the water resources. The conservation can maintain the upstream area as the water absorption zone and keep the river clean instead of changing the function of natural lake into a housing area or industrial area. This water conservation effort finally will increase the quantity and all at once quality of the drinking water.

4.7 Water Resources Vulnerability

4.7.1 General

The quality and the quantity of groundwater and water resources in general receive widespread attention all over the world. Based on case studies, the negative impacts have been identified (Civita, 1993). Hydrological and other related information are essential to the effective protection and management of the quality and quantity. Effective protection should be aimed at the prevention of problems, and it requires a sound information base to determine the sustainability of water resources. Water-resource vulnerability maps are important tools to assist in relaying this information.

Originally, water resources vulnerability classification was advised by Vladimirskij in 1961 (Zaporozec, 1993) which is focused on groundwater protection. He called attention to the fact that the maps showing sources of potential groundwater degradation are indispensable. He also suggested the classification of conditions and sources of the water degradation. He, furthermore, prepared a methodology for constructing water vulnerability map. Since 1980s, considerable numbers of vulnerability map have been produced throughout the world, based mostly on aquifer vulnerability.

The concept of the water vulnerability maps relies on the assessment and representation of related important attributes and depends on the scenario and objective for which a particular map is being compiled (Widodo, 2005-b). Initially, the concept of the vulnerability was introduced in terms of both quality and quantity. This research focuses on the quantity vulnerability that assesses the related data such as land use, rainfall, runoff, etc. Maps are important tools to overcome problems of haphazard, uncontrolled development of land use and of undesirable activities having an impact on water quality and quantity.

The vulnerability of water resources is a relative, non-measurable, dimensionless property. The accuracy of the assessment depends on the amount, quality, representation, and reliable data. The principal attributes used in this research assessment of the integrated vulnerability are land use, the ratio of runoff/rainfall, groundwater degradation, groundwater fluctuation, and PDAM services. The secondary important attributes of the assessment are intrinsic factors, which are the thickness of aquifer, the depth of the groundwater level, and the types of aquifers such as poor, minor, or major. Those attributes are then combined to be a water vulnerability map.

The water vulnerability map is a map showing a more or less subjective view of the capacity of physical environment to conserve water resources, primarily in terms of water quantity and quality. It is subjective because the contents of the map must meet the requirements or criteria of map user. The essential purpose of the map is subdivision of an area into several classes showing the different potencies for specified purpose and use. Unlike usual maps from which they are derived, water resources vulnerability maps are time dependent and constantly requiring updating to portray changes in both the characteristics of the water resources system, location and the nature of potential resources that causes water resources degradation.

A vulnerability map consists of the most accurate information assessment of water resources sensitivity to human impact and relative water resources sensitivity between different locations. The map combines several thematic maps of selected physical resource factors into a water-resource vulnerability map that identifies different areas of the sensitivity of water resources to natural and human impacts. The mapping is used as a technique of quantifying the assessment of vulnerability and displaying it in a fashion that makes it useful and convenient for actual application in decision-making process.

The analysis of water vulnerability is conducted through the application of GIS using the method of measured weight overlay. The map of vulnerability is resulted through the conduct of scoring of each parameter, which is multiplied by the weight, and finally the overlay of each layer existing on available parameters.

4.7.2 Methodology

The methods and techniques available for the assessment of water resources vulnerability vary according to the physiography of the study, purpose of the study, and quantity and quality of data. According to Vrba (1994), the methods can be grouped into three basic categories:

1) The hydrological setting methods are universally suitable for large areas with a variety of natural features. The methods involve the comparison of a subject area to criteria judged to represent vulnerable conditions,
2) The parametric methods include matrix systems, rating systems, and point count systems. The overall procedures for the systems begin with the selection of parameters as the representative

for vulnerability assessment. A multiplier may be assigned to each parameter to reflect the relationships among the parameters and their importance for the assessment. Each of the selected parameters has a given range, which is subdivided into discrete hierarchical intervals. Each interval is assigned a value reflecting the relative degree of vulnerability. The rating points are the summed. The final numerical score is divided into segments expressing a relative vulnerability degree,

3) Analogical relations and numerical models are based on mathematical symbols resulting in a vulnerability index. These methods are generally applicable for the assessment of specific vulnerability only.

The research selects and develops the second method by combining physical data and geographical information systems. The vulnerability is based on related hydrological evaluation from both anthropogenic and natural impacts. This method offers an excellent advantage to perform the tasks. Data and detail scoring and weighing systems are described in Table 4.54 and 4.55.

A close correlation exists between the densities of data, the number of data obtained, and the proposed map scale. On the other hand, for areas in which the density and the number of data are low, only simple assessment methods can be used and resulting in a small-scale map. Vulnerability maps are compiled for practical uses; therefore, they are prepared as not too sophisticated and over crowded with data, which may lead to misinterpretation or misuse. In order to have such communicative maps, the analyzed results are generalized to be simpler.

The vulnerability assessment requires hydrological and other related data (Wang, 1999). Data can be accessed from government agencies, universities, research institutions, and consulting companies. However, water quality data are not completely available; therefore, it is difficult to be analyzed spatially. The rainfall data are analyzed directly from primary data. The runoff is calculated by using curve number method. Land use is directly analyzed from LANDSAT TM image. The map of PDAM service distribution is analyzed from the bill data of each office and controlled by assessing three-year data. Geological, hydrogeological, and topographical data are derived from secondary data.

The data used in this research include:

1) The Topographic Map of Indonesia with the scale of 1: 25,000, Bakosurtanal (2003),
2) The land use change map based on LANDSAT images of 1994, 1996, 1998, and 2000,
3) The rainfall data,
4) The runoff, which is based on the model of Curve Number,
5) The data of degradation and fluctuation of groundwater, which are as secondary data through the field verification test,
6) Data of the degree of PDAM services, and
7) The geohydrological data focusing on aquifer types.

This research consists of two main steps of activities, these are:

1) *Data Base Preparation*: The database used for the shaping model of the vulnerability of water crisis is in the form of spatial database. The database is prepared in the form of vector.

2) *Result-Analysis*: In order to determine the degree of water vulnerability anthropogenically, the application of quantitative approach of the weighed-standardized overlay is conducted. This approach is done by giving certain standard or value on each variable that will be used in this step and giving the weight value or pair-of-scales factor on each variable. The vulnerability of water crisis discussed in this research especially is the anthropogenic vulnerability of water crisis that is determined as derived from the overlay result of the parameters of land use, runoff/rainfall ratio, groundwater surface fluctuation, groundwater surface degradation, and the degree of PDAM service. In the meantime, the overlay of the types of aquifer, which are as the part of natural parameter, is done directly using other parameters without doing the measured weighing. The types of aquifer will anthropogenically complete the region crisis so that the vulnerability developed from such condition will result the more comprehensive information of the vulnerability level.

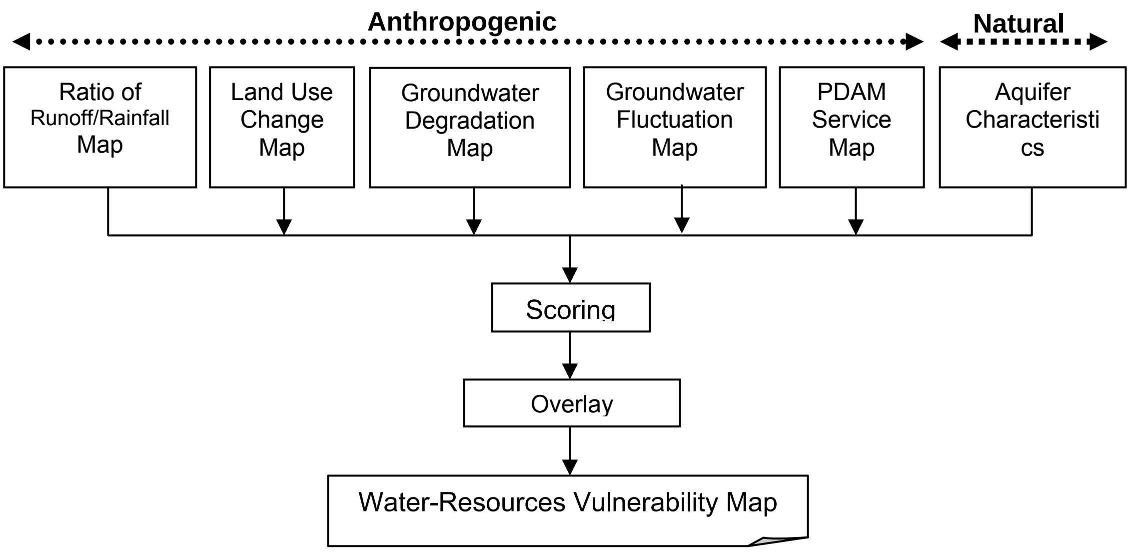


Figure 4.39: Flowchart of steps on water-resources vulnerability mapping

4.7.2.1 Anthropogenic Parameters

4.7.2.1.1 Land Use

The data show that the extent of agricultural field is getting narrower to fulfill the need for housing area, which keeps increasing. The large extent of housing areas, related to dense population, will tend to increase the quantity of runoff, i.e. decrease of groundwater infiltration. Such problem will be more complicated along with the increasing rate of the groundwater extraction by the people in densely populated areas and the growing industry in that area. This population density will also potentially increase groundwater pollution.

4.7.2.1.2 Ratio of Runoff/Rainfall

A ratio of runoff/rainfall is a number that shows the comparison between the volume of the surface runoff and the volume of the rainfall. For example, if the runoff/rainfall ratio is 0.1 it means that 10 percents of the total rainfall will be surface runoff. Mathematically, the runoff/rainfall ratio can be explained as follows: *runoff* (mm)/rainfall (mm) x 100 %.

The value of runoff/rainfall ratio is one of the indicators used to determine whether a certain watershed or area has experienced physical disturbance or not (Asdak, 2007). A high value of runoff/rainfall ratio shows that much rainfall becomes surface runoff rather than being absorbed into the ground (Sri Harto, 2000). This fact causes a little loss from the aspect of the water resources conservation since the volume of water, which turns into groundwater, will decrease. Another form of loss is that if the amount of the rainfall volume, which turns into surface runoff, becomes larger, the threat of the erosion and flood events will be bigger. The number of runoff/rainfall ratio is between 0 % - 100 %. The number 0 % indicates no runoff, but all rainfall is intercepted and/or infiltrated. The number of 100 % shows that all rainfall flows off as surface runoff.

4.7.2.1.3 Groundwater Degradation

The groundwater surface in a certain area should always be in a balanced condition, which means that it does not change much in height; i.e. there is a balance between water input and output (Hendrayana, 2003). However, if there is too much interference by the people in that area, especially if they make use of groundwater as drinking water or for activities such as washing, taking a bath, cooking, agriculture, and industry, the condition of the groundwater will deteriorate year by year, in both quantity and quality. This happens when the extraction of groundwater is larger than the groundwater recharge volume. To avoid this, legislation is needed for protecting the *recharge* area, limiting the use of groundwater, and adding the quantity of artificial groundwater recharge (UGM, 2001, Sri Harto, 2000).

The data about the decrease in groundwater level were gained by comparing the maps of the annual dry season isohip in 1983, 1995, 1998 with the isohip maps of the rainy seasons 1983, 1995, and 1998 (Hendrayana, 2003). In this research, the inflow consists of the rainwater and the surface water, which is infiltrated becoming groundwater, while the outflow consists of springs, and the use of groundwater. The volumes of inflow among the years of 1983, 1995, and 1998, are assumed as the same, and the same as the flow of groundwater, which comes out of the ground. Thus, the change on the position of the groundwater surface is caused by the increasing amount of the use of groundwater done in the same period. It is also assumed that there are not any changes in the flow rate or debit of spring in 1983, 1995, and 1998 (Wilopo, 1999, UGM, 2001).

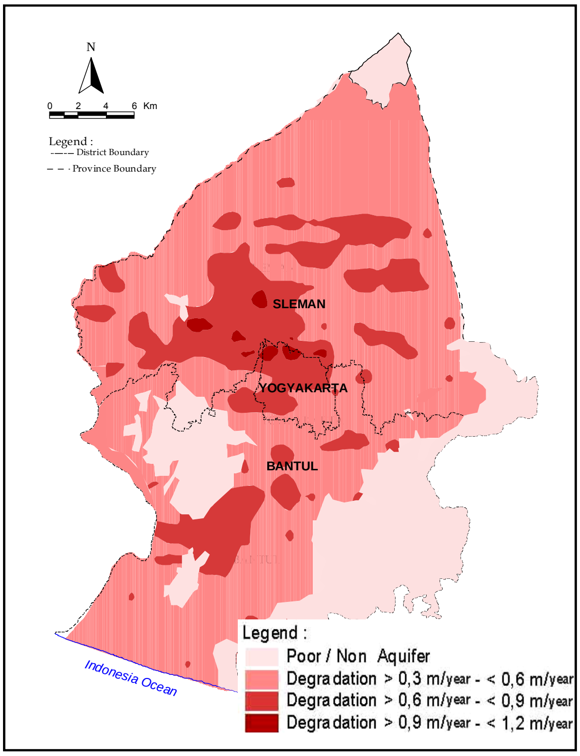


Figure 4.40: Spatial distribution of groundwater degradation level (Source: adapted from Wilopo, 1999)

Furthermore, it is explained that in DIY, specifically in the urban areas with high population density, there has been a degradation of the groundwater surface caused by the very high usage of groundwater with various degradation range, between 0 – 0.3 m/year up to more than 0.9 m/year (Figure 4.40). The degradation of the groundwater surface may influence the people's wells, which should be dug deeper during the dry season to get groundwater or by adding the power of the water pump with bigger power to get more water. The degradation of groundwater surface that continually occurs potentially can be worse by the existence of land *subsidence* (UGM, 2001). The aquifer that used to be filled with groundwater is empty because there is groundwater degradation and the groundwater above it cannot endure the burden of the building above it; therefore, the ground sinks several centimeters per year, such as in Jakarta, Bandung, and other big cities (Asdak, 2007). Information about the regions that have faced the degradation of groundwater surface can be used as the reference of the areas, which are vulnerable of facing groundwater crisis, and as the reference for the government to decide on laws and regulations to prevent groundwater degradation.

4.7.2.1.4 Groundwater Fluctuation

The fluctuation of groundwater surface is the changing in the elevation of groundwater surface, either on the phreatic surface of free aquifer or piezometric surface of stressed-aquifer that is caused by the changing of atmospheric pressure in the aquifer. Each change in the pressure of groundwater will cause the changing of the groundwater level. Other factors which influence the groundwater level either directly or indirectly are the flow variation, the change of weather, the rise and fall of the tide, urbanization, earthquake, burdening from outside and the ground degradation (Hendrayana, 2003, UGM, 2001).

The types of groundwater fluctuation include:

1) *Secular Fluctuation*: Secular fluctuation of the groundwater happens at the range of long annual events since the dry season is longer or shorter than the normal one, and the rainfall that happens is above or below the annual average volume. However, it is necessary to be concerned that the large or small amount of rainfall is not the only indicator that causes the groundwater fluctuation to happen.
2) *Seasonal Fluctuation*: This fluctuation happens because of the rainy season and the dry season.
3) *Temporary Fluctuation*: A temporarily fluctuation of the groundwater surface happens during a short time range. This fluctuation may happens since there is a temporarily pumping up activity, such as pumping up the groundwater for the domestic need, which causes the changing of the groundwater surface and its environs (Todd, 1980).
4) *Surface flow*: The surface flow of rivers can function as the influent stream and as the effluent stream. It will be as the influent stream if the position of the surface flow is shallower than the position of the groundwater surface. It will be as the water receiver/effluent stream if the position of the surface flow is lower than the position of the groundwater surface (Sri Harto, 1999).

The factors, which cause groundwater surface fluctuation at the non-pressured aquifer, for example are (Adji and Noordianto, 2006, UGM, 2003):

1) *Evapotranspiration*: Free aquifer with the condition of the groundwater surface, which is not too deep, will face a daily fluctuation caused by the evapotranspiration. The evapotranspiration causes the release of the groundwater to the atmosphere. The large or small amount of the groundwater losing through the evapotranspiration process depends on the capillary zones, the depth of the plant root, and factors that influence the evapotranspiration itself. White (Todd, 1980) gave a formula to count the loss of groundwater caused by the evapotranspiration, that is Vet = Sy (24 h $\pm$ s); Vet is the groundwater loss caused by the evapotranspiration, Sy is *specific yield*, h is the slanting of the curve, and s is the increase of the groundwater in 24 hours.

2) *The condition of weather:* The change of the air pressure, rainfall and groundwater, with the change on the pressure is called the barometric efficiency, which is formulated as B = γ Δh/ΔPn, where B is the barometric efficiency, γ is the water specific gravity, Δh is the changing of the piezometric surface, and ΔPn is the changing of the air pressure. The influence of rain on the groundwater surface is clear enough to understand. When the rain is falling, the groundwater surface will increase, while if there is no rain for a long time, the groundwater surface will decrease (UGM, 2001).

Figure 4.41: A dug well in Prambanan has a serious groundwater fluctuation between the dry and rainy seasons (Photo: Widodo, July 2005)

3) *Wind*: The influence of wind on the groundwater fluctuation is only temporary. This condition may happen when the wind blowing over wells causes the air pressure over the wells to decrease, thus the groundwater level will increase.

4) *The rise and fall of the tides*: The changing of the rise and fall of the river water and the ocean in fact influences the groundwater surface.

5) *Urbanization*: Urbanization causes the changing of the groundwater surface since there is an increase in the groundwater taking and a decrease in the groundwater filling up.

6) *Earthquake*: The observation result shows that an earthquake influences the groundwater. This matter is shown by the decrease and increase in the groundwater surface of wells, the changing of the spring flow rate, the emergence of new springs, and also the water and mud eruption out of the ground. However, the event that often happens is the existence of a little fluctuation on the *freatic* surface.

7) *Burdening from outside*: The elastic character of the confined aquifer influences the changing of hydrostatic pressure whenever there is a change in the burden (UGM, 2001). A simple

example of this phenomenon is the changing of the groundwater surface in the wells near a railway track; at the time a train passes by, there will be an increase in the burden of the ground, thus the groundwater surface increases.

8) *The decrease in the ground*: The decrease in the ground surface can change the groundwater surface, i.e. causing a decrease in the groundwater surface in a certain area.

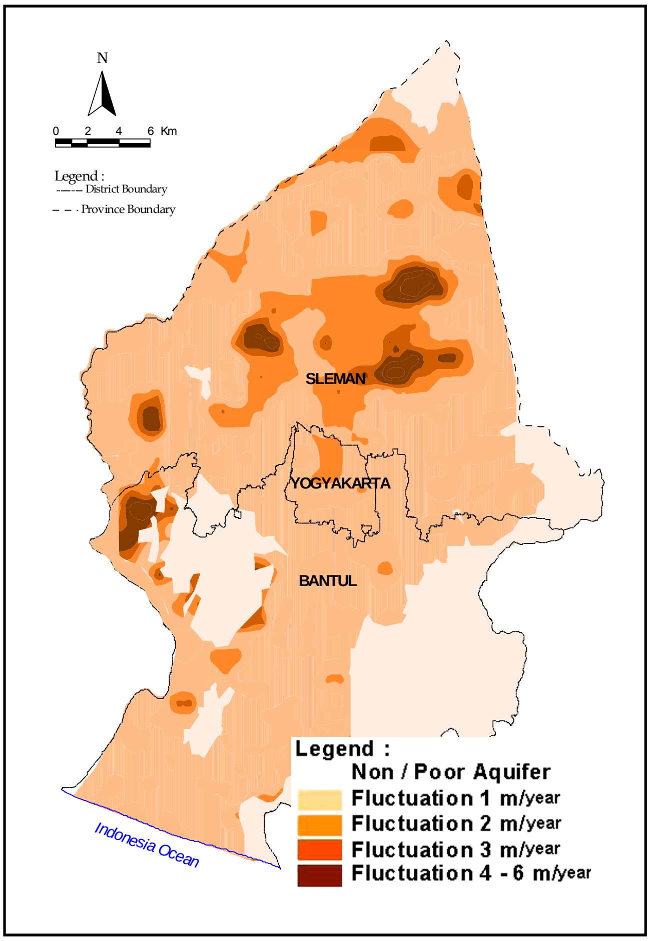


Figure 4.42: Spatial distribution of groundwater fluctuation level (Source: adapted from Wilopo, 1999)

The data of the groundwater fluctuation were obtained from the secondary data of 1998, which were about the research on the groundwater management of DIY that had been done by the Mining Service of DIY in its cooperation with the Geological Engineering Faculty of UGM (UGM, 2001). This data had been verified on the field in July 2005 by interviewing the local people who experienced the fluctuation. This verification is meant only to clarify since it is only done through the conduct of interview towards the people; it is subjective. Figure 4.41 illustrates the field verification by visiting the dug well of Mr. Suwito in Prambanan, which has serious groundwater fluctuations. The interview result shows that more than 90 % of the respondents showed the same indication with that of the available condition in the research data.

The area that has a high groundwater fluctuation indicates that it has a bad condition of groundwater since there is an imbalance between the filling up and the taking of the groundwater (Figure 4.42). This matter is specifically caused by human activities of using the groundwater without considering the condition of aquifer and the available groundwater quantity, so it often happens in the area that has a high density of population; its groundwater fluctuation is higher than that of the sub-urban where the its population is not very dense. Through the mapping of the groundwater surface fluctuation, which area has experienced the groundwater crisis can be found by using the indicator of groundwater fluctuation, and it also can be used to find the trend and the direction of the groundwater surface fluctuation, specifically which directs to a water crisis. This matter will be useful for determining the policy relating to the groundwater resources management.

4.7.2.1.5 PDAM Service

The low quality of the groundwater especially that is observed in the people's wells shows that the existence of PDAM (piped water supply company) is important for people as the alternative water resources. Thus, this study assumes that the absence of PDAM service in a certain place means that the place has the vulnerability of water resources. Based on this, the use of clean water from the pipe-system becomes a choice for people, specifically those who do not have wells or who face problems of groundwater in their wells, either in its quantity or in quality. However, considering the condition of PDAM whose coverage of service is low, it is a quite difficult problem for the people who cannot use groundwater as their clean water resources since there are problems in either its quantity or quality. Therefore, this situation can cause clean water crisis, specifically in the places that are unreachable from the Municipal Waterworks (PDAM, 2003, Puser Bumi, 2001). The detailed explanation of PDAM can be read in the Sub-Chapter 4.6.

4.7.2.2 Natural Parameters

The natural parameters are taken from the types of aquifer based on the potency of the storing and distribution of groundwater. This type of aquifer consists of:

1) Major aquifer, which covers Merapi aquifer system,
2) Minor aquifer, which covers sand dune formations,
3) Poor aquifer, which covers the regions of Sentolo, Sambipitu, and Wates formations,
4) Non-aquifer, which covers the region of Kebo Butak Semilir formation. The aquifers of type 2, 3, and 4 are types of aquifer that are not potential if their groundwater resources is developed.

4.7.3 Data Analysis of Water Vulnerability

The vulnerability map is gained through the conduct of overlay on several parameters that influence the crisis level. The anthropogenic parameter is assumed as having a crisis level which covers:

1) Land use,
2) Ratio of runoff/rainfall,
3) Groundwater surface degradation,
4) Groundwater surface fluctuation, and
5) Level of PDAM services.

The analysis process used in this section is the type of weighed-in stages, which means that besides each parameter is classified into several classes; there are also different weights between one parameter and the others. The volume of the weight of each parameter is in accordance with its influence degree on the crisis level, the bigger the influence, the bigger its weight value; the lesser the influence, the smaller its weight value. As a supporter, the weight of each parameter is also counted according to the accurate level of the data; if the data come from the accurate source and are reliable, the result will also contain/have a high reliability.

The secondary data, which are taken as parameters, are the degradation and fluctuation of the groundwater surface. Before the data are used in this analysis, the validation test is previously done. The way of doing the validation is by determining samples including 30 people chosen from each parameter. The field verification is done by conducting interview towards the people who have an open well because they know the estimation of the change in their well water, either its degradation or its fluctuation. This interview is indeed very subjective. The result of this interview is only as a data clarification that is used in this section. The result of the verification test through the conduct of interview gives the validation level of the groundwater degradation, which reaches 90%, while the validation for the data of groundwater fluctuation reaches 95%. This data validation was done during May – June 2005.

The degree or value of each variable shows the influence of that class on the water vulnerability. The variable of the crisis potency whose value = 1 shows that classes of that variable have low potency/influence on the water crisis vulnerability; the biggest influence on the water vulnerability is shown by the value = 5.

Each variable used in this research has a different influence on the water vulnerability. In order to show the existence of that variation, the weight-factor of each variable is also determined. The value of the weight-factor of each variable varies depending on how deep the influence of that variable on water vulnerability is. The variables, which are assumed as having deep impact, will also have big weight.

Table 4.54: Parameters and scoring system

No	Parameter	Urgency of Data (%)	Data Reliability (%)	Total Score (%)	Weight
1	Land use	100	95	195	23
2	Ratio of runoff/rainfall	100	95	195	23
3	Degradation of groundwater	95	90	185	18
4	Fluctuation of groundwater	95	90	185	18
5	Piped water supply service	90	85	175	18
T o t a l				935	100

Source: modified from Vrba (1994)

The weight is the multiplier number of each score on every class of a certain parameter. Therefore, it can result in the total score of each class of a certain parameter. For example, for the parameter of the land use for housing area of class 5, the final score of this parameter is the weight of land use x the score of housing area of class 5, which means 20 x 5 = 100. The following is the list of weights for all determining parameters of the crisis level (Table 4.55).

The type of overlay used in this part is the union type, thus the mathematical operation, which is valid for the over-piled process, is by adding the value of each variable used as estimation after it is being multiplied by the weight-factor. In a simple way, this shaping can be shown through the following formula (Bonham-Carter, 1998, Civita, 1993):

$$Pk = (V1 * B1) + (V2 * B2) + (V3 * B3) + (V4 * B4) + (V5 * B5)$$

where:

Pk	= total score of water vulnerability	B1	= factor of V1
V1	= variable for land use	B2	= factor of V2
V2	= variable for the ratio runoff/rainfall	B3	= factor of V3
V3	= variable for groundwater degradation	B4	= factor of V4
V4	= variable for groundwater fluctuation	B5	= factor of V5
V5	= variable for PDAM service		

The degree of water vulnerability resulting from the formula has various values; therefore, in order to ease the analysis of the total degree of each mapping unit, it is classified into 5 (five) classes of water crisis vulnerability, including very low, low, moderate, high, and extremely high. Table 4.56 is the table of the water vulnerability classes.

Table 4.55: Description of parameters, classes, and scores

No	Parameter	Class	Score
1	Land use	Non settlement	0
		Settlement - class 1	1
		Settlement - class 2	2
		Settlement - class 3	3
		Settlement - class 4	4
		Settlement - class 5	5
2	Ratio of runoff/rainfall	Low (< 46%)	1
		Moderate (46%--63%)	2
		High (> 69%)	3
3	Degradation of groundwater	Low (< 0,3 m/year)	1
		Moderate (>= 0,3 - < 0,6 m/year	2
		High (>= 0,6 - < 0,9 m/year)	3
		Extreme (>= 0,9 m/year)	4
4	Fluctuation of groundwater	Low (0 - 3 meter/year)	1
		Moderate (3 - 6 meter/year)	2
		High (> 6 meter/year)	3
5	Piped water supply service	Very high (> 75%)	1
		High (50% - 75%)	2
		Medium (25% - 50%)	3
		Low (0% - 25%)	4
		No service (0%)	5

Source: modified from Vrba (1994), Wilopo (1999), PDAM (2000)

Because the file of each parameter is quite big, the software used in this research is unable to do all-at-once overlay; therefore, each parameter is divided into eight parts. The overlay is done one by one on each parameter.

The type of overlay used in this research is the union type, so that the mathematic operation, which is valid for the over-piled process, is the addition. The result of the overlay is the total class value, which is the amount of the total score of each parameter. Then, the result of the overlay is categorized into 5 classes of crisis as mentioned above.

4.7.4 Results and Discussion

The water crisis is caused by anthropogenic processes. The vulnerability of water in this research is in terms of its quantity. The dimension of the water crisis is gained from the over-piled parameters mentioned above. Based on the result of the overlay, it can be seen that in the research area, the water crisis can be divided into 5 categories of crisis. The following is the discussion of the overlay result on water crisis (Figure 4.43).

Table 4.56: Classification of vulnerability

No	Vulnerability Classification	Total Score	Criteria	Description
1	I	21-81	Very low	Areas that have very good water resources condition and have almost no parameters that are potentially significant in degrading water resources to be vulnerable
2	II	82-143	Low	Areas that have good water resources condition, having very little parameters, which are potentially significant in degrading water resources to be vulnerable
3	III	144-205	Medium	Areas, which have moderate water resources condition and are potential to be worse without a proper management, and vice versa
4	IV	206-267	High	Areas, which have bad water resources condition, having some parameters that potentially contribute in degrading water resources, called high vulnerable areas.
5	V	268-329	Extremely high	Areas, which have very bad water resources conditions, having many parameters, which potentially contribute in degrading water resources, called extremely high vulnerable areas.

Source: modified from Vrba (1994)

4.7.4.1 Areas of Extremely High Vulnerability

Areas of extremely high vulnerability can be found in 2 regions. The location of the extremely high vulnerability areas are presented in Table 4.57. It can be seen that the majority of the areas, which are very vulnerable of having a water crisis, are located in Yogyakarta with the extent of 15.94 km^2 or 91.6% of the total extent of the areas that are very vulnerable of having a water crisis. The rests are located in Sleman covering the extent of 1.46 km^2 or 8.4%. All sub-districts in Yogyakarta have experienced very high vulnerability. Indeed, some parts of the region in each sub-district are not included as very vulnerable. Sleman has the areas, which are very vulnerable, located in 5 sub-districts that in fact are generally the nearest ones from Yogyakarta.

The large extent of the very vulnerable areas located in Yogyakarta is because Yogyakarta has a very high population density and a very large number of housing areas, and the people’s activities that often do the land use change from rice fields, yards, or plantation into housing areas, offices, or industrial centre s. The process of land use change causes the high runoff/rainfall ratio; there is much rainwater that falls into the ground and becomes runoff without any chances to be infiltrated into the ground, thus there is much rainfall that directly flows to the canals and is uselessly wasted that it cannot fill up the groundwater supply.

Besides, in the urban areas, there are many people consuming groundwater abundantly, this will cause a strong groundwater fluctuation and degradation, which can cause the city to be very vulnerable of water crisis. Sleman likewise, specifically Depok, Mlati, Godean, and Ngaglik sub-districts previously were rural areas, but now they are changed into urban areas as the rapid growth exists. They are characterized by the existence of a large number of housing area, trading centre, industrial centre, and the increasing clean-water need from the groundwater while its availability tends to decrease all the time. Such situation makes those areas potentially face a water crisis.

Table 4.57: List of extremely high vulnerability areas

No	District	Sub-district	Village	Area (km^2)
1	Sleman	Godean	Sidorejo	1,46
		Mlati	Sinduadi	
		Depok	Caturtunggal	
		Ngaglik	Minomartani	
		Depok	Condongcatur	
2	Yogyakarta	Danurejan	Bausasran, Tegalpanggung	15,94
		Gedongtengen	Sosromenduran, Pringgokusuman	
		Gondokusuman	Terban, Klitren, Demangan, Baciro Ngupasan, Prawirodirjan	
		Jetis	Cokrodiningra, Gowongan	
		Kotagede	Rejowinangun, Purbayan	
		Kraton	Panembahan, Kadipaten, Patehan	
		Mantrijeron	Suryodiningra, Mantrijeron	
		Mergangsan	Wirogunan	
		Ngampilan	Ngampilan	
		Pakualaman	Notoprajan, Purwokinanti	
		Tegalrejo	Gunungketur, Bener	
		Umbulharjo	Tegalrejo, Kricak, Semaki	
		Wirobrajan	Tahunan, Warungboto, Pakuncen Wirobrajan, Patangpuluhan	
T o t a l				17.40

Table 4.58: Areas of extremely high vulnerability

No	District	Area of Extremely High Vulnerability	
		(km^2)	(%)
1	Sleman	1,46	8.4
2	Yogyakarta	15.94	91.6
Total		17.4	100.00

The areas included in the category of very vulnerable of facing a water crisis needs a priority to be specifically considered, for example through the conduct of controlling act on the activities of the groundwater taking done by individuals, community groups, or institutions that is not based on the valid principles, rules, and laws. The control is done regularly by checking the license of the groundwater taking. If it is found out that there is no license, the related party must immediately close its groundwater wells because if we let it happen, it will damage the environment, especially the availability of groundwater in Yogyakarta basin. Table 4.58 does explain the extent and percentage of the extremely high vulnerability areas in the research location.

4.7.4.2 Areas of High Vulnerability

High vulnerability area is defined as the area that potentially can experience a water crisis. The areas included in the criteria of high vulnerability remain in 3 regions. The location of the high vulnerability area can be seen in Table 4.59.

According to Table 4.59, it can be seen that most areas included in the category of high vulnerability in the region of Sleman cover the extent of 50.70 km^2 or 67.2% of the total extent of the high vulnerability areas. The rests are located in Bantul covering 10.02 km^2 or 13.3% and in Yogyakarta that covers 14.77 km2 or 19.6%.

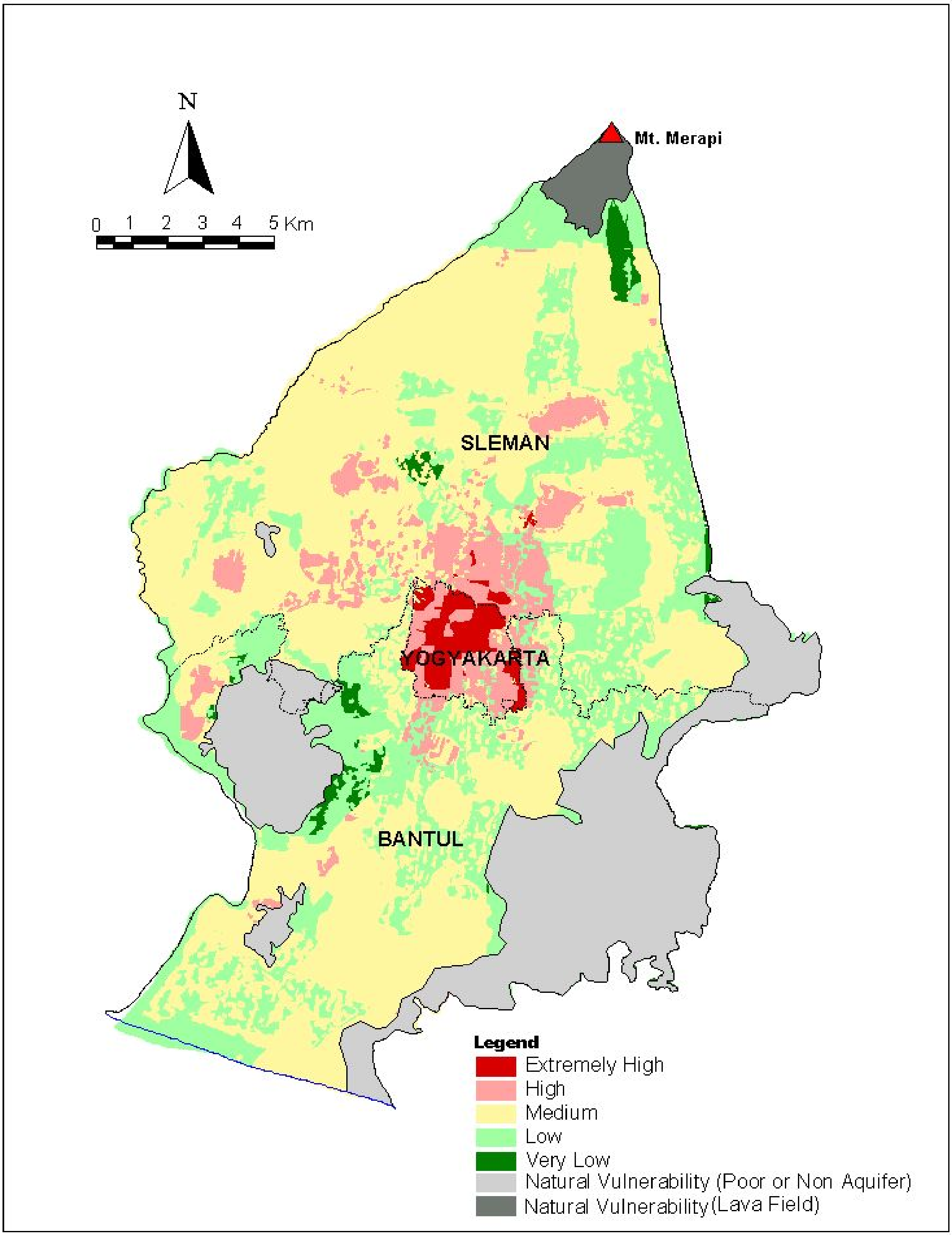


Figure 4.43:Spatial distribution of water vulnerability level

The large number of high vulnerability areas in Sleman is caused by the high population growth and the development of the local region. Since 1990s, there has been a phenomenon of housing area development, which is very significant in Sleman. Fifteen (15) sub-districts out of 17 sub-districts located in Sleman in fact have been included in the category of high vulnerability areas. The government has tried to limit the development rate, but it seems that the result is still far from being successful. The land use change, where lands are previously in the form of rice field, yard, or plantation and have changed specifically into housing areas, causes a serious threat on the sustainability of the water resources in this area and the space below it. The more often floods that happen in Yogyakarta urban area become a real indication of the existence of increasing runoff coming from the upstream area of Sleman.

Table 4.59: List of high vulnerability

No	District	Sub-district	Village	Area (km2)
1	Bantul	Banguntapan	Banguntapan, Jagalan, Tamanan Wirokerten	10.02
		Bantul	Ringinharjo	
		Kasihan	Ngestiharjo, Tirtonirmolo	
		Sedayu	Argosari	
		Sewon	Panggungharjo, Bangunharjo	
2	Sleman	Cangkringan	Kepuhharjo, Glagahharjo, Wukirsari	50.70
		Depok	Caturtunggal, Condongcatur, Maguwoharjo	
		Gamping	Trihanggo, Nogotirto, Banyuraden	
		Godean	Sidomoyo, Sidorejo, Sidoagung, Sidokarto, Sidoarum	
		Kalasan	Selomartani	
		Minggir	Sendangarum	
		Mlati	Sumberadi, Tlogoadi, Tirtoadi, Sendangadi, Sinduadi	
		Moyudan	Sumberagung, Sumbersari	
		Ngaglik	Sariharjo, Sukoharjo, Sardonoharjo, Sariharjo, Minomartani	
		Ngemplak	Umbulmartani, Widodomartani, Wedomartani	
		Pakem	Harjobinangun, Candibinangun	
		Sayegan	Margomulyo, Margoagung, Margoluwih	
		Sleman	Caturharjo, Triharjo, Pendowoharjo	
		Tempel	Mororejo, Pondokrejo	
		Turi	Girikerto	
3	Yogyakarta	Danurejan	Suryatmajan	14.77
		Gedongtengen	Pringgokusuma	
		Gondokusuman	Terban, Kotabaru	
		Jetis	Bumijo, Cokrodiningra	
		Kotagede	Prenggan	
		Kraton	Panembahan	
		Mantrijeron	Gedongkiwo, Suryodiningra, Mantrijeron	
		Mergangsan	Wirogunan, Keparakan, Brontokusuman	
		Ngampilan	Notoprajan	
		Pakualaman	Gunungketur	
		Tegalrejo	Karangwaru, Kricak, Bener, Tegalrejo	
		Umbulharjo	Sorosutan, Mujamuju, Warungboto, Tahunan, Pandeyan, Giwangan	
		Wirobrajan	Pakuncen, Wirobrajan	
Total				75.49

The areas included in the category of high vulnerability also need to be the priority of special attention, for example through the conduct of controlling act on the developing system of housing areas by limiting the extent of the space for housing areas and by making the zones of development management. Table 4.60 explains the extent and percentage of the high vulnerability of water-crisis areas in the research location.

Table 4.60: Areas of high vulnerability

No	District	Area of High Vulnerability	
		(km^2)	(%)
1	Bantul	10.02	13.3
2	Sleman	50.70	67.2
3	Yogyakarta	14.77	19.5
Total		75.49	100.00

4.7.4.3 Areas of Medium Vulnerability

The medium vulnerability area is defined as the area that potentially can experience a water crisis. The locations included in medium vulnerability of water-crisis area are shown in Table 4.61. According to Table 4.61, the medium vulnerability areas cover 3 regions; they are Bantul, which covers the extent of 136.79 km^2 or 29.3% of the total extent of the medium vulnerability areas, Yogyakarta, which covers the extent of 2.15 km^2 or 0.5 %, and Sleman, which has the extent of 328.68 km^2 or 70.2%. In Sleman, the medium vulnerability areas are located in 17 sub-districts; in Yogyakarta, the medium vulnerability areas are located in 8 sub-districts, while in Bantul, the areas included in this category are located in 13 sub-districts. The occurrence of medium vulnerability areas, for example, is caused by the anthropogenical influence, i.e. the human activities of land use change by changing the yard, garden/plantation or rice field into housing area or industry. It increases the volume of rainwater that becomes runoff, from which there will be only a small volume of rainwater is absorbed into the ground and much of it becomes the surface flow rate. Besides, there are activities of pumping up the groundwater at an abundant volume that cause the degradation of the groundwater surface; thus, such area is potentially vulnerable of facing a groundwater crisis.

In Bantul and Sleman Regencies, the medium vulnerability areas are located in the areas influenced by the development of Yogyakarta, so the density of those areas continually increases according to the number of housing area and industrial activities. There are many yards or rice fields changed into housing area or business place; this situation will lessen the ability of rainfall to be absorbed into the ground, and much rainfall will turn into surface runoff. Many areas located in Bantul and Sleman are started to be in the category of medium vulnerability areas; thus, it needs to be seriously overcome through the conduct of limitation on the flow rate of taken water to be less than 200 liters/minute. This is done as an effort to control the taking of groundwater whose surface becomes lower each time. It is also suggested that all businesspersons who take the deep groundwater or shallow groundwater economize its usage. Besides, it is instructed to people and businesspersons to make absorption wells around factory areas, make rainwater reservoirs, do the reforestation, recycle the wastewater, and manage alternative water resources. Those are meant to prevent the areas from being in a very critical condition such as Yogyakarta and some parts of Sleman. Table 4.62 explains the extent and the percentage of the areas that are medium vulnerable of having a water crisis located in the research location.

4.7.4.4 Areas of Low Vulnerability

A low vulnerability area is defined as an area that is potential to be vulnerable of facing a water crisis. The areas included in the criteria of low vulnerability are in Table 4.63. Based on the data from Table 4.63, the low vulnerability areas cover three regencies and the widest extent is in Sleman, the next is in Bantul, and the smallest extent is in Yogyakarta. Sleman has low vulnerability areas in 16 sub-districts with the extent of 134.12 km^2 or 64.8% of the total extent of the low vulnerability areas.

Table 4.61: List of medium vulnerability areas

No	District	Sub-district	Village	Area (km2)
1	Bantul	Bambanglipuro	Sumbermulyo, Mulyodadi	136.79
		Banguntapan	Baturetno, Tamanan, Banguntapan Potorono, Singosaren, Jambidan	
		Bantul	Bantul, Trirenggo, Sabdodadi, Ringinharjo, Palbapang	
		Imogiri	Karangtalun, Kebonagung	
		Jetis	Sumberagung, Patalan, Canden	
		Kasihan	Ngestiharjo, Tirtonirmolo, Ngestiharjo	
		Kretek	Tirtomulyo, Donotirto, Tirtosari, Tirtohargo	
		Pleret	Wonokromo, Pleret	
		Pundong	Srihardono, Panjangrejo,	
		Sanden	Gadingsari, Murtigading, Srigading	
		Sedayu	Argosari	
		Sewon	Bangunharjo, Panggungharjo, Timbulharjo,Pendowoharjo	
		Srandakan	Trimurti, Poncosari	
2	Sleman	Berbah	Kalitirto, Tegaltirto, Jogotirto, Sendangtirto	328.68
		Cangkringan	Glagahharjo, Kepuhharjo, Umbulharjo, Wukirsari, Argomulyo	
		Depok	Condongcatur, Maguwoharjo, Caturtunggal	
		Gamping	Trihanggo, Nogotirto, Banyuraden	
		Godean	Sidomoyo, Sidoluhur, Sidoagung, Sidoarum, Sidokarto, Sidomulyo	
		Kalasan	Tamanmartani, Selomartani, Purwomartani,Tirtomartani	
		Minggir	Sendangmulyo, Sendangrejo, Sendangsari Sendangagung, Sendangarum	
		Mlati	Sumberadi, Tlogoadi, Tirtoadi, Sinduadi	
		Moyudan	Sumberagung, Sumberarum, Sumbersari Sumberrahayu	
		Ngaglik	Donoharjo, Sariharjo, Sukoharjo Sardonoharjo, Sinduharjo, Minomartani	
		Ngemplak	Umbulmartani, Widodomartani, Bimomartani, Wedomartani	
		Pakem	Hargobinangun, Purwobinangun, Candibinangun, Pakembinangun, Harjobinangun	
		Prambanan	Bokoharjo, Sambirejo, Madurejo,Sumberharjo	
		Seyegan	Margoagung, Margomulyo, Margokaton,Margoluwih	
		Sleman	Trimulyo, Caturharjo, Triharjo,Pendowoharjo, Tridadi	
		Tempel	Merdikorejo,Lumbungrejo, Margorejo,Pondokrejo, Mororejo, Sumberrejo,Tambakrejo, Banyurejo	
		Turi	Wonokerto, Bangunkerto, Donokerto,Girikerto	
3	Yogyakarta	Gondokusuman	Baciro	2.15
		Jetis	Cokrodiningra	
		Kotagede	Prenggan, Rejowinangun	
		Mantrijeron	Suryodiningra	
		Mergangsan	Wirogunan, Keparakan	
		Tegalrejo	Kricak, Bener, Karangwaru, Tegalrejo	
		Umbulharjo	Sorosutan, Mujamuju, Tahunan	
		Wirobrajan	Pakuncen, Patangpuluhan	
Total				467.62

Table 4.62: Areas of medium vulnerability

No	District	Area of Medium Vulnerability	
		(km^2)	(%)
1	Bantul	136.79	29.3
2	Sleman	328.68	70.2
3	Yogyakarta	2.15	0.5
Total		467.62	100

In Bantul, the low vulnerability areas are in 14 sub-districts with the extent of 72.01 km^2 or 34.8%. In the meantime, in Yogyakarta, the low vulnerability areas are in 3 sub-districts with the extent of 0.93 km^2 or 0.4%. The low vulnerability area happens because of the influence of several factors with small intensity, so they do not really influence the availability of groundwater but still there is a possibility that it will face water vulnerability. The low vulnerability areas are generally located in sub-urban areas where the population is not as dense as that of the centre of the city. In the meantime, in Bantul and Sleman, their low vulnerability areas are generally located in the areas, which relatively have been improved. The activities of land use change with the intensity are not high start to emerge. Therefore, there are not many plantations or rice fields changed into housing areas or industrial sector. It does not cause big runoff; besides, the groundwater availability is relatively adequate to fulfill the need for clean water of the people living in its environs.

The extent of the low vulnerability areas (26%) shows that in those three areas, the people living in its environs begin to feel the water vulnerability, although with a small intensity especially during the dry season, which is marked by the decreasing groundwater surface. If this condition is neglected without conducting any follow-up acts, especially the limitation on the taking of groundwater, it is very possible that the area can change into the medium vulnerability area, even into high vulnerability or extremely high vulnerability area. The result of the counting on the extent of low vulnerability area in the research location can be seen in Table 4.64.

4.7.4.5 Areas of Very Low Vulnerability

The very low vulnerability areas are defined as areas that temporarily do not potentially face a water crisis. Thus, such areas are included in the category of relatively safe from water crisis. The location included as the very low vulnerability of water crisis area can be seen in Table 4.65.

Based on the data from Table 4.65, the very low vulnerability areas can be found in 2 regencies, in Sleman and Bantul. In Sleman, the areas that are not vulnerable of water crisis can be found in 4 regencies with the extent of 22.09 km^2 or 62.6% of the total extent of the non-vulnerability of water crisis areas. In Bantul, the non-vulnerability of water-crisis areas can be found in 5 regencies that reach the extent of 13.18 km^2 or 37.4%. Meanwhile, in Yogyakarta, there are not any very low vulnerability areas.

The very low vulnerability areas still have a natural area condition that can be in the form of forests, rice fields, or plantation, and there are not many land use changes. Those areas have a small runoff/rainfall ratio, so there is much rainfall absorbed into the ground to fill up the groundwater supply, or it means only a small amount of rainwater turns into runoff. Besides, the groundwater availability is abundant enough, so the water need of the people or of the agriculture and animal husbandry can be well fulfilled.

Table 4.63: List of low vulnerability areas

No	District	Sub-district	Village	Area (km2)
1	Bantul	Bambanglipuro	Sumbermulyo, Mulyodadi,	72.01
		Banguntapan	Banguntapan, Tamanan, Baturetno Potorono, Singosaren, Wirokerten	
		Bantul	Bantul, Ringinharjo, Sabdodadi, Trirenggo, Palbapang	
		Imogiri	Karangtalun	
		Jetis	Sumberagung, Patalan	
		Kasihan	Ngestiharjo, Tamantirto, Bangunjiwo, Tirtonirmolo	
		Kretek	Tirtomulyo, Donotirto	
		Pajangan	Triwidadi, Sendangsari, Guwosari	
		Pandak	Wijirejo	
		Piyungan	Srimartani	
		Sanden	Gadingsari, Murtigading, Srigading, Gadingharjo	
		Sedayu	Argomulyo, Argosari, Argorejo, Argodadi	
		Sewon	Bangunharjo, Panggungharjo, Pendowoharjo, Timbulharjo	
		Srandakan	Trimurti, Poncosari	
2	Sleman	Berbah	Kalitirto, Tegaltirto, Jogotirto, Sendangtirto	134.12
		Cangkringan	Glagahharjo, Kepuhharjo, Umbulharjo, Argomulyo	
		Depok	Condongcatur, Maguwoharjo, Caturtunggal	
		Gamping	Nogotirto, Banyuraden, Balecatur, Ambarketawang	
		Godean	Sidomulyo	
		Kalasan	Tamanmartani, Selomartani, Purwomartani	
		Minggir	Sendangsari, Sendangrejo, Sendangagung Sendangarum	
		Mlati	Sumberadi, Tlogoadi, Sendangadi,	
		Moyudan	Sumberagung, Sumberrahayu, Sumberarum	
		Ngaglik	Donoharjo, Sariharjo, Sukoharjo, Sinduharjo, Minomartani	
		Ngemplak	Umbulmartani, Sindumartani, Widodomartani, Bimomartani, Wedomartani	
		Pakem	Hargobinangun, Purwobinangun, Pakembinangun, Harjobinangun	
		Prambanan	Bokoharjo, Sambirejo, Madurejo, Gayamharjo, Sumberharjo, Wukirharjo	
		Seyegan	Margodadi, Margoluwih	
		Sleman	Trimulyo, Triharjo, Tridadi, Pendowoharjo	
		Turi	Wonokerto, Girikerto	
3	Yogyakarta	Tegalrejo	Karangwaru, Tegalrejo	0.93
		Mergangsan	Keparakan, Brontokusuman	
		Umbulharjo	Mujamuju, Pandeyan, Giwangan	
			Total	207.05

Table 4.64: Areas of low vulnerability

No	District	Area of Low Vulnerability	
		(km^2)	(%)
1	Bantul	72.01	34.8
2	Kota	0.93	0.4
3	Sleman	134.12	64.8
Total		207.06	100

According to the discussion above, the areas included in the criterion of very low vulnerability have the extent of 35.27 km^2 or 4% of the total extent. The low vulnerability areas reach the extent of 207.05 km^2 or 26%, the moderate vulnerability areas cover the extent of 467.615 km^2 or 59%, the high vulnerability areas have the extent of 75.49 km^2 or 9%, and the areas included in very high vulnerability cover the extent of 17.4 or 2%. Therefore, such condition needs to be seriously concerned since if it is neglected, the moderate vulnerability areas can turn into high or even very high vulnerability areas.

Table 4.65: List of very low vulnerability areas

No	District	Sub-district	Village	Area (km2)
1	Bantul	Bantul	Bantul	13.18
		Kasihan	Tamantirto	
		Pajangan	Guwosari	
		Sedayu	Argomulyo, Argorejo	
		Sewon	Pendowoharjo	
2	Sleman	Cangkringan	Kepuhharjo	22,09
		Pakem	Hargobinangun	
		Prambanan	Bokoharjo, Sambirejo,	
		Sleman	Tridadi, Pendowoharjo	
Total				35.27

Table 4.66: Areas of very low vulnerability

No	District	Very Low Vulnerability	
		(km^2)	(%)
1	Bantul	13.18	37.4
2	Sleman	22,09	62.6
Total		35.27	100

4.7.4.6 Natural Vulnerability

The areas included in the category of natural vulnerability consist of areas with limited types of aquifer and areas having the type of lava field (Figure 4.45). The natural vulnerability areas are the areas having minor aquifer, poor aquifer, or even non-aquifer, i.e. the rocks that are difficult or not able to keep and/or release water. The areas included in this category are to be in the geological formation of Sambipitu (siltstone, shale, and tuff), Kebo and Butak formation (conglomeritic shale and tuff), Nglanggran and Semilir formation (breccias, shale and tuff), Old andesite formation (andesitic breccias, tuff), Jonggrangan formation (basal conglomerates, tuffaceous, and calcareous sandstones), and Sentolo formation (limestone). These areas are generally included as dry areas, thus the water availability in those areas becomes the main problem. Therefore, it is important to do the efforts to fulfill the water need; one of them is by preserving the effective and efficient water-catching area.

Table 4.67: Areas of total anthropogenic vulnerability category

No	Vulnerability	Area (km^2)	%)
1	Very Low	35.27	4
2	Low	207.05	26
3	Medium	467.615	59
4	High	75.49	9
5	Extremely High	17.4	2
Total		802.825	100

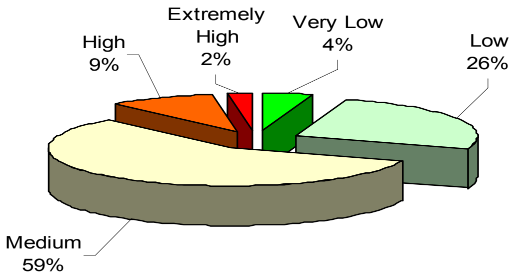


Figure 4.44: Percentage of anthropogenic vulnerability areas

Table 4.68: Natural vulnerability areas covered by Nanggulan and Old Andesite Geology Formation

No	District	Sub-district	Village	Area (km^2)
1	Sleman	Sayegan	Margodadi	0.38
		Godean	Sidorejo	0.81
Total				1.19

The areas included in the category of natural lava field vulnerability can only be found in Sleman. The natural vulnerability areas are the area mostly seriously affected by Merapi volcano; they can experience the effect of the eruption of Merapi volcano in the form of lava flow, lapilli, bomb, nues ardante or hot cloud, and dust, so it is recommended that those areas should not be dwelt since its status can be dangerous for people's safety. It is recommended that the areas will remain as a natural forest area or a national park; therefore, it can function as the water-absorption area. Tables 4.68 to 4.72 explain the composition of the category of natural vulnerability and their extent. Table 4.73 and Figure 4.46 show comprehensive vulnerability areas. This includes parameters of anthropogenic and natural areas, its category, and its area. It indicates that medium is the biggest portion and the natural vulnerability is the second biggest area, which is 27%. Figure 4.47 explains the comprehensive vulnerability composition based on the total area of study, i.e. Sleman, Yogyakarta, and Bantul.

Table 4.69: Natural vulnerability areas covered by Jonggrangan and Sentolo Geology Formations

No	District	Sub-district	Village	Area (km^2)
1	Sleman	Gamping	Ambarketawang	5.51
			Balecatur	4.2
		Cangkringan	Argomulyo	3.97
		Minggir	Sendangsari	8.301
		Sedayu	Argodadi	2.59
			Argorejo	4.11
			Argosari	0.019
2	Bantul	Kasihan	Bangunjiwo	10.50
		Pajangan	Guwosari	3.62
			Triwidadi	10.98
		Pandak	Gilangharjo	1.05
			Triharjo	1.77
			Caturharjo	2.23
		Bambanglipuro	Sidomulyo	0.58
Total				50.51

Table 4.70: Natural vulnerability areas covered by Sambipitu, Kebo, Butak, Nglangran, Semilir Geology Formations

No	District	Sub-district	Village	Area (km^2)
1	Sleman	Prambanan	Bokoharjo	0.91
			Gayamharjo	6.64
			Madurejo	0.15
			Sambirejo	7.24
			Wukirhajo	4.98
			Sumberhajo	1.79
2	Bantul	Jetis	Trimulyo	1.18
		Dlingo	Dlingo	9.04
			Jatimulyo	9.57
			Mangunan	11.85
			Muntuk	13.76
			Temuwuh	7.43
			Terong	8.87
		Imogiri	Girirejo	1.40
			Imogiri	0.05
			Karangtengah	1.04
			Selopamioro	19.05
			Sriharjo	2.43
			Wukirsari	14.01
		Kretek	Parangtritis	4.65
		Piyungan	Sitimulyo	4.03
			Srimartani	5.35
			Srimulyo	8.87
		Pleret	Bawuran	3.52
			Segoroyoso	3.14
			Wonolelo	4.62
		Pundong	Seloharjo	7.82
Total				163.38

Table 4.71: Natural vulnerability areas covered by Merapi Peak Geology Formation (lava field)

No	District	Sub-district	Village	Area (km^2)
1	Sleman	Pakem	Hargobinangun	14.79
Total				14.79

Table 4.72: Resume of natural vulnerability areas covered by weak aquifers

No	Formation	Sleman		Bantul		Total	
		km^2	(%)	km^2	(%)	km^2	(%)
1	Sambipitu, Kebo, Butak, Nglanggran, and Semilir	36.9	49.29	126.49	77	163.39	68.4
2	Jonggrangan and Sentolo	21.98	29.36	37.45	23	59.43	24.9
3	Merapi peak	14.79	19.75	0	0	14.79	6.2
4	Nanggulan and Old Andesite	1.19	1.58	0	0	1.19	0.5
Total		74.861	100	163.94	100	238.8	100

Table 4.73: Total comprehensive vulnerability category and area

No	Parameter	Category	Area (km^2)
1	Anthropogenic	Very Low	35.27
		Low	207.06
		Medium	467.615
		High	75.49
		Very High	17.4
2	Natural	Natural	297.8
	Total		1100.635

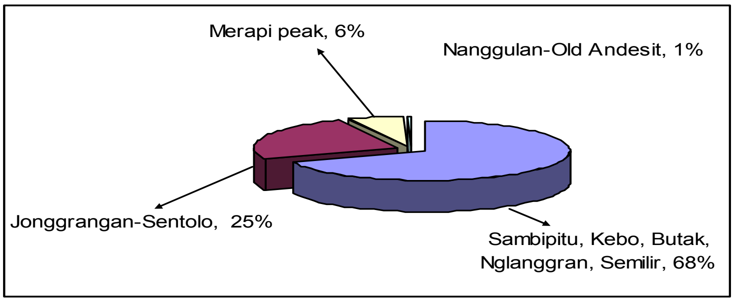


Figure 4.45: Percentage of natural vulnerability areas

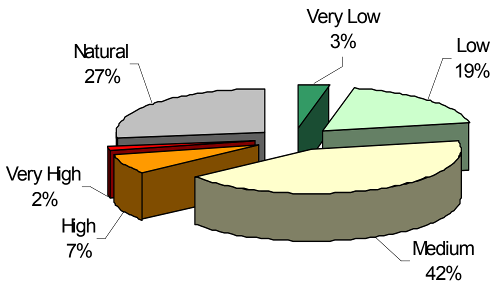


Figure 4.46: Total comprehensive vulnerability category and area

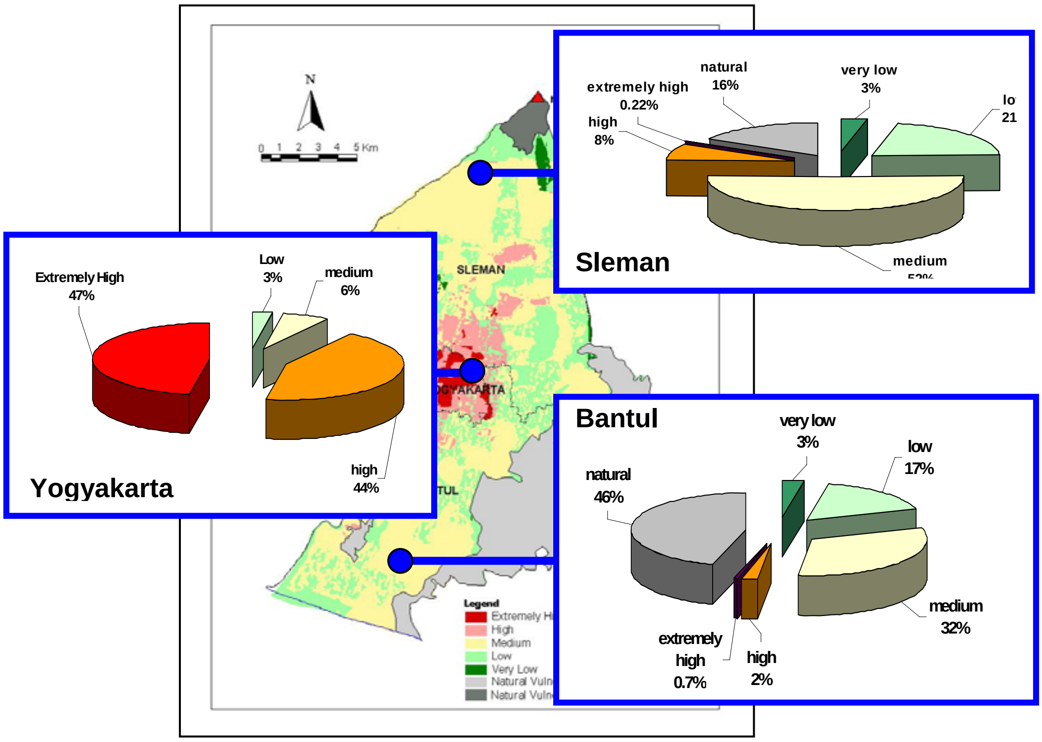


Figure 4.47: Comprehensive overview of vulnerability areas for Sleman, Yogyakarta and Bantul

4.8 Economic and Social Analysis

4.8.1 General

For a sustainable water resources development with IWRM and RWH approaches, Prinz (2000) stated that some important socio economic factors of water conservation and RWH are:

1) Selection of appropriate low cost technology is a prerequisite for widespread implementation.
2) Planners should consider both traditional and modern technologies.
3) The price of water determines largely the investments justified to avoid water losses.

According to Muta'ali (2000), the criteria to select water conservation measures are: program costs, cost-effectiveness, ease of implementation, budgetary considerations, staff resources and capability, environmental impacts, rate payer impacts, environmental and social justice, water rights and permits, legal issues or constraints, regulatory approvals, public acceptance, timeliness of savings, and consistency with other programs. A socio-economic analysis can be based on certain categories and vulnerability classes (Table 4.74). Anthropogenic vulnerability areas are concentrated in the urban areas.

Table 4.74: Water resources vulnerability categories

No	Main Category	Vulnerability Class
1	Recharge Area (RA)	
2	Anthropogenic Vulnerability Area (AVA) (Focus on urban area)	1. Extremely High 2. High 3. Medium 4. Low 5. Very Low
3	Natural Vulnerability Area (NVA)	

This study is oriented towards the development of an optimum concept, especially in recovering and managing the vulnerability. Many stakeholders are demanded to take part in the implementation of RWH. For optimum implementation, the society's participation is the most significant factor. Hadi (2001) stated that the insight formed among people is significant for the optimum achievement of development objectives; besides, society involvement can be an effective media for public education. Consequently, this management should keep the synergy between the top-down and bottom-up patterns as well as the collaboration between the scientific recommendation and local knowledge participation. The result of this research is in the form of scientific recommendation, a different side of the society's insight with the same position but not as strict as the government policy. The strong tightness will be achieved if it can be recommended as a policy to the government.

Ismail (2005) explained that the development policy must be based on the principles of objective clarity, advantage, authority, conformity of content type and material, applicability, formulation clarity, openness, efficiency, laws, justice, un-discriminatory, and law assurance. Those principles are then connected to the low education level and dominant economic factor of people. Hence, the important principles are the clearness of objective, advantage, and applicability of RWH. This chapter contains the analysis of RWH applicability from the social-economic aspect, i.e.

the description of cost and benefit, the level of society's ability to pay it, and the willingness of the society to participate.

The feasibility study is meant to find how far the RWH can be optimally applied in several aspects, which are aspects of technical, management, social-culture, finance, and economy (Gittinger, 1986), Gray (1997) added externality, while Tarigan (2005) added environmental aspect. The aspect of technical implementation of RWH may refer to the carrying capacity of the environment and/or materials.

This analysis is based on the method of survey combined with the secondary data analysis. For effectiveness, the analysis of economy feasibility level uses the secondary data taken from the result of previous study and the institutional data (Singarimbun and Efendi, 1995). This is done to identify the society's acceptance and willingness level to participate in developing RWH. The survey takes samples from population and uses questionnaires to collect the main data of social-economy condition that may influence the feasibility of RWH implementation based on the analysis domestic unit.

Family is chosen as an analysis unit considering that domestic matters are the subjects as well as the objects in the implementation of RWH. The sample taking applies a quota sampling technique by determining a certain number of samples. According to Faisal (1999), it is in accordance with the data collection of public opinion. Singarimbun and Efendi (1995) stated that at least 20 data are required to analyze a frequency table. Here, the respondents consist of 30 family units in the recharge and natural vulnerability areas and 60 units in the urban vulnerability area. The anthropogenic vulnerability area would be the priority because this area is the most complex.

The analysis considers the difference in local characteristics. The technique of purposive sampling is used to determine the analysis region sample based on the criteria of differences on the critical level of water resources. The data of family conditions are compared, and the chosen areas are the ones with water surplus in the recharge, anthropogenic vulnerability, and natural vulnerability areas.

The detail economy feasibility is evaluated using the cost benefit analysis with the criteria of Net Present Value (NPV), Cost-Benefit Ratio, Pay-Back Period, and Internal Rate of Return (IRR), and the analysis of Ability to Pay (ATP*).* NPV is the project cash value to describe the advantage value based on the present value. It is gained from the subtraction of the benefit cash value and the cost-cash value or:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

In which:

B_t =gross social benefit of project at t - year

C_t = gross social cost of project at t - year

n = economic years of project

i = social opportunity on capital stated as the social discount rate

Positive NPV value marks the economic feasibility. Discount the NPV value results in the Cash Value. The discount interest rate is a certain coefficient that will determine the high and low of the social opportunity cost (Gray, 1997). Development projects funded by personal cost generally use the rate of social discount interest, i.e. the interest rate that makes the present value equal to zero. It includes the elements of tax risk and inflation rate. Determining the interest rate is important because the results of a project may vary depending on the chosen interest rate. However, no standard criterion for determining this rate applies; hence, to get an extreme result, this study uses the maximum rate, i.e. 15%.

The next important consideration is determining the cost and benefit. The cost in the project covers: preparation, investment, operational, repairing and maintenance (Kadariah, 1999). The preparation cost is used before the project is run, not included in the investment and project evaluation cost, and fully burdened to the society. The investment cost includes the cost for land, construction, equipment, instrument, and/or capital. The cost for damages is included in the operational cost. Other costs reflecting true value such as pollution and unproductive land are difficult to calculate in money. The component of benefit consists of direct, indirect, and related benefit (Kadariah, 1999). In this research, the analysis is only based on direct benefit and limited because of the difficulty in calculating it through the economic perspective.

The criterion of the second analysis is Cost-Benefit Ratio (CBR), an analysis to compare between benefit and cost in the implementation of RWH. To get the value of CBR, this formula is used:

$$NetB / CRatio = \frac{\sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t - B_t}{(1+i)^t}}$$

In which:

B_t = gross social benefit of project at t - year.

C_t = gross social cost of project at t - year.

n = age of economic project.

i = social opportunities on capital stated as the social discount rate

Note: RWH is economically viable, if the CBR value is more than 1.

The criterion of the third analysis is Pay Back Period, the time needed to make the advantage of project recover the whole costs (Tarigan, 2005). To get the real time value, the cost and benefit used also show their real values, with a discount. This criterion has the same concept as Break Event Point, i.e. the time when the input value is the same as the output value, or when the position of profit equals to zero (0). The feasibility based on this criterion may be obtained if the value of Pay Back Period is smaller than the predicted age of the project.

The final criterion used in the economic analysis is Internal Rate of Return (IRR). IRR is a discount rate that treats NPV project as zero; the formulation of IRR is as follows:

$$\sum_{t=1}^{n} \frac{B_t - C_t}{(1+IRR)^t} = 0$$

The value of IRR usually cannot be determined directly. Hence, the interpolation method is conducted with the following steps:

1) Determining the i discount level considered as approaching the real IRR value.
2) Negative NPV means the i experiment value is too high; so, the next step is determining the new lower i value.

3) Positive NPV means the i experiment value is too low; therefore, it requires a new higher i value.
4) If i value of the first experiment is i_1 and that of the second experiment is i_2, the NPV in the first experiment is NPV_1 and the second one is NPV_2 then the prediction of IRR value, which approaches accurateness level, can be determined by using the following formulation:

$$IRR = i_1 + \frac{NPV_1}{(NPV_1 - NPV_2)} (i_2 - i_1)$$

If IRR is bigger than *i*, NPV project will be zero (0); then, if IRR is smaller than i, NPV project will be less than zero. On the other hand, IRR that is equal to i shows that NPV equals zero. A project is considered as worth to carry out if its IRR value is bigger or equal to the valid i-value, and it is invaluable if IRR is smaller than the valid i-value.

The aforementioned economic analysis is done to 20-year projects. Some references for determining the period of a certain project stated by Kadariah (1999) are:

1) As a general measure, it is possible to choose a period that has the same economic age as that of the project. The economic age of an asset is the number of years as long as the exploitation of the asset can minimize its annual cost.
2) For the projects with a very big investment capital, the technical age is easier to use than the main age of investment. In this case, it is important to consider that the technical age of the major elements of an investment is long, but the economic age can be much shorter because of the existence of obsolescence. This circumstance is often found in agricultural projects.
3) For the projects that are more than 25 years, it can be taken after 25 years with the discount rate of 10% or more.

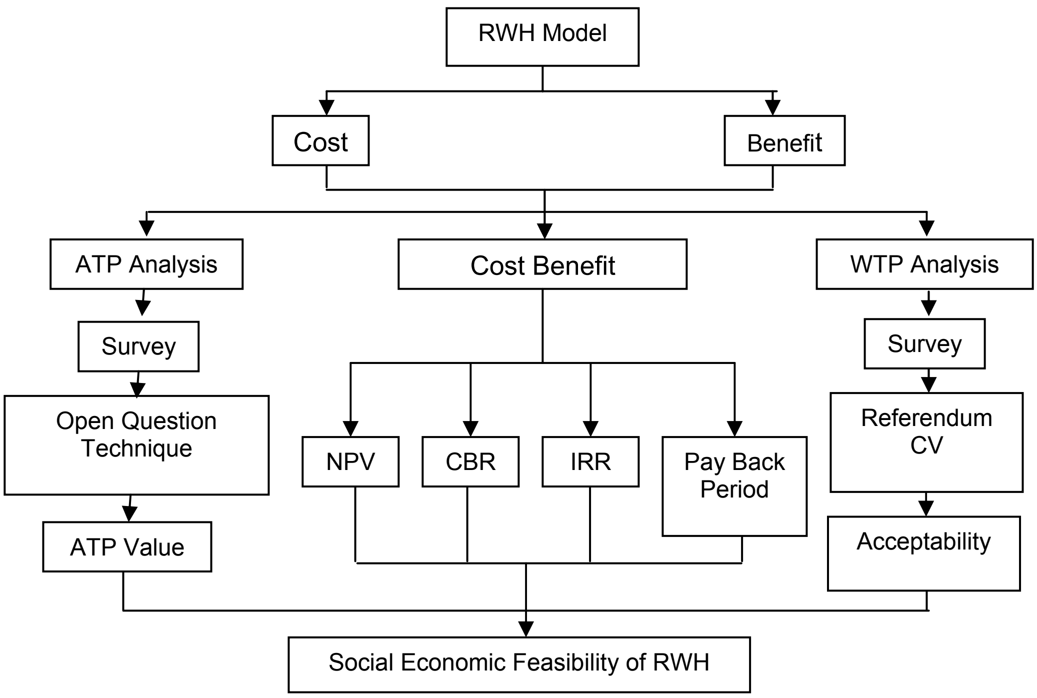


Figure 4.48: Steps in social economic analysis

The pattern of society's participation in RWH implementation refers to the agent or the funding source based on their self-supporting principle. Therefore, the description of benefit and cost is still insufficient for the feasibility study. On the other hand, the economic feasibility also needs to consider the ability of agent. This research uses a comprehensive economic study of *Ability to Pay* (ATP). ATP is an analysis to find how far the society can afford RWH through a survey research of open questions. Open questions or unstructured questions are questions without provided answers, so the respondents should formulate their own answers (Faisal, 1999). This technique is chosen because there is no limitation in determining ATP value. It is generally obtained from the mean score of answers. If the respondents can pay the cost that is equal to or more than the predicted cost then the RWH model is worth to develop.

The economic feasibility will influence the social feasibility since the economic factor, especially the construction cost, is still very influential in making a decision. In this research, the social feasibility is focused on the society's willingness to implement RWH. It is analyzed using the Willingness to Pay (WTP) method through a survey research. According to Tamim (1999), WTP is the willingness of users to accept a reward for the service they get. Thus, in this research, WTP means the society's willingness to conduct RWH using a certain model that interests people by considering the benefit that it shows. The WTP of respondents towards a certain model can be found by distributing questionnaires consisting of a form of questions based on the method of stated preference (Setiawan, 2000).

Some methods of stated preference are Contingent Valuation (CV) Methods, Conjoint Analysis, and Choice Modeling (CM). Contingent Valuation (CV) is a technique to predict values by combining some alternative scenarios that consist of Open Ended CV Method for environmental factor and Referendum CV Method for respondents to choose. The Conjoint Analysis covers Conjoint Rating, Conjoint Ranking and Paired Comparison. Conjoint Rating gives an opportunity to respondents to judge the offered alternatives using rating scales. Conjoint Ranking is almost the same as Conjoint Rating, but its scoring is different. Paired Comparison gives two alternatives to respondents, where one alternative shows the condition at a time, and the other one shows a change. The third method is Choice Modeling, where the respondents are required to choose between more than two alternatives.

In this research study, WTP analysis is chosen using the Referendum Contingent Valuation and Choice Modeling. The level of willingness to implement RWH is entirely determined by using Referendum Contingent Valuation because it is more effective and suitable for the research objectives. Using the method, explicit answers 'willing to' or 'unwilling to' from the society to implement RWH are easier to get. In the social research, the alternative of choices follows the model of Guttman scale that also has a goal to get explicit answers (Faisal, 1999). Figure 4.48 shows the diagram of the steps in this analysis.

4.8.2 Cost Benefit Ratio (CBR)

4.8.2.1 General

Some alternative technical models of RWH for the society are for example the rainwater recharge-well, rainwater reservoir, and conservation pool. The new paradigm of drainage system and river polder is mostly accommodated in these RWH methods. In a certain area, the model value can be a priority even when there is only a single choice. As an illustration, in a natural vulnerability area, there is not any effective alternative except the rainwater reservoir.

In the area with a high risk of flood caused by the overflow from the river or with a fast-flowing river, the polder or infiltration basin becomes the major alternative. Furthermore, open space may not become an alternative for an urban area. As explained in the previous part, three units of physiographical area are also considered in the analysis of economic feasibility.

Those three areas are chosen because they can result in an extreme description of the carrying capacity of environment, the needs, and the ideal plan. The natural vulnerability area has a low carrying capacity with deficit availability of groundwater and low possibility of rainwater infiltration. The anthropogenic vulnerability area has a crisis of water because the population growth is far above the water availability and the space for living, mostly in urban areas, is very dense and limited. The recharge area is located on highlands with abundant availability of water.

4.8.2.2 Data Analysis and Calculations

The following explanation will analyze the economic feasibility of each unit model. Due to the absence of a standard physical size, a higher capacity will result in greater advantages. Therefore, each unit model has its separate analysis. Similar to the others, the benefit value is quite difficult to predict, particularly the indirect benefit, because it can cover a very large area for a long time. The analysis is for a 20-year period, which is assumed as the mean-age of the storing model with 16% discount level.

The first model is the rainwater recharge well. Its shape is generally the same as that of digging-well, but the function is to catch rainwater from the house-rooftop and to store runoff. There is no standard shape and dimension of absorption well. Yet, technically, an accurate calculation is necessary for optimal infiltration and minimum cost of construction. In his research, Sunjoto (1988) developed the dimension of recharge wells, which accommodates the soil infiltration factor. The predicted construction cost is described in Table 4.75.

The total cost of Rp. 1,170,000 includes the cost for equipment, materials, and labors. The value is based on the average price in the research area, land price, and maintenance cost. The land is measured according to the well diameter; 1 m^2 of land is equal to Rp. 100,000. In addition, the maintenance cost is predicted per 5 years for draining the well to make its infiltrating ability back to normal; it requires Rp 100,000 per draining process.

Next, the evaluation of benefit is only based on the influence of recharge well on the groundwater level. Moeljono (2000) found that the existence of recharge wells in Yogyakarta has increased the groundwater level to 0.282 $meter^2$ per year. This finding becomes the reference to assume the benefit value of recharge wells in the research area. The increase is measured for three months by comparing only the increase at the beginning and at the end of the research. The economic value is based on the average standard of PDAM rate per $meter^3$, i.e. Rp 1,500/$meter^3$. The mean of domestic water use per capita is 4 people x 0.1 m^3/day x 90 days + (3.14x0.5x0.5) x 0.282 m = 36.221 m^3. Meanwhile, the absorption capacity depends on the condition of rainfall. The value is resulted when the mean of rainfall is 800.6 mm, while it is 2133.33 mm/year in the research area. Therefore, the prediction of groundwater surface increase is (2133.33/800.6) x 36.221 x 3 = 144.59 m^3; it equals to Rp. 216, 884.80. Table 4.76 shows the result of cost-benefit ratio analysis.

Table 4.75: Cost estimation of artificial recharge well construction

Component	Volume	Unit	Unit Price	Total Price
Cylindric concrete	6	Piece	Rp. 25,000	Rp. 150,000
Cement	8	Sack	Rp. 30,000	Rp. 240,000
Sand	1	Truck	Rp. 120,000	Rp. 120,000
Gutter	20	Meter	Rp. 5,000	Rp. 100,000
Pipe	4	Piece	Rp. 40,000	Rp. 160,000
Labor	4	4 Days	Rp. 25,000	Rp. 400,000
Total				Rp. 1,170,000

Remark: 1 Euro ≈ Rp. 12.000 in the year of 2005

Table 4.76: Cost-benefit ratio of an artificial recharge well

Parameter	Total Value
Net Cost (15%)	1413700
Net benefit (15%)	1560052.48
Net Present Value (NPV)	146352.48
Cost-Benefit Ratio	1.10

The net benefit resulted in this calculation is more than the net cost; the difference of Rp 146,352.48 is the value of net benefit based on the net present value (NPV). The positive NPV indicates that the cost-benefit ratio is more than 1.00, i.e. 1.10 in the table. It means that economically the rainwater recharge well is worth to implement in the research area. The next analysis is to determine the pay back period. In Figure 4.49, the value is located on the intersection point of net cost and net benefit. The graph shows that the pay back period of absorption well occurs in the 13th year of the project. Therefore, starting from the 13th year onwards, the society can enjoy the net profit of using a recharge well. The pay back period occurs before the project age is over; it means the recharge well is worth to implement.

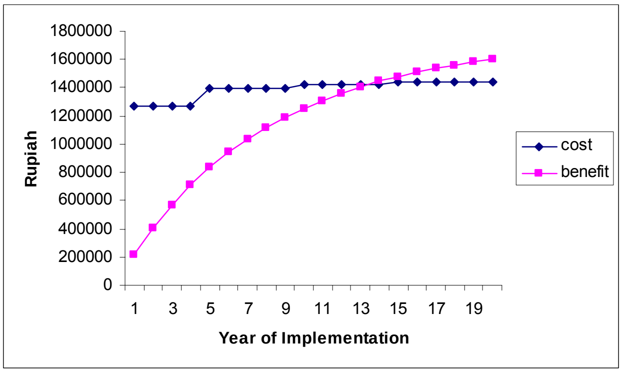


Figure 4.49: Pay Back Period of an artificial recharge well

The next criterion is the internal rate of return (IRR). Through the process of trial and error, the NPV value is contrary to the one used previously. Using 28% discount rate, the NPV value is 985741.4905. Thus, the IRR = 15% + (183352.4843 / (183352.4843 + 985741.4905)) x (28% - 15%) = 19.59%. This value is above the previously defined social discount; hence, this project can be conducted.

The second model of RWH is rainwater reservoir functioning only for storing. Its locations can be above buildings, above the ground, or below the ground. Above buildings, the reservoir will be easier to use and suitable for an urban area although it needs a high cost to construct. Locating the reservoir above the ground is more efficient, but it needs some space. The last option of location does not depend on space, but it needs a higher construction and pumping cost. This research chose the construction above the ground because it is feasible and more efficient.

The shape of rainwater storage can be cylinder, square, ball, or others. Considering the effectiveness and efficiency of the making, the square shape is chosen. The cost components include the construction, space, and maintenance costs. The construction cost consists of the material, labors, and treatment costs. The rainwater is harvested through a certain treatment to be drinking water; and in this research, a filter instrument is chosen to keep the cleanness and to anticipate turbidity. It is more efficient than putting alum into the water periodically. Table 4.77 shows the details of the preliminary cost.

Table 4.77: Cost estimation of rainwater storage construction

No	Component	Volume	Unit	Unit Price	Total Price
1	Material:				
	• Cement	20	Sack	Rp. 30,000	Rp. 600,000
	• Brick	4000	Piece	Rp. 300	Rp. 1,200,000
	• Sand	2.5	Truck	Rp. 120,000	Rp. 300,000
	• Tap	2	Piece	Rp. 10,000	Rp. 20,000
	• Iron	40	Piece	Rp. 10,000	Rp. 400,000
	• Filter	20	Square meter	Rp. 5,000	Rp. 100,000
2	Labor	4	4 Days	Rp. 25,000	Rp. 400,000
	Total				Rp. 3,020,000

In the building process, that cost is added to the cost of water draining cost, i.e. Rp 50,000 per year. For comparing the total cost, this research chose the economic value of rainwater used during the dry season, assuming that the storage becomes the absolute choice in the dry season. The storage capacity is based on the need for water during the dry season that covers 221 days x 4 people x 0.1 m^3 = 88.4 m^3. Therefore, its benefit cost is 88.4 x Rp. 1500 = Rp. 132, 600.00. This value matches the considerable price of PDAM water in the research area.

Table 4.78: Cost-benefit ratio analysis of rainwater storage

Parameter	Total Value
Net Cost (15%)	5329650
Net benefit (15%)	953791,8
Net Present Value (NPV)	-4375858,2
Cost-Benefit Ratio	0,18

The cost and benefit values are shown in Table 4.78. The cost value is much higher than its benefit, resulting in negative NPV and CBR less than one. It indicates that the research area is generally inefficient for rainwater reservoir construction. Constructing the reservoir on the rooftop may minimize the cost, particularly for the space, and increase the ease to use. In addition, the pay back period and IRR analysis proves the aforementioned unfeasibility. Moreover, through the process of trial and error using 0% discount rate, the NPV is still negative.

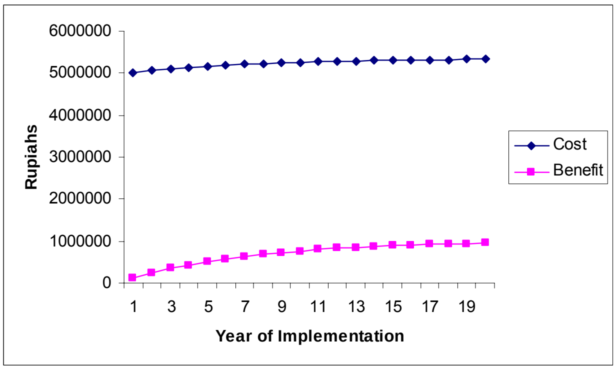


Figure 4.50: Pay Back Period of rainwater storage

According to the physical analysis in a natural vulnerability area, the only alternative is rainwater reservoir or storage. Its construction cost is the same as that of other areas in general. The benefit cost is slightly different since the area is lack of PDAM service, thus, the water value is very high. In such area, the people have to pay Rp 60,000 for one tank (5000 liters) of water (1 m^3 = Rp. 12,000). The benefit cost of one rainwater reservoir in this area is 88.4 x 12,000 = Rp. 1,060,800.

Table 4.79: Cost-benefit ratio analysis of rainwater storage in natural vulnerability areas

Parameter	Total Value
Net Cost (15%)	5329650
Net benefit (15%)	9537918
Net Present Value (NPV)	4208268
Cost-Benefit Ratio	1.79

The BCR analysis in Table 4.79 shows positive NPV and CBR more than 1. By using 40%-discount rate, the IRR is more than 15%, i.e. 37.26%. The pay back period shown in Figure 4.51 is in the 5th year. It means the rainwater reservoir in the natural vulnerability area is feasible to manage.

The next manageable RWH facility is the conservation pond. It is almost the same as a fishpond, but it is made with or without buildings around, utilizing the ground to infiltrate water. The analysis of economic feasibility in this study is conducted for each square meter, because there is not any standard size.

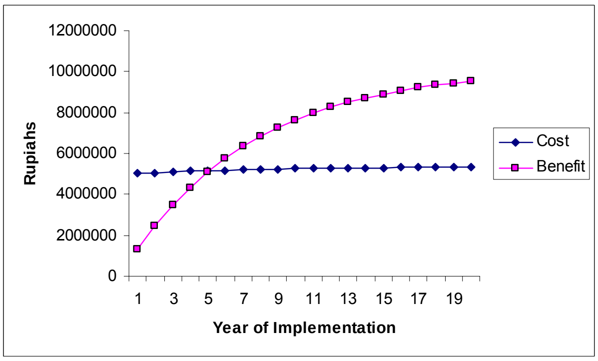


Figure 4.51: Pay Back Period of rainwater storage at natural water vulnerability

The construction cost includes the dredging of ground and construction of buildings around it, which presumably will require Rp 200,000 with the land price of Rp. 100,000 (Table 4.80).

Table 4.80: Cost estimation of conservation pond development

Component	Volume	Unit	Unit Price	Total Price
Labor	4	2 days	Rp. 25,000	Rp. 200,000
Land	1	Square meter	Rp. 100,000	Rp. 100,000

Table 4.81: Cost-benefit ratio analysis of conservation pond

Parameter	Total Value
Net Cost (15%)	343000
Net benefit (15%)	1554220.46
Net Present Value (NPV)	1210000
Cost-Benefit Ratio	4.53

The maintenance done by dredging the pond ground every 5 years to prevent over-sedimentation will need Rp 50,000. Its measurable advantage is the same as that of recharge well, i.e. the groundwater increase. Todd (1980) stated that each m^2 of a pitch, which has almost the same model as this pond, is able to infiltrate 7% of rainwater. Compared to the benefit of recharge well, the economic value of conservation pond can reach Rp 216,074 per year, which is far above its cost as shown in Table 4.81. The NPV is positive and the CBR is 4.53. This value may become higher if it is also managed for fishery.

Furthermore, the value can be used to determine the pay back period occurring in the second year (Figure 4.52). Next, the process of trial and error results in more than 15% IRR because the 40% discount rate still shows a positive NPV. In conclusion, the conservation pond is feasible to manage.

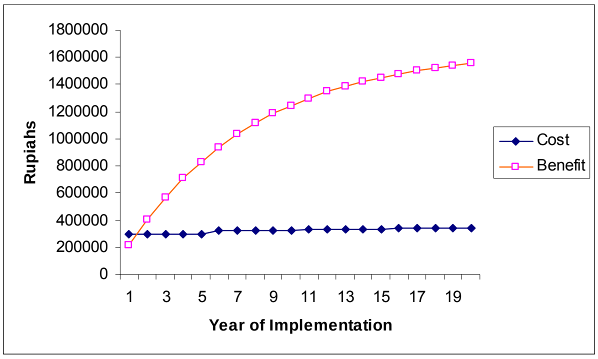


Figure 4.52: Pay Back Period of conservation pond

The analysis result is utilized to recommend the priority for the development of RWH facility (Table 4.82). The priority shows the cost effectiveness of each type. All types are in the priority scale because the benefit is limited and it has not shown the indirect advantage and benefit for other areas.

Table 4.82: Priority of RWH development

No	RWH Model	NPV (Rupiah)	CB - ratio	Pay back period (Year)	IRR (%)	Economic Feasibility	Priority
1.	Recharge well	183352.48	1.13	12.1	19.59	Feasible	II
2.	RWH storage	-4375858.2	0.18	> 20	< 15	Not Feasible	III
3.	Conservation pond	1210000	4.53	1.5	> 15	Feasible	I

The types of feasible facility are conservation pond, recharge well, and rainwater storage respectively. The values are determined using the general assumption and specific assumption, i.e. the general characteristics found in the research area, such as the physiographic condition, economic value of water, rainfall, availability of land, and other similar regional economic conditions. This assumption, and therefore the values, is invalid for other types of area, such as the natural vulnerability area.

4.8.3 Ability to Pay (ATP) and Willingness to Pay (WTP)

4.8.3.1 General

The development of RWH should consider the society's ability to afford and willingness to implement, which are determined using ATP and WTP analysis. They are obtained based on the survey towards the simplified three-research areas covering water-resource recharge area (RA), anthropogenic vulnerability area (AVA) or urban area, and natural vulnerability area (NVA).

4.8.3.2 Data Analysis and Calculations

The recharge area has a high fertility level and a relatively high number of land ownership, almost the same as that of the natural vulnerability area having a low fertility level. On the other hand, the anthropogenic vulnerability area is generally located in a densely populated urban area.

Table 4.83: Existing respondents' RWH ownership

Existing	RA		AVA		NVA	
	F	%	F	%	F	%
Having RWH at least 1 model	0	0	4	6.67	8	26.67
Having no RWH model	30	100	56	93.33	22	73.33

F: Frequency of samples, **RA**: Recharge Area, **AVA**: Anthropogenic Vulnerability Area, **NVA**: Natural Vulnerability Area

Hence, such condition influences the ownership level of RWH facility. Table 4.83 shows that no respondents living in the recharge area have RWH. On the contrary, there are only 6.67% respondents in the anthropogenic vulnerability area have RWH while the natural vulnerability area shows a better condition in which 26.67% respondents have RWH facility. Besides water needs and physical environment, it is proven that the space availability affects the level and types of RWH facility ownership, as shown in Table 4.84.

No RWH facilities are owned by the respondents in the recharge area. On the contrary, in the anthropogenic vulnerability area, there is one type but not dominant RWH facility; 6.67% respondents have a recharge well. In the natural critical-area, 26.67% respondents have been using the rainwater storage. It is useful for overcoming the water problem in this area, although people are accustomed to allocating much money for buying water during the dry season.

Table 4.84: Existing respondent's RWH type profile

RWH Type	RA				AVA				NVA			
	Owning		Not Owning		Owning		Not Owning		Owning		Not Owning	
	F	%	F	%	F	%	F	%	F	%	F	%
Artificial recharge well	0	0	30	100	4	6,67	56	93,33	0	0	30	100
RWH storage	0	0	30	100	0	0	60	100	8	26.67	22	73,33
Conservation pond	0	0	30	100	0	0	60	100	0	0	30	100

Table 4.85: Respondents' motivation in having existing RWH facilities

Motivation Source	RA		AVA		NVA	
	F	%	F	%	F	%
By Awareness	0	0	45	75	15	50
By Order	0	0	15	25	11	37
No intention	0	0	0	0	4	13

According to the data in Table 4.84, no respondents at the recharge area have RWH facilities. Therefore, the respondents' motivation is 0%. The opposite condition is found in the other two areas; the awareness has dominantly supported the managing of RWH facility. The respondents' awareness is 75% in the anthropogenic vulnerability area and 50% in the natural vulnerability area. This is in line with their need for water and the limited amount of land for natural vegetation. This shows the ineffective environmental education and insufficient execution of regulations. The regulation-based management of this matter then needs cooperative participation at each step.

Table 4.86: Economic profile of respondents

Expenditure /Month	RA		AVA		NVA		Poverty Category	RA		AVA		NVA	
	F	%	F	%	F	%		F	%	F	%	F	%
≤ Rp. 427,000	5	16.67	8	13.33	13	43.33	Poor	5	16.67	8	13.33	13	43.33
Rp. 427,001 - Rp.800,000	13	43.33	12	20	9	30	Not poor	25	83.33	52	86.67	17	56.67
Rp.800,001 - Rp.1,200,000	6	20	30	50	5	16.67							
≥ Rp.1,200,001	6	20	10	16.67	3	10							

The economic conditions of respondents, which influence the RWH development in the research area, are typically the same although the levels vary. It can be seen from the poverty level that may be determined, according to Muta'ali (2000), based on the equivalent expense of rice of a family that equals to BPS (2002-a) standard, i.e. 320 kg/capita/year. The determined mean value of rice is Rp 4,000/kg; therefore, the family expense is Rp 1,280,000/capita/year.

The average number of family members in the research area is four people (BPS, 2002-a), so the family expense is Rp 5,120,000/year or approximately Rp 427,000/month. According to Table 4.86, the average economic level of the research area is above the poverty line. Only 16.67% of people in the recharge area and 13.33% of respondents in the anthropogenic vulnerable area are considered poor. On the other hand, in the natural vulnerable area, 43.33% respondents are poor because this area is infertile and in general is dominated by agricultural land. Such condition generally indicates that the respondents are able to manage RWH facility, because a part of the cost is only for the preliminary development. Table 4.87 shows the quantitative value of the respondents' ability to pay (ATP) for RWH facility.

The highest respondent's ATP is Rp 1,250,000, found in the anthropogenic vulnerable area, since the respondent's economic level is the highest and there is the demand to fulfill the need for RWH. Based on the value, RWH facilities that are possible to manage soon by considering the costs needed are the recharge well, conservation pond, vegetation, or open space.

In the middle condition, the natural vulnerable area covers Rp 965,000, with the same demand as that of the anthropogenic vulnerable area, but its economic condition is lower. RWH facilities that are possible to implement are the conservation pond, vegetation, and/or open space. However, these facilities are not recommended considering that less-optimal fiscal condition can be benefited from them. The respondents cannot afford the rainwater storage as the most considerable facility to manage in this area; therefore, the focus is effective on how far the society is able to manage it.

The lowest ATP is at the recharge area reaching Rp 605,000, although its economic condition is good with small demand for life need. The RWH facilities that can be managed are the conservation pond, vegetation or open space. It shows that the awareness of the long-term benefit and benefit for other areas has not grown yet. Economically, they can have more ability, but when combined with the willingness or awareness, the value becomes smaller. This demands the guidance of management, which focuses more on building awareness intensively and effective managerial cooperation among regions. However, the effort related to economic matter still needs more attention, such as the possibility to give stimulant help, the management of credit system, or others that make it easier, and to optimize the managing of RWH facility in a short time. It is also more effective not to depend always on other areas, considering that the cross-area management is still difficult to do.

Table 4.87: Respondent's ATP (Ability to Pay) for RWH development

Zone	Ability to Pay (Rupiah)	Recommended RWH	Investment Cost	
			RWH Type	Rupiah
Recharge Area (RA)	605,000	Conservation pond	Artificial recharge well	1,170,000
Anthropogenic Vulnerability (AVA)	1,250,000	Artificial recharge well, Conservation pond	RWH Storage	3,020,000
Natural Vulnerability (NAV)	965,000	Conservation pond, RWH storage	Conservation pond	300,000

To strengthen the feasibility analysis, the ATP analysis is also supported by the WTP analysis. WTP analysis is done to know the willingness and perception of respondents to implement RWH. Since rainwater has indirect benefit and negative image, it is necessary to consider the economic feasibility and WTP influenced by the respondents' perception of rainwater.

Table 4.88: Respondent's perception of rainwater

Perception	RA		AVA		NVA	
	F	%	F	%	F	%
Need to be harvested	13	43.33	36	60	21	70
Neglected	11	36.67	10	16.67	6	20
Has to be flown away	6	20	14	23.33	3	10

Most respondents perceive that rainwater needs to be harvested (Table 4.88). The biggest perception is found in the natural vulnerable area (70%), followed by the perception to neglect rainwater (20%) and to throw rainwater away (10%). Such perception is caused by the fact respondents feel more benefit and very little negative impact of rainwater. A large number of rainwater storages are also possible to use during the dry season. At the anthropogenic vulnerable area, 60% of respondents consider harvesting rainwater, 16.67% consider neglecting it, and 23.33% think it should be thrown away. The perception of keeping rainwater is influenced by the education level and the life demand while neglecting rainwater or even throwing it away is perceived because people think that rainwater is a source of disease and disaster. Realizing that it is due to the wrong treatment, people are still skeptical about the ineffectiveness of rainwater processing.

In the recharge area, 43.33% respondents perceive rainwater harvesting, 36.67% people choose to neglect it, and 25% people are to discard it. The relatively significant perception of harvesting rainwater is possibly because of the good education level and the ease to access information. This can support the opportunity to participate in the development of RWH facilities. The perception of neglecting rainwater is possibly because people count on the natural process of rainwater absorption. Then, the perception of discarding rainwater is because the environment is no longer able to infiltrate rainwater optimally.

Table 4.89: Respondents' acceptance in RWH development

Acceptance	RA		AVA		NVA	
	F	%	F	%	F	%
Accept	18	60	44	73.33	27	90
Reject	12	40	16	26.67	3	10

The aforementioned perception level is used for the analysis of respondents' acceptance to develop RWH facility. The WTP of the three areas shows a positive condition for RWH development (Table 4.89). In line with the respondents' perception of keeping rainwater, the ranks of acceptance level are the natural vulnerable area/NVA (90%), anthropogenic vulnerable area/AVA (73.33%), and recharge area/RA (60%). This shows that knowing the benefit, some respondents who perceive neglecting rainwater are also willing to try to harvest rainwater. Therefore, the effort to convince the society becomes the main key to get a broader acceptance.

Referring to the results of Cost-Benefit, ATP, and WTP analyses, the economic-social feasibility of RWH development is shown in Table 4.90. The adequate RWH facilities for the recharge area are the recharge well, conservation pond, vegetation and open space, while the rainwater storage is inadequate. The priority in developing RWH facilities is optimum for such more natural facilities as vegetation, open space, or conservation pond since they are cheap and the space is still available. Thus, the society's participation can be quantitatively optimal, and all at once, it becomes a strategy to control the speed of land conversion.

As in the recharge area, the rainwater storage is the only improper factor in the anthropogenic vulnerable area since its investment cost is high and space is limited. On the other hand, this area is physically good to infiltrate water, so it is more effective and adequate for a recharge well or conservation pond. Since the location is mostly in the urban area with limited space and good economic level, the development of RWH facility will be more effective and beneficial if the flexible recharge well becomes the priority. Finally, for the natural vulnerable area, the analysis result shows a considerable fact that the most possible facility is rainwater storage. Its development strategy needs to consider the economic problems, its low ATP value, which may require a set of gradual development, the availability of light facility of loan, the extension of stimulating helps, or others.

Table 4.90: Socio-economic feasibility of RWH facilities

RWH Type	Cost Benefit Analysis			ATP			WTP			Social Economic Feasibility		
	RA	AVA	NVA	RA	AVA	NVA	RA	AVA	NVA	RA	AVA	NVA
Artificial recharge well	+	+	*	-	+	*	+	+	+	+	+	*
RWH storage	-	-	+	-	-	-	+	+	+	-	-	+
Conservation pond	+	+	*	+	+	*	+	+	+	+	+	*

Remark: (+) feasible, (*) not recommended, (-) not feasible

4.8.4 Results and Discussion

The pattern of potential and opportunities to develop RWH can be observed for each research zone. The recharge zone has the potential to develop RWH considering that many respondents own RWH facilities (93.33%). However, there are only vegetation and open space because they naturally exist in an available vast area. It is also proven by the fact that the motivation is still dominated by unintentional-act (76.67%). Both the effort to urge awareness and the form of command are still possible to complete by developing the recharge well and conservation pond. Moreover, 43.33% of respondents have understood that rainwater needs to be infiltrated (Figure 4.53). It is clearer as the rate of respondents' willingness to manage RWH is relatively high (60%).

Different conditions prevail in the anthropogenic vulnerability area, in which more respondents do not have RWH facilities because of limited land-ownership. A very good opportunity is shown by the fact that the small number of RWH facilities is made based on the people's self-awareness. It is also proven by the respondents in majority (60%) of cases who understood the importance of storing rainwater. This feature is supported by 73.33% of respondents who are willing to manage RWH (Figure 4.54).

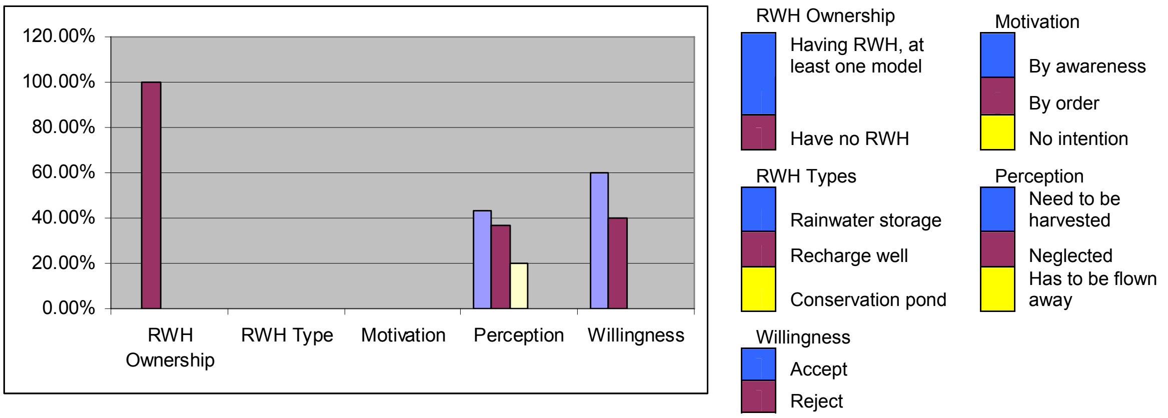


Figure 4.53: Condition of potential and opportunity of RWH in the recharge area

The natural vulnerability area is almost the same as the recharge area in terms of land availability. The rainwater storage as the most effective facility is only owned by 26.67% of respondents. However, the awareness has grown, and the natural aspects influence the respondents' understanding about the importance of storing rainwater (67.67%). About 90% of respondents are willing to manage RWH (Figure 4.55).

The socio-economic feasibility related to RWH facility is presented in Table 4.90. The suitable RWH facilities for the recharge area are: recharging well, conservation pond, vegetation, and open land, while the rainwater storage is considered as inadequate due to the low cost and the land availability. The development of recharge wells should get first priority and can be managed collectively to be more effective. As in the recharge area, only rainwater storage is not appropriate in the anthropogenic vulnerability area due to high investment cost and limited land. Besides, this area is good for infiltrating water that it is more effective and sufficient to manage the recharge well and conservation pond.

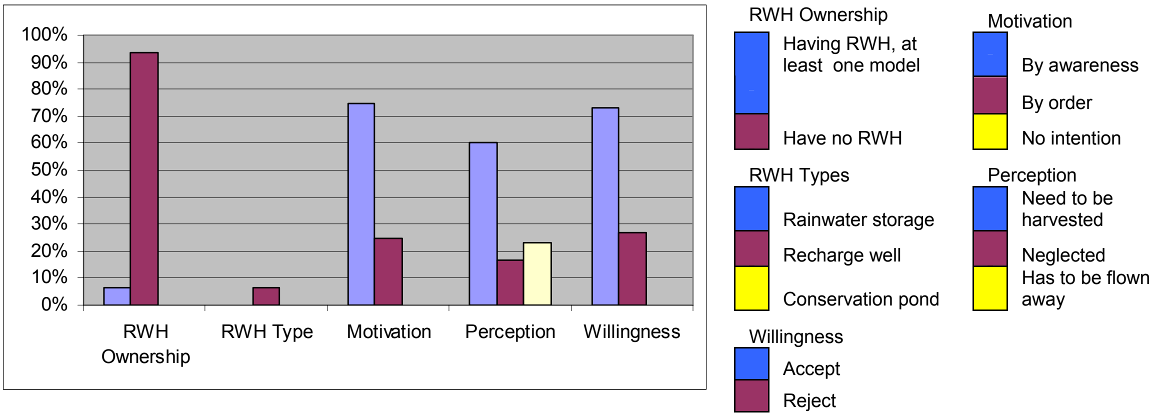


Figure 4.54: Condition of potential and opportunity of RWH in the anthropogenic vulnerability areas

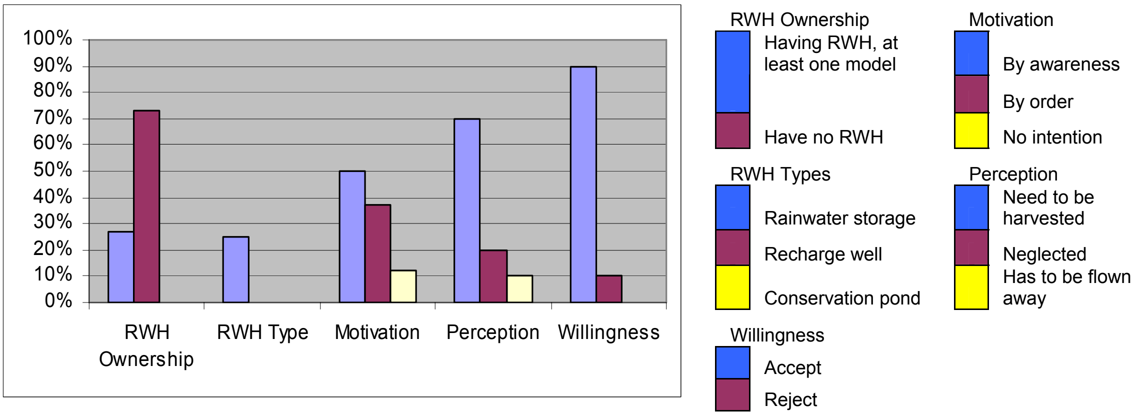


Figure 4.55: Condition of potential and opportunity for RWH in the natural vulnerability areas

Finally, for the natural vulnerability area, the most possible facility is only rainwater storage. Its development strategy needs to consider the economic problems, its low ATP value, and the gradual development, the supply of soft loan facilities, the giving of incentives or others.

CHAPTER 5

SCENARIOS OF BEST RAINWATER MANAGEMENT PRACTICES

5.1 RWH Model Alternatives

5.1.1 Overview

The rainwater potential in the study area can be seen in Table 5.1. It shows that Sleman and Bantul have rainwater surplus when the demand for domestic, industry, and irrigation use is covered. However, Yogyakarta City's rainwater is not enough for those demands, which is (-) 38,861,970 m^3/year. Altogether, the three areas have about 70% surplus of rainwater. Therefore, the abundant rainwater has to be managed properly by developing RWH, technically and non-technically.

Table 5.1: Rainwater potential in the study area

No	Description	Sleman	Yogyakarta	Bantul
1	Area (km^2)	574.82	32.50	506.85
2	Rainfall (mm/year)	2500	2100	1800
3	Population (2000)	901,377	396,711	781,013
4	Potential RWH (m^3/year)	1,437,050,000	68,250,000	912,330,000
5	Domestic water demand (m^3/year)	35,873,001.8	21,422,394	32,488,578.8
6	Total water demand (m^3/year)	358,730,018	107,111,970	324,885,788
7	Surplus/deficit (m^3/year)	+ 1,078,319,982	- 38,861,970	+ 587,444,212
8	Total 3 areas' potential RWH (m^3/year)	2,417,630,000	100%	
9	Total 3 areas' water demand (m^3/year)	790,727,776	32.71% of total potential RWH	
10	Total 3 areas' potential water surplus (m^3/year)	1,626,902,224	67.29% of total potential RWH	

Assumptions:

1 Water consumption is 100 litres/capita-day for rural people and 150 litres/capita-day for urban people (PDAM, 2002, 2002-a, 2002-b)
2 Water demand at urban areas: domestic (20%), industry (60%), and irrigation (20%)
3 Water demand at rural areas: domestic (10%), industry (10%), and irrigation (80%) (PDAM, 2002-a/-b)

5.1.2 Rooftop RWH

5.1.2.1 Storages

5.1.2.1.1 General

Harvesting rainwater can be done from most types of roof. The rainwater is collected in gutters around the overhang of building. The gutters drain water to a down-pipe, which discharges it into a storage tank. The down-pipe should be made swivel in order that the collection of the first run-off can run for the first foul flush, thus preventing accumulated animal droppings, leaves, dust, and debris from entering the storage. Sometimes a collecting box with a mesh strainer and additional filter media consisting of gravel, sand, charcoal, and pea gravel is used for preventing the penetration of pollutants. Alternatively, a dirt/foul-flush box, which can be drained separately, may be fitted between the down-pipe and the storage.

The run-off from a roof is directly proportional to the amount of rainfall and the plain area of the roof. The guttering and down pipes should be sized to be capable of carrying the peak volume of run-off. In the tropics, this can occur during high intensity, short duration storms. The capacity of storage is based on several design criteria, i.e. rainfall patterns and volume, and duration of the dry period and demand estimation. The provision of storage is the most costly element of a rainwater-harvesting project, usually about 90% of the total cost. The storage can range from small used-containers, for example oil drums, food cans, etc., up to large storages of 150 m^3 or more at the ground level, or sometimes beneath. These storages are made of concrete and are used as storage for schools, offices, mosques or other institutions with large roof areas.

Storages for household use can be made cheaply in various ways: (1) *Basket storage* is a basket made of bamboo, originally intended for carrying or storing maize, which has been plastered internally and externally with sand/cement mortar. Storage of up to 2 m^3 can be provided by such baskets, and (2) *Brick storage* is a favorable construction, as the material is very familiar for Indonesian people. It needs precise mixing of sand and cement to stick the bricks to each other. For 1 m^2 wall, it requires 77 bricks (Pancapana, 2004). To avoid cracking, it is suggested to add water resist cement onto the internal and external layer of the construction. As it is familiar for Indonesian people, the maintenance problem is expected to handle. Sometimes it is difficult to prevent the surfaces from being polluted. If so, it is sensible to use the water collected from these surfaces for any other purposes but drinking, such as house cleaning, laundry, horticulture, flushing toilets etc. From clean roofs, the water can be used for drinking, cooking, and personal hygiene.

5.1.2.1.2 Dimension of Storages

Usually, the main calculation carried out by the designer when planning a domestic RWH system will be for sizing the water storage correctly to give adequate storage capacity. The storage requirement will be determined by a number of interrelated factors. They include local rainfall data and weather patterns, size of roof or other collection-area, runoff coefficient, number of users and consumption rates. The coefficient varies between 0.5 and 0.9 depending on the roof material and slope. In this case, some figures to calculate the dimension of the storage are assumed. Table 5.2 and 5.3 show the assumptions, which reflect the situation in dry areas, such as Prambanan, Dlingo, and Pajangan. Table 5.2 implies that the required space of storage for a small family consisting of 4 people is only 10 m^3 volume when it is assumed that the rainwater consumption is 25 litres/capita/day with the rest of water demand supplied by groundwater or other resources, and it is used for 100 dry day period.

To minimize the construction cost, it is suggested that bricks are chosen as construction material for the cistern. The total cost is expected to be €100. However, if the dry period is assumed 221 days and the rainwater consumption is 100 litres/capita/day then the storage dimension would be 88.4 m^3 or 20 m^2 of space area (Table 5.3).

Since old houses in many parts of urban Yogyakarta have individual shallow wells, it is possible to put the new storage on top of the well. The advantage is, it saves cost of material and space. Another advantage is if there is overflow from heavy rain, the water can be stored in the old shallow well underneath. It is also environment friendly because the overflow can be recharged into the ground and to the downstream.

Table 5.2: Three alternatives of storage dimension with a half average dry period

No	Items	Calculation Approach		
		Alternative 1	Alternative 2	Alternative 3
1	Plain roof size (m^2)	100	100	100
2	Number of people in a family	4	4	4
3	Half average dry period (days)	100	100	100
4	Consumption of rainwater (litres/capita-day)	100	50	25
5	Total consumption (litres/day)	400	200	100
6	Storage requirements (m^3)	40	20	10
7	Storage dimension (m^3)	(4 x 5 x 2)	(2 x 2 x 5)	(2 x 2 x 2.5)

Note: The water consumption is 50 or 25 litres/capita-day especially for the dry areas assuming that the remaining water demand shall be supplied by shallow groundwater or other sources.

Table 5.3: Three alternatives of storage dimension with a full average dry period

No	Items	Calculation Approach		
		Alternative 1	Alternative 2	Alternative 3
1	Plain roof size (m^2)	100	100	100
2	Number of people in a family	4	4	4
3	Average dry period (days)	221	221	221
4	Consumption of rainwater (litres/capita-day)	100	50	25
5	Total consumption (litres/day)	400	200	100
6	Storage requirements (m^3)	88.4	44.2	22.1
7	Storage dimension (m^3)	(4 x 5 x 4.5)	(4 x 3 x 4)	(3 x 2 x 4)

Note: The water consumption is 50 or 25 litres/capita-day especially for the dry areas assuming that the remaining water demand shall be supplied by shallow groundwater or other sources.

5.1.2.2 Artificial Recharge Wells

5.1.2.2.1 General

Groundwater is replenished by precipitation and, depending on the local climate and geology, is unevenly distributed quantitatively and qualitatively. Natural refilling of aquifers at depth is a slow process because groundwater moves slowly through the unsaturated zone and the aquifer. However, aquifers can be replenished artificially.

There are several types of artificial recharge. However, only some types fit to the local conditions, those are:

1) Injection wells: The injection well is suitable for houses with some open areas. It gathers and infiltrates rainwater into artificial soil layers that have high permeability to enable higher infiltration rate. The layers also function as a filter, which can increase the water quality.
2) Filtered and closed wells: The collected rainwater does not infiltrate into deeper soil layers, but it is retained in the well. To increase the quality of collected water, before entering the well, water flows through artificial layer of sand filter.

Using this technology, the increase in groundwater level takes place after a long period, but for a smaller plot, it can show a direct advantage because during the dry season, the groundwater table remains high. However, for most people, the maintenance is too complicated since it is situated underground

The major difference between the two types is the injection well functions as a groundwater recharge while the closed and filtered well functions as a direct water collector without a recharging function. In the injection well, materials like gravel and artificial geo-textile replace the natural soil layers. The replacement will increase the infiltration capacity of soils. A recharged rainwater-harvesting model is more pragmatic for Merapi aquifer area than other storage models.

The following factors need to be considered in successfully constructing a shallow or deep recharge well:

1) The rainwater recharge well is placed in relatively hollow or flat plains.
2) The water flowing into the recharge well is unpolluted rainwater.
3) The safety of buildings around the recharge well must be considered.
4) The local regulations and customs must be considered.

5.1.2.2.2 Dimension of Wells

The technical requirements of recharge well construction are as follows:

1) The minimum groundwater level is 1.50 m in the rainy season.
2) The soil permeability coefficient is ≥ 2.0 cm/hour.
3) The distance between the recharge well and other buildings can be seen below.

Table 5.4: Minimum distance between the rainwater recharge well and other buildings

No	Building Type	Minimum distance from the rainwater recharge well (m)
1	Rainwater recharge well/domestic water well	3
2	Foundation of building	1
3	Absorption area/septic tank absorption well	5

Source: Public Work Department, 2002 (SNI: 03- 2453-2002)

Moreover, this SNI guides the calculation of the dimension of rainwater recharge well which is approached by developing the following formula of runoff volume:

$$\mathbf{V_{ab} = 0,855\, C_{storage}\, A_{storage}.\, R}$$

Where:

V_{ab} = Volume of runoff to be stored in the recharge well (m^3)

$C_{storage}$ = Runoff coefficient of the storage area (no unit)
$A_{storage}$ = Dimension of the storage area (m^2)
R = Average daily-rainfall depth (m/day).

The volume of rainwater infiltration can be calculated using the formula of $\mathbf{V_{rsp} = t_e/24.A_{total}.K}$.

Where:

V_{rsp} = Volume of rainwater infiltration (m^3)
t_e = Duration of effective rainwater (hour) = $0,9.R.^{0,92}/60$ (hour)
A_{total} = Dimension of well's wall + base (m2)
K = Soil permeability coefficient (m/day).

Table 5.5 illustrates the correlation between land area and recharge well dimension.

Table 5.5: Correlation between land area and recharge well dimension

No	Land Area (m2)	Volume of Well (m^3) with Drainage channels	Volume of Well (m^3) without Drainage Channels
1	50	1,3 – 2,1	2,1 – 4,0
2	100	2,6 – 4,1	4,1 – 7,9
3	150	3,9 - 6,2	6,2 – 11,9
4	200	5,2 – 6,2	8,2 – 15,8
5	300	7,8 – 12,3	12,3 – 23,4
6	400	10,4 – 16,4	16,4 – 31,6
7	500	13,0 – 20,5	20,5 – 39,6
8	600	15,6 – 24,6	24,6 – 47,4

Source: Supirin, 2004

5.1.3 Infiltration Basin

Raising the retention of rivers is another method to control runoff flowing into rivers. The purpose of this retention is to slow down the stream flow on the river by spreading the flood along the river from the upstream to the downstream. Small floods will occur along the river, but big floods at the downstream can be minimized. This holdback river water can be useful to supply the groundwater. River retention can be developed by revitalizing the river parts that can temporarily hold water before it flows to the downstream. The more the number of 'water retention areas' along the river, the more the opportunities are to reduce flood during the rainy season and to reduce drought during the dry season in the related area of river watershed. However, it is quite difficult to find the location in the upstream to develop a 'polder' because of the river's steep structure. Therefore, the better location for a 'polder' is in the middle or downstream because these areas are relatively flat (Figure 5.1).

The system is a construction of basins along the riverbank to collect excessive water during the rainy season and let water infiltrate into soil during the dry season. This technology is famous in Germany and has been well applied to control the annual high water situation in Rhine River (Pancapana, 2004). The advantages of applying this technology are:

1) Controlling the volume of water during flood events by collecting water in the polder,
2) Increasing the groundwater recharge for dry season reserve.

However, its main disadvantage is the requirement of large tracks of land. If the basins' dimension is too small, its function for flood control and groundwater recharge will not be optimal. Another factor to consider is the sedimentation. Since it is static water, the low velocity of water circulation will allow particles to settle. If the collected water has high particle concentration, additional dredging work is required to maintain the basin capacity. In the research area, the new construction must be sufficient to gather the runoff from Progo, Opak, Winongo, Code, and Gajahwong rivers.

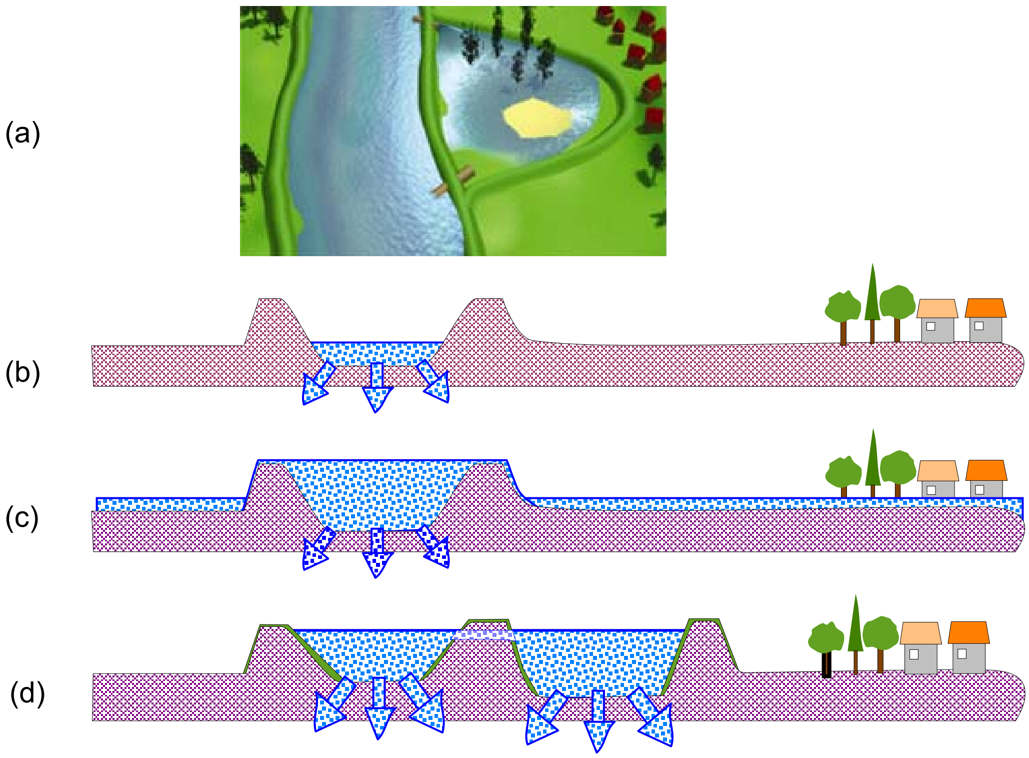


Figure 5.1: (a) An infiltration basin model, (b) Low water level, (c) Flooding, high water level without infiltration basin, (d) High water level with infiltration basin, safe from flooding (Source: adapted from Pancapana, 2004)

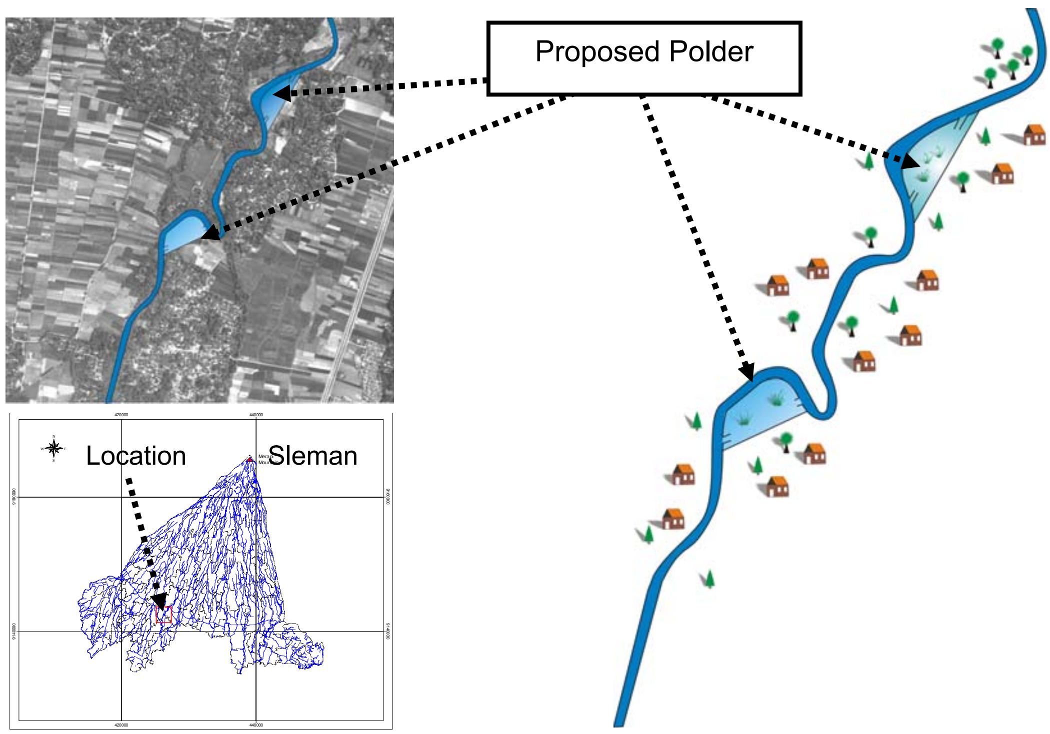


Figure 5.2: A proposed polder as an illustration at Bedog River in Mlati Sub-district, of Sleman Regency. It is identified from aerial photographs of 1:10,000 scale

The criteria for a 'polder' area are:

1) Located within the distance of 500 meters from the main river to reduce the construction cost.
2) Placed in less populated areas to reduce land acquisition and other social costs.
3) Constructed on young volcanic rock, as it has a higher infiltration capacity than the lake deposits.
4) Availability of a more than 10-hectares empty area to enable engineers to design the ideal polder.

As an illustration, Figure 5.2 shows a proposed potential polder. It was identified using an aerial photograph scale of 1:10,000. This polder is located in Mlati Sub-district of Sleman Regency. A number of polders can still be identified in the study area to prevent flood and drought and to recharge groundwater.

Unlike the rooftop RWH application, this construction is large; therefore, the investment to build it is also very high. However, the design can minimize work force during operations except for dredging and sometimes gate control.

5.1.4 Conservation Ponds

Raising the number of conservation ponds in all areas is an effective way to catch rainwater that turns into runoff. These retention ponds can be developed in forests, plantations, rice cultivation, dry-land cultivation, empty yards, or settlements. It can be practiced by the community and proposed to the government. The construction of this pond is simple, i.e. by finding a low location and transforming it into a pond (Figure 5.3 and 5.4). Maryono (2005) suggested that every real estate complex should have a retention pond to catch rainwater. Developing the conservation ponds in various locations will also revise the model of drainage system.

A conservation pond actually can be made by exploiting the existing *'galengan'* (small dikes) in rice fields or in dry-land cultivation or by modifying the border of settlement areas. To make its elevation different from the surrounding, the settlement border can be changed into a dike (Figure 5.3). The borders can be elevated by planting trees. In the case of a house garden paved for parking or other purposes, the conservation can be managed using grass concrete-blocking system. It has spaces for infiltrating the rainwater up to 42% (Figure 5.5).

A conservation pond can also be utilized as an ornament of a park or garden. Sleman has an example of conservation pond for fishing and restaurants (Figure 5.6). This phenomenon has become a new trend for the last 10 years. According to Prinz (2003), to minimize evaporation and erosion, a pond should be planted by vegetation (Figure 5.7). The vegetation can also be useful for maintaining the aquatic ecosystem. A conservation pond can also be combined with irrigation system or river polders such as Subak (Figure 5.8).

Subak, an organization of Balinese farmers, is a good example to learn RWH development based on conservation pond and river polder. Since the 11th century, all peasants whose fields were fed by the same watercourse joined a single Subak or irrigation cooperative, a traditional institution regulating the construction and maintenance of waterworks and the distribution of life-giving water.

This organization controls and manages village life, rice fields, irrigation in particular, and water conservation. Each village has one or more Subak, or members of different small villages are members of one Subak. The Pekaseh, the head of Subak, is chosen by the members for a certain period. Subak is responsible for coordinating the seeds planting and seedlings transplantation to achieve optimum growth as well as for organizing ritual offerings and festivals at the Subak temple.

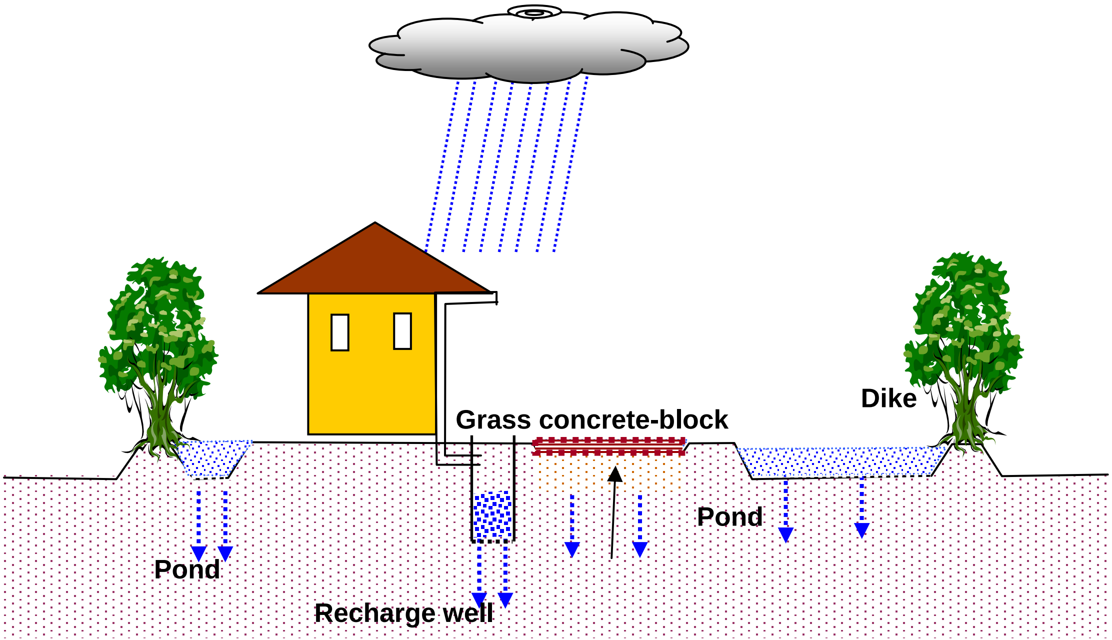


Figure 5.3: A dike, recharge well, pond, and vegetative modification in a housing area with grass concrete-block system

Figure 5.4: An example of a conservation pond in Germany (Source: Prinz, 2004)

Figure 5.5: An example of grass concrete-block construction for garden or parking area (Source: Prinz, 2004)

The most important technical duties undertaken by Subak are the construction and maintenance of canals, tunnels, aqueducts, dams, water locks, and water conservation. A conservation pond can be modified closely to a natural pond (Figure 5.9). The water conservation of Subak is a unique example of RWH development based on local wisdom for the study area.

Figure 5.6: A pond used for fishing and water conservation in Sleman (Photo: Widodo, 2005)

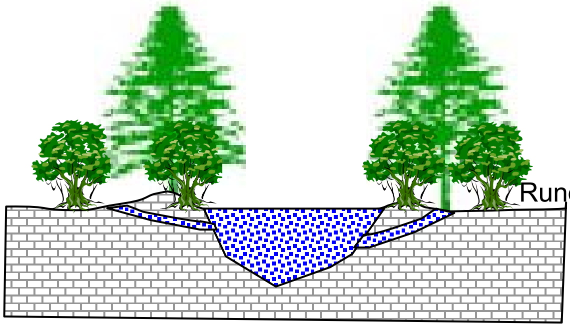


Figure 5.7: A pond model is planted in order to minimize evaporation and erosion

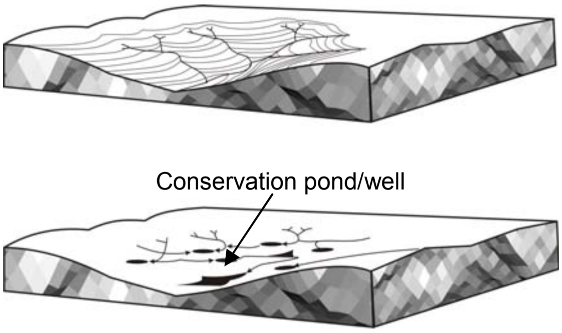


Figure 5.8: Subak traditional water conservation of Bali develops RWH as an integrated part of water resources development (Source: adapted from Suryadarma, 2006)

Figure 5.9: Natural conservation pond in Bantul (Photo: Widodo, 2006)

5.1.5 Paradigm Reform on the Drainage System

The drainage channels in urban areas of DIY usually form grids and parallel patterns, making use of the nearest river as the outlet. Some drainage channels follow the street pattern, but some others cross streets or buildings to drain water directly to the outlet. For the nearest streets to the river, the drainage channels usually form a bend and cross the street to the outlet. The drainage channels in alleys or small streets are usually of the close type, while the channels in asphalted streets are of the open type.

The inlet type for drainage channels is a gutter inlet, making use of the street body to form a plan or horizontal inlet. Gutter inlet is a drainage-channel opening from iron bars/rods for enabling rainwater to flow directly into the channel. Besides using iron bars, the drainage channels in spatial planning also make use of channel lids as the inlet by making holes in them. The disadvantage of using a horizontal gutter inlet is if chunks or wastes are dragged by the flow, they will clog the inlet, hindering the flow of rainwater into the channel, and form puddles when the rainy season comes.

(a) (b) (c)

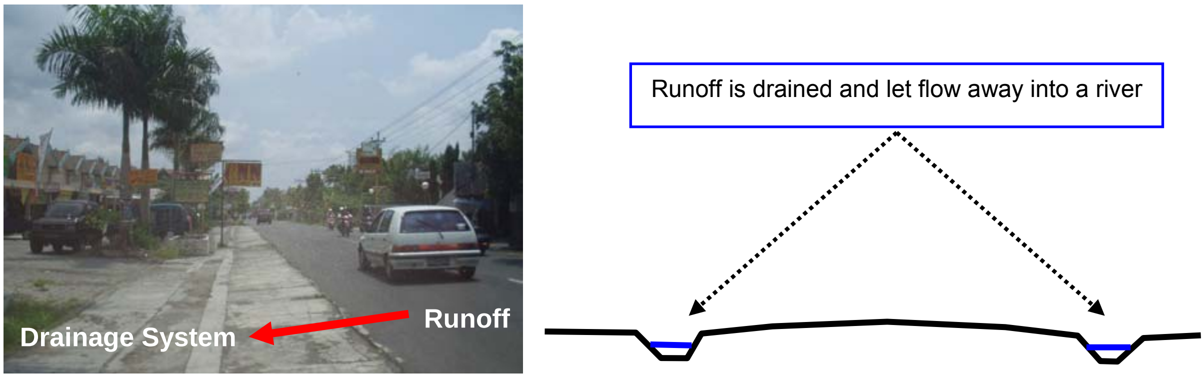
Figure 5.10: Patterns of drainage channels: (a) along the street, (b) bended channel, and (c) crossing the street

The fact is the available drainage channels contain not only rainwater but also domestic wastewater to be discarded into the river. This condition inflicts the health of the environment, particularly if the main river flows through the city centre, as it will decrease the quality of water in the area.

People in Yogyakarta urban area have been using the fast drainage of rainfall as the drainage system with Code River and Winongo River as the main desiccating area supported by Gajahwong River for the eastern part. Rainwater is flowing to the river through 'riool' or channels that have been built and or are being built. To speed up the flow of rainfall, the government also builds many cemented 'taluds' on the flood plain of the river. Considering the water resource carrying capacity in the research area is continually dropped due to the high population growth and land conversion, the paradigm of drainage system development must be reformed. Principally, the new drainage system should slow down the runoff or stream flow of rainwater to the river by:

1) Catching rainwater to be directly consumed,
2) Catching rainwater to be infiltrated into the ground,
3) Constructing 'polders' along the possible parts of the river,
4) Constructing conservation ponds, and
5) Developing reforestations, particularly in the upstream areas.

As rainwater catchment, the roofs of houses/buildings, courtyards, or even highways can be used. According to the principle of highway engineering, roads/streets must be kept free from water; therefore the drainage system has to be effective in draining the water directly to the nearest river (Figure 5.11). This system must be reformed (Figure 5.13), as it makes some areas in Yogyakarta City prone to floods (Figure 5.12).



(a) (b)

Figure 5.11: (a) An existing drainage system in a street, Jl. Palagan Monjali, Yogyakarta. Runoff is quickly flowing into the drainage system and from there into a river (Photo: Widodo, 2004). (b) Typical, conventional road drainage system

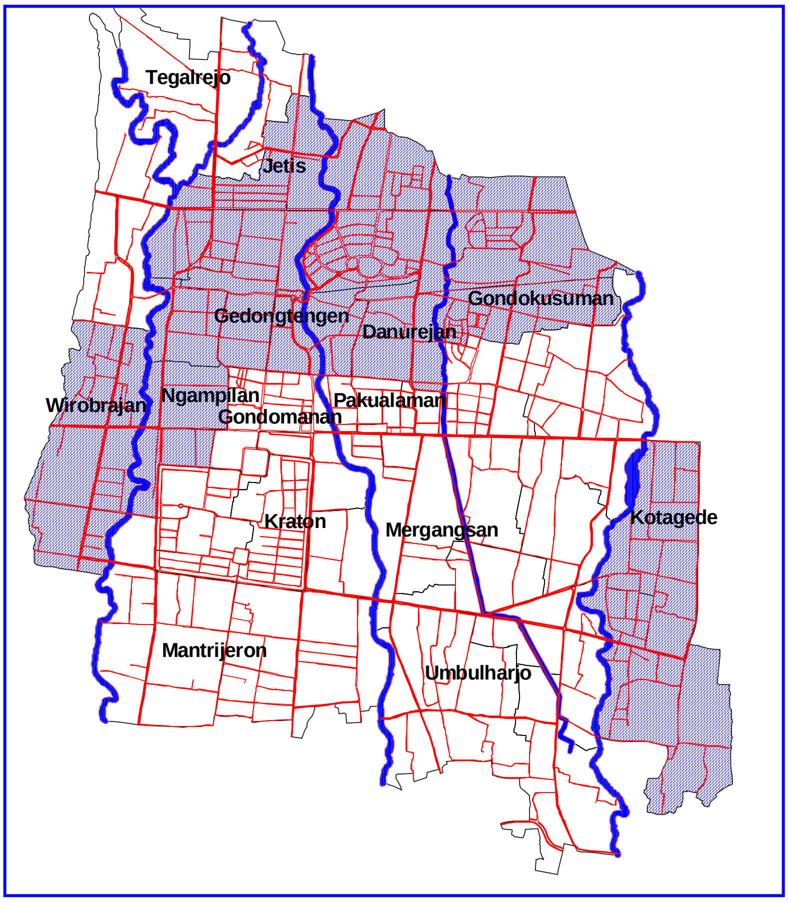


Figure 5.12: Parts of Yogyakarta area (shaded-in areas), which are frequently flooded due to mal-function of drainage system, i.e. Danurejan, Gedongtengen, Gondokusuman, Jetis, Kotagede, Ngampilan, Wirobrajan Sub-district (Source: Environmental State Ministry, 2004)

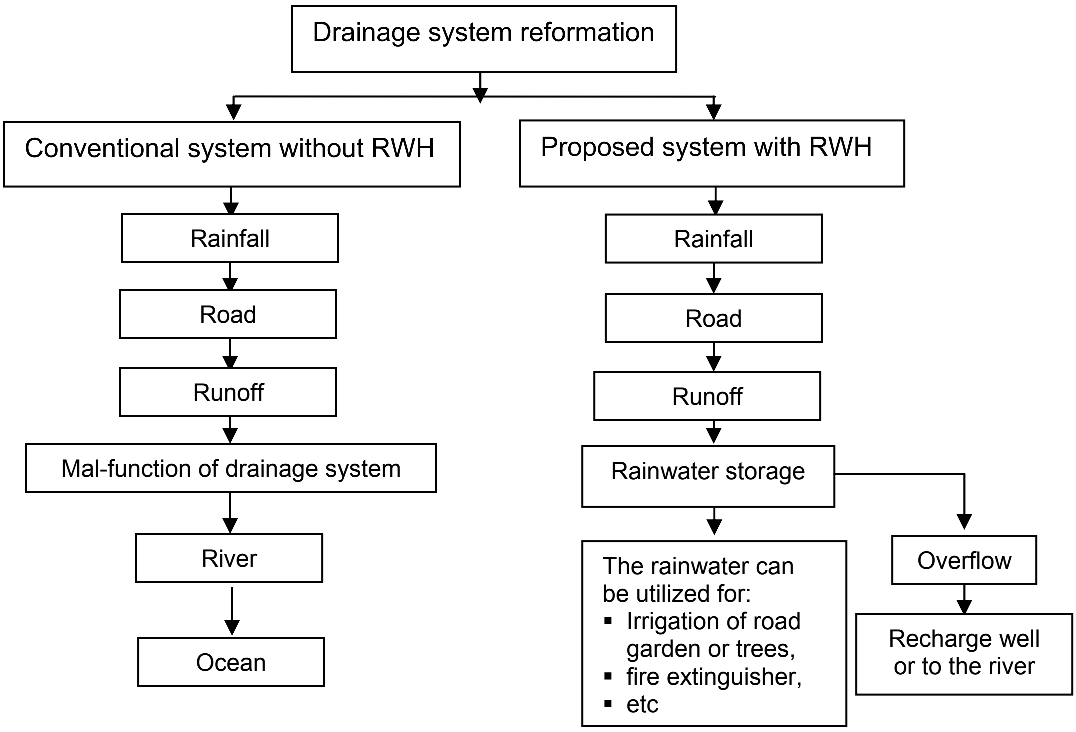


Figure 5.13: Reformation concept on road drainage system

To make use of rainwater and prevent highway damage, the model of rainwater catching developed in China (Figure 5.14) can be applied in Indonesia, including in Yogyakarta. The rainwater caught along the streets in China is drained to a certain location using the gravity system for the purpose of irrigation.

Figure 5.14: Catching runoff from highway and storing the water for other purposes, a case in China

Using this model, the runoff is flowed to the right and left side of the street then to a drainage system. For each certain distance, for example every 200 m – 500 m or as needed, the rainwater is kept in a special storage for irrigation, fire extinguisher, and other needs, or it is directly recharged into the ground to supply groundwater (Figure 5.15 and 5.16). The recharging process is expected to be safe for the street construction since the recharging wells have been made far away from the existing street body.

The rainwater quality in Yogyakarta is quite good (Anjalipan, 2005); therefore, the pollutant threat may come from the street surface, such as oil pollution. Applying a simple treatment by discarding the upper layer can control this oil pollution.

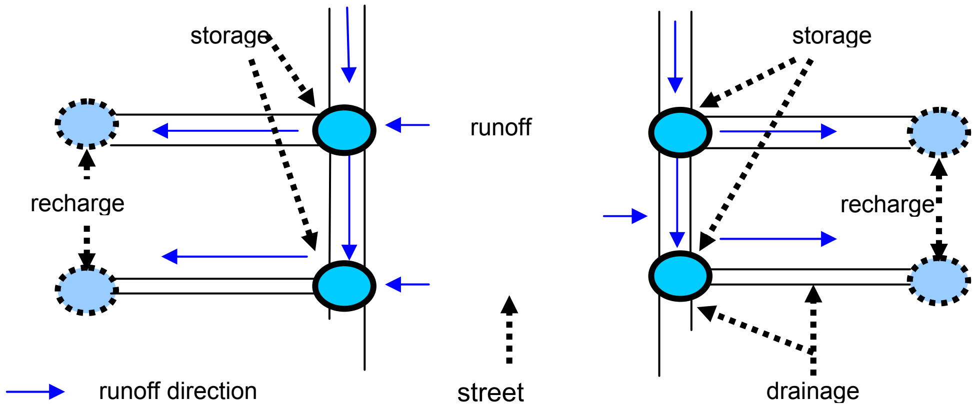


Figure 5.15: A proposed drainage system from a road or highway. Runoff is drained into drainage systems then stored for watering trees or recharged into the ground. This model conserves rainwater without any negative effect to the highway construction

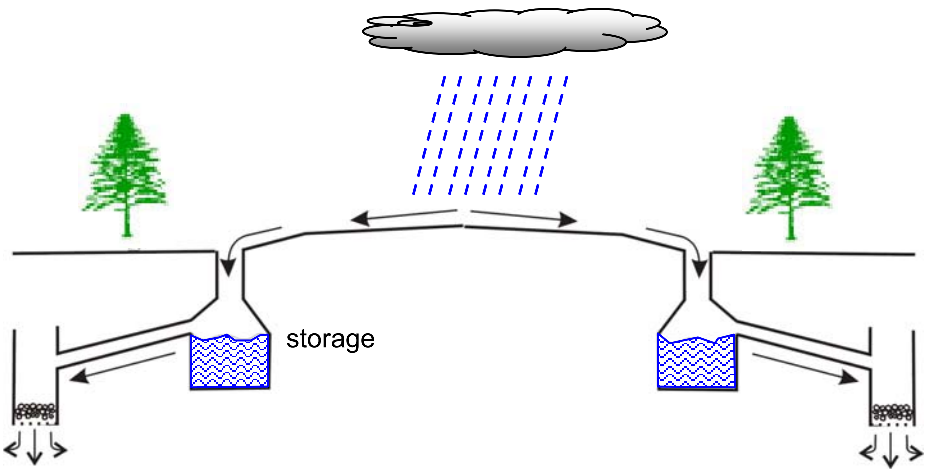


Figure 5.16: A profile of a proposed drainage system from a road or highway. Rainwater stored in the first step can be utilized for watering trees, fire extinguisher, etc. Finally, the rainwater can be recharged into the ground with appropriate location

5.2 RWH Development

5.2.1 Guidelines

The different conditions, potential, and opportunities in each research area require a different recommendation although the general direction is the same. The recharge zone can develop the recharge well and conservation pond, while the rainwater storage is economically insignificant. The recharge well in this area has not been well developed due to the cost and benefit problems. However, the problems can be solved by constructing a strong affordable well that can function optimally. Another alternative can be in the form of soft loan or stimulant fund from the government or non-government institutions. The more essential factor is the individual benefit. The people living in lower areas or even cross-administrative areas may feel more direct-benefit. In the context of KarTaManTul, the role of regional government and management cooperation among regencies are expected considering that developing RWH facilities, conservation pond and open space requires an arrangement of reward/disincentive mechanism, either in the regional or family level. It must also be realized that there is only a small opportunity to depend on the awareness and willingness of the society. The type of RWH having almost no constraints is the managing of vegetation as a natural and productive effort from the society. The effort to optimize its existence will urgently need the government's role in the future, as the land conversion in this area is getting higher.

Table 5.6: Recommendations for RWH development at recharge area

RWH Types	Potential	Existing	Constraint	Recommendation	Target
Recharge well	Feasible	Less developed	Cost	• Simple construction • Soft loan • Stimulant fund	▪ Family ▪ State ▪ Business
			Individual benefit	Rewards/ disincentive	▪ Family ▪ State ▪ Business ▪
RWH storage	Not feasible	-	-	-	-
Conservation pond	Feasible	Has not been developed yet	Individual benefit	Rewards/ disincentive	▪ Family ▪ State ▪ Business

For the anthropogenic vulnerability area, the limited land availability restricts the recommendations in comparison to the recharge zone. Only the recharge well can be potentially developed at the family level. The costs might limit the implementation. Therefore, the same as in the recharge zone, an efficient construction and giving soft loans or incentives are recommended. Then, considering that the major parts of this area are in the urban area, various types of construction can be recommended. The recharge well is placed under the floor of building, so it is physically safe and it requires lower costs. Alternatively, the construction can use a communal system with a bigger size of well depending on the extent of the recharge zone. This alternative is suitable for larger units and government institutions. The management seems to be more complicated and therefore this might only serve as second alternative. The same alternatives are also recommended for the conservation pond, which does not involve large costs. For the communal system, the community group can make use of individual empty-land or village-land. The government is expected to manage the state land or the land in the government's office complex. The same as for the recharge zone, rainwater storage is not recommended since it is here economically not suitable.

The natural vulnerability area only has one recommendation, i.e. developing rainwater storage, due to its natural environment. Moreover, developing Rainwater Storage is cheaper than buying water for domestic use. In this area, agriculture is still the main sector although the soil fertility is low. It leads to the low economic level of the society, making the development of Rainwater Storage facing a cost constraint. The recommended solution is a soft loan or incentives from the government or non-government institutions. A simpler construction is not recommended considering that rainwater storage is already cheap and durable and the physical strength and size of building are the main requirements. Moreover, it should be prioritized because the society in this area is very dependent on this facility for their life. The government's creativity to manage the participation of donor institutions and non-governmental institutions is meaningful. The most important factor is the ability to build the society's awareness and to convince the people through, in this case, academic elements, non-governmental organizations (NGO) or the government itself.

Table 5.7: Recommendation of RWH development at anthropogenic vulnerable areas

RWH Types	Potential	Existing	Constraint	Recommendation	Target
Recharge well	Feasible	Has not been developed yet	Cost	• Simple construction • Soft loan • Incentives	• Family • Office • Campus, etc
			Land	• Underground construction • Communal system	• Family • Community group • State/ Government
RWH storage	Not feasible	-	-	-	-
Conservation pond	Feasible	Has not been developed yet	Land	Communal system	• Community group • State/Government

Table 5.8: Recommendation of RWH development in the natural vulnerable areas

RWH Types	Potential	Existing	Constraint	Recommendation	Target
Recharge well	Not feasible	-	-	-	-
Rainwater storage	Feasible	Not seriously developed yet	Cost	• Soft loan • Stimulant fund	Family
Conservation pond	Not feasible	-	-	-	-

Table 5.9: Priority 1 in developing RWH for recharge area

RWH Type	Village	Sub-district	District	Area (km^2)
(1) Recharge well (2) Conservation pond (3) Eco-drainage system redevelopment	Glagahharjo, Kepuhharjo, Umbulharjo, Wukirsari, Argomulyo	Cangkringan	Sleman	204.25
	Tamanmartani, Selomartani	Kalasan		
	Donoharjo, Sukoharjo Sardonoharjo, Sariharjo, Sinduharjo, Sinduharjo	Ngaglik		
	Umbulmartani, Sindumartani, Widodomartani, Bimomartani, Wedomartani, Wedomartani	Ngemplak		
	Hargobinangun, Purwobinangun, Candibinangun, Pakembinangun, Harjobinangun	Pakem		
	Trimulyo, Caturharjo, Triharjo, Pendowoharjo, Tridadi	Sleman		
	Merdikorejo, Lumbungrejo, Margorejo, Pondokrejo, Mororejo, Sumberrejo, Tambakrejo	Tempel		
	Girikerto, Wonokerto, Bangunkerto, Donokerto	Turi		
Total				204.25

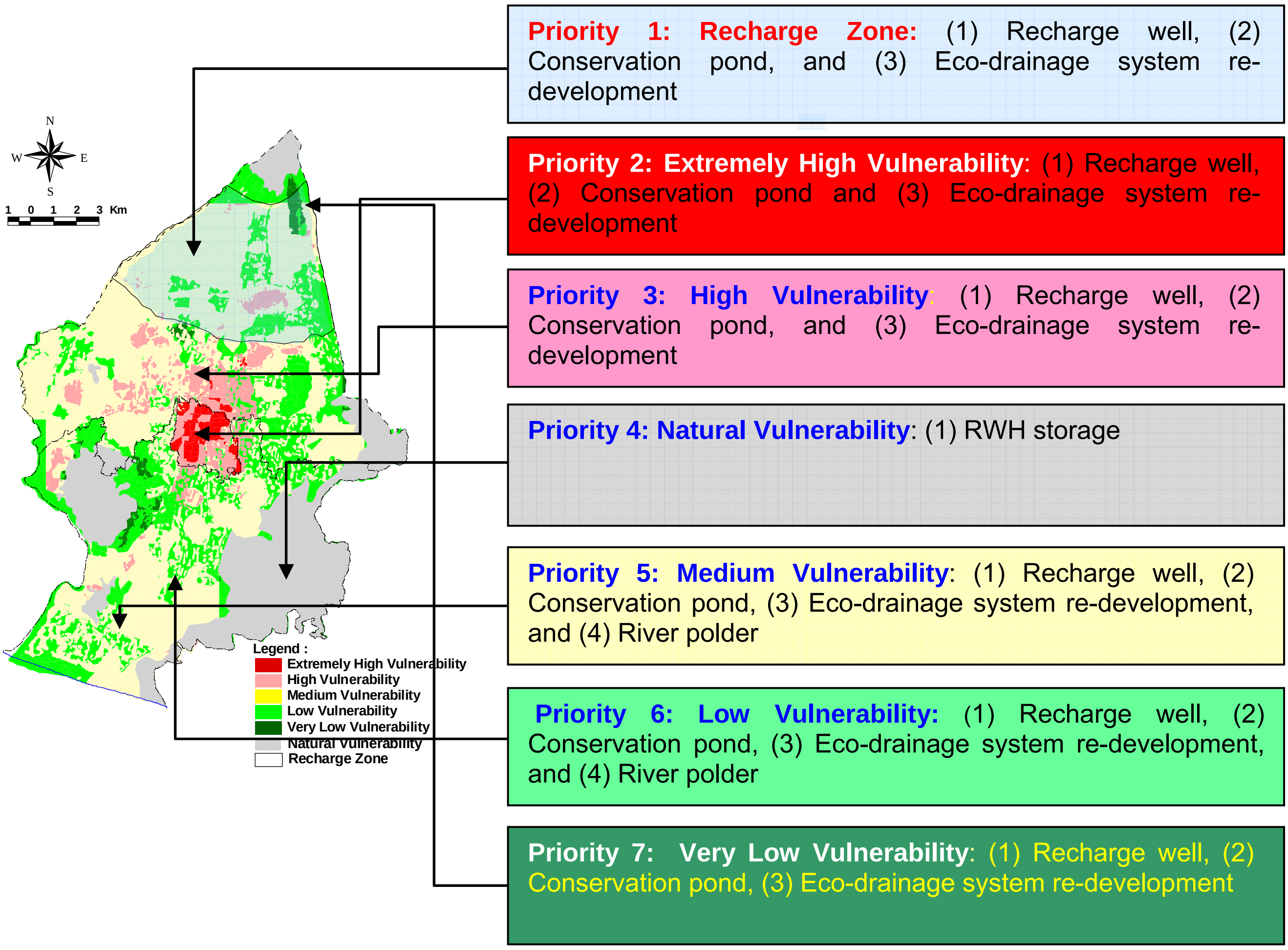


Figure 5.17: Prioritizing developing RWH based on the vulnerability level and the types of RWH model

5.2.2 Priorities

The priority of RWH development is based on the vulnerability criteria and the urgency (Figure 5. 17). The proposed RWH developments are divided into two main groups: the first group is RWH recharge well, RWH storage, and conservation ponds for domestic, commercial, and government or state sectors; and the second group is developed especially by the government or related state agencies such as river polder and eco-drainage system.

Priority 1 is in the recharge area (Table 5.9), which is important for sustaining the water resources system, especially for groundwater, not only for Sleman but also for Yogyakarta and Bantul. This recharge area is a part of Merapi Aquifer system in the north of Sleman that has serious issues with the fast housing development. Therefore, this area is considered very crucial to be treated as soon as possible with all efforts. The RWH alternative models that can be developed based on social economic and physical aspects are: (1) recharge well, (2) conservation pond, and (3) eco-drainage system re-development. Eco-drainage systems include development of bore hole infiltration (Indonesian: *bio-pore*).

Priority 2 is in Extremely High Vulnerability areas (Table 4.57). This area is mostly in Yogyakarta City and its surrounding urban areas. The population and settlement density in this area is very high that it can trigger water resources quality and quantity degradation. The recommended RWH alternatives are: (1) recharge well, (2) conservation pond, and (3) eco-drainage system re-development.

Priority 3 is for the second category of anthropogenic water resources vulnerability area, which is mostly in urban areas – high vulnerability (Table 4.59). The recommended RWH developments are: (1) recharge well, (2) conservation pond, and (3) eco-drainage system re-development.

Priority 4 is proposed for the natural vulnerability areas (Table 4.68 to Table 4.71). This natural water crisis consists of: (1) Nanggulan and Old Andesit, (2) Jonggrangan and Sentolo, (3) Merapi Peak, (4) Sambipitu, and Kebo Butak, Nglanggran, Semilir. The areas usually face serious drought in every dry season. A recommendation for RWH focuses on rainwater storage.

Priority 5 is focused on the medium vulnerability area, which is the majority in the study area (Table 4.61). Finally, **Priority 6** and **7** are for the low vulnerability and very low vulnerability areas (Table 4.63 and Table 4.65). The recommended RWH developments for priority 5, 6, and 7 are (1) recharge well, (2) conservation pond, and (3) eco-drainage system redevelopment. Besides the mentioned alternatives, river polder is suitable to be developed at the areas of Priority 5 and 6.

5.3 Administrative and Political Aspects

Relating to Law No. 25/1999, regencies and municipalities have more autonomy in the decentralization. This apparently influences the local governments' behavior as they usually have strong interest in their own jurisdiction. As a positive impact, they become busy to increase the local revenue, give more service to people, and make policies that are relevant to what people confront. On the other hand, they become more inward-looking, resulting in more conflicts among local governments when cross-border issues take place.

When a city grows and exceeds the administrative jurisdictions, natural resource and infrastructure management could be complicated. Rivers, groundwater, surface water, and roads are some examples of borderless resources, urging a cross-border management to be applied. Such management requires the involved jurisdictions to find a system that takes into account every integrating factor and accommodates all interests for avoiding conflicts. A legal body or institution that involves all relevant local governments is then required to manage the system. Difficulties may arise in the implementation, but such integrated system can result in an optimum performance of the resources.

5.3.1 Joint Secretariat KartaManTul

To respond such issue, in Yogyakarta, the Joint Secretariat KartaManTul (JSK) is established. JSK serves the three local governments of Municipality of Yogyakarta (*Karta*), Regency of Sleman (*Man*), and Regency of Bantul (*Tul*). Agreed in 2001 on a document signed by the heads of the three local governments with the supporting signature of the governor, this joint is aimed at the balanced and harmonious management and development of urban infrastructure of the three local governments. They agree to enhance the coordination in planning, implementation, monitoring, and evaluation of urban infrastructure. Originally, the cooperation still focuses on the urban infrastructure management, such as solid disposal, transportation, drainage, and water supply.

As the recharge area, Sleman is required to maintain its function while it has its own interest in Bantul and Yogyakarta as its disposal area. Meanwhile, Yogyakarta is the locomotive of economic activities in the region; it needs Sleman as the water supplier and Bantul as the disposal area. Bantul itself needs Sleman and Yogyakarta for its development. These coherent, intertwining pieces of interest, also the critical water resource issues, urge JSK to implement a system for water resources management.

5.3.2 KartaManTul Water Commission

As stated before, water is a borderless matter. Hence, all hierarchical authorities that deal with the water systems despite administrative borders should work together. Yogyakarta City, which faces the most critical water problems, should initiate to gather the representatives of the relevant authorities. A new body, formed as a commission and an integrated part of JSK, should take over the coordination of activities.

The overall goal of this commission is to develop a long-term water resources management strategy focusing on water quantity and quality in the area. It is expected that the commission will become a model for water management in other areas. It should respond to environmental and water concerns while allowing the economic development.

The commission will consist of high rank staff or decision makers from local KartaManTul governments and the province. An advisory board could be established; experts from universities, business people, NGO representatives, and other vested stakeholders could be the members. In the commission, each authority retains its functions in the existing structure but it is complemented by the new function. The commission will bring issues not only directly related to water management but also covering other aspects that presumably affect water catchment. It also tries to find solutions while considering economical, socio-cultural, and technical aspects of water demand and supply. The other important point is the commission should have the power to make decisions relating to water management issues.

Each member of the commission, especially those from the local government, should have ranks, which enable the member to make decisions or at least have the capacity to influence the decision-making process in his/her authority. Within the commission, the members have opportunities to exchange opinions, information, and strategies in regular meetings or other conventions. The funding of this commission should come from local governments, provincial government, central government, and industries.

The establishment of the commission must involve stakeholders from the early stages. At the beginning, the most crucial factors like budgeting should be clearly discussed. Therefore, the involvement of private and business people is also very important. Furthermore, the core members should consist of people with the same point of view. It will determine the pace of work at the early stage.

The commission should prepare a priority list of works, i.e.:

1) Evaluating the existing rainwater harvesting system, focusing on the artificial recharge well,
2) Arranging the regulations, including regional policy, such as protection of catchment areas in the northern parts of Sleman, protection of riverbanks from economic development, protection of water bodies from pollutions, and limitation of groundwater exploitations,
3) Defining the ownership of lands that naturally influences water resources,
4) Arranging the form of campaign, not only for ordinary people living in the area but also for the decision makers,
5) Building a computerized information system, e.g. GIS, that offers a large data storing and faster analysis process. It is important also for disaster mitigations.

The tasks of this commission are:

1) Development of a watershed and basin management strategy,
2) Decision-making relating to water management issues,
3) Assessment of anthropogenic impacts on water resources,
4) Water resources monitoring,
5) Campaign, education, and information dissemination.

5.3.3 Regional Regulations

Until today, there is no integral regulation of the area in terms of water management especially for rainwater harvesting. The local governments have different perspectives for the general spatial planning relating to this issue. It affects the development trends in the area. To initiate the program, there must be legislation as the umbrella to implement the actions and reinforce them in the community. This grand regulation will influence other water related regulations, become an important consideration for a new general regional planning of the local governments, and affect the directions of regional development.

The legislation should include:

1) Land use regulation, such as zoning system for area near the water body, water sources and limitation of development in the potential groundwater recharge areas,
2) Water supply regulation and support for new resource development like RWH, drinking water quality standards, public water system staffing requirements, and strict permit for large-scale withdrawals of surface water and groundwater,
3) Water resource assessment management for defining the water resource protection area, conducting a contaminant source inventory, determining the susceptibility of the public water supply, identifying contamination from the inventoried sources, and
4) Wastewater program that focuses on septic systems, establishing standards for such design parameters as minimum percolation rate, leaching field area, storage size and design, and wastewater flow rate. The regulation also specifies minimum setback distances from water supply areas, distribution lines, water resources and wells, hazardous materials including hazardous waste generation, treatment, storage, transportation and disposal, underground storages, solid waste facilities in terms of water source management, pesticides: controlling the

use of pesticide, which presumably will spill on the water body, and residential hazardous waste.

5.3.4 Reform of “IMB”

Another rule needed to be reformed is IMB (a license to construct a building). Up to now, IMB is merely the means of *KKN* (*Korupsi*-Corruption, *Kolusi*-Collusion, and *Nepotisme*-Nepotism). IMB should have been the main controlling means of development, particularly in developing houses and other buidings. The balance between the land use and regional planning must be a priority in controlling the development requiring IMB. Therefore, a review or evaluation on the regional planning is urgent to conduct to make a better control over the development system.

IMB has been a means of gaining taxes for the sake of local real income, and it is still only for fulfilling the license requirement. The evaluation and examination of IMB process have hardly been done in practice. The construction of artificial recharge well as an obligatory to be included in every blueprint of licensed house or buildings is only a formal requirement. Its realization is never examined, so most community members do not conduct the work based on the blueprint, particularly in the part of constructing the artificial recharge well.

The limited government officers can actually be substituted by developing the people-organization function at the lower level, i.e. head of *RT (RT=Rukun Tetangga/* the lowest communal organization - about 50 families), head of *RW (RW=Rukun Warga/* the second higher communal organization – about 4 RTs), and/or *Kepala Dusun* (the chief of several *RT*s and *RW*s). The lowest levels of institution can be directly involved in controlling the development in their own area. They can give a license to construct a building to the dwellers in their area, and they can examine the construction to check its compatibility with the suggested plan. However, their lack of construction knowledge can hinder this effort although trainings can be held for them to anticipate.

5.4 Social Mobilization

The always-dynamic social aspect is important in water resource management. Social change usually occurs whenever there is a water problem. Thus, a water problem must be wholly considered from different sides. It should be understood as a problem from the society, by the society, and for the society for the sake of better life in the present, in the next generation and even in the eternal life.

The philosophy of win-win solution is a relevant concept for Javanese people who have ”*menang tanpa ngasorake*”, ”*keno iwake ora buthek banyune*”, ”*nglurug tanpa bolo*”, and ”*tepo sliro*”. All the philosophies give an insight that each of us must have a discussion (Javanese: *Rembugan*) to find the best solution of a problem, including the water resource problem, without feeling lose or losing face.

To implement the water resource management, specifically RWH development, the social communication relating to cultural aspect is very important to develop. According to Kodoatie and Sjarief (2005), the social instrument that can urge the community to develop RWH for sustainable water resources are for example water education, communication, campaign, and expansion of public participation.

The education, in this case, should involve the formal and non-formal education, such as starting from kindergartens for formal education. The content should be fitted to each education level. Seeing directly the fact in the surroundings is the best model for environment and water education besides books, photos, and/or films. The role of educator is indeed strategic in terms of increasing attitudes and concerns of students towards the environment and its system, including rainwater.

An interview conducted towards kindergarten teachers in Yogyakarta City and its surroundings in August 2005 showed that the teachers' understanding on rainwater resource is still very low. Most of those teachers said that rainwater is dirty, a lasting common opinion. Some others said rainwater is not completely dirty. This is related to people's myth, especially among children, that playing under the rain is forbidden since it can cause a flu/cold/fever. The rainwater falling at the beginning of the season indeed can potentially cause a disease because it may contain pollutant material from the air. The rainwater, which has been falling for some period after the rainy season, can be considered clean (Anjalipan, 2005, Sudarmaji, 2005). For that reason, in formal education, before the students learn about the use of rainwater resource, the teacher should give explanation first about the environment, water resource, and rainwater resource.

Non-formal education can be conducted through the training programs and elucidation to practitioners, public figures, businesspersons, bureaucrats, politicians, and NGO activists. This education refers more to the reorientation of water resource management. If all this time the development of water resources is only seen from the side of engineering or civil engineering, nowadays it must have covered the multi-discipline knowledge (Grigg, 1996). The water resource development conducted in Indonesia all this time is focused more on the aspect of civil engineering and in fact has caused new problems; even there is often a mal-practice (Maryono, 2005, Kodoatie and Sjarief, 2005). Training of trainee (ToT) is one of the good non-formal educational methods. The existence of more than 100 higher institutions/universities in Yogyakarta, Sleman, and Bantul can be used to mobilize the community education using the proper methods and communication in order to make the community immediately aware of the environmental condition, including water matter.

Besides the educational factors, communication is another important means to develop the public capacity for sustainable water resources. According to Kodoatie and Sjarief (2005), the role of communication is in the first rank compared to intellectual level, self confidence, maturity, etc. in gaining a success.

The water resources' stakeholders should understand their roles in communicating; they can be categorized into 7 groups, i.e. service provider, regulator, planner, executor, supervisor, supporting organizations, and users. For that reason, the stakeholders should use an appropriate communication method from the view of accurateness, accessibility, and justice. The mass media, elucidation, training, leaflet, open house, dialog, and others can be the alternative means of communication fitted into the target community.

A good communication can be applied through the campaign on environmental awareness, including the conservation of rainwater. Water campaign is very important for improving the patterns of understanding and the people's way of thinking, for example many people consider that water is still so abundant that it is unnecessary to save water; that water conservation is unnecessary; that water related problem is merely the government's responsibility; and many more. Thus, at the early stage, it is urgent to awaken people's awareness about the importance of water for human life, the limitedness of water resources, the existing threat of water resource scarcity, the cultural and religious perspectives toward water, etc. "Water is everyone's business" is the proper term that is in line with what is established by United Nation at the commemoration of World Water Day. The water campaign should be a two-way communication. The success in conducting the campaign can increase the people's participation in developing water resources.

Finally, the people's involvement will be the key point of the successful development of water resources. The increase in public's participation should be directed not only to people who have certain direct needs for water resources but also to all parties involved in this case and to those who give either direct or indirect contribution toward water resources. The community in the upstream is not more threatened by the scarcity of water resources than that living in the downstream. Nevertheless, it does need the participation of people in the upstream, considering that the conservation of upstream water resources deeply determines the performance of life in the downstream. The rich will be safer from the risk of water scarcity than the poor, but the participation of the rich should be touched first instead of the poor, since the rich usually consume more amount of water.

Successful campaigns often start out with just one or two people determined to change the matters in their neighborhood. As a campaign gains momentum, it inspires more people to be involved directly. A campaign that can claim widespread support from local people, community organizations, and local businesses will have greater coverage from the media. To make the campaign successful, it should have a well-defined aim. Therefore, among the campaigners there has to be the same understanding on the objective of this campaign. It also has to be measurable, achievable, realistic, and time-specific.

The campaign will start from the most important level to the least ones. As it is important to get support from the highest-rank decision makers of each government, the campaign should start focusing on this group. Since psychologically the decision makers in Indonesia put trust more in educational institutions rather than their own staff, the scientists from prominent universities fit to this task.

The second target group is school-age students because children have bigger acceptance of transfer of ideas, and they are the biggest part of the population. The campaign is arranged at school's situations and involved as part of the curriculum of environmental introduction subject, and then it becomes a continuous work. For the other groups of inhabitants, the recruitment of public figures is very important. The local media, TV, and local radio station can be involved in the cooperation. Key persons such as *kyai* (a leader of Muslim community), informal leaders, and others should be as the main actors in conducting the program campaign.

The campaign to business people and the have will be important, as they are potential in financial aspect to support the program. On the other hand, another target like the low class community may not be ignored. They share the large portion of population and affect significantly the change of environmental quality in very dense dwelling areas.

The campaign method needs to be well selected in order to achieve the target community. The forming of public opinion relating to the importance of water resources management must be continually conducted. It should never stop until the community is aware, making movements, and actively doing real acts in saving water resources through IWRM. The law enforcement can also be used as a means to increase public's participation. The people's awareness to obey the existing rules is a very positive step to start the rainwater management. Violation of the rules requires explicit and fair act and should be widely announced to people; therefore, everyone will be reluctant to break the rules. On the contrary, a reward should be awarded to anyone who has helped to develop RWH and the water resource system as a unity. This reward and punishment systems are expected to be able to support the people's act to do good deed and, vice versa, they will be wary of doing bad things in the context of RWH development. The public's participation should refer to the principle of togetherness, thus it may minimize the risk of social conflicts.

Conflict is one of the social interaction forms. This conflict can be prevented in managing water resources, including in the effort of RWH development. A resolution is expected to be able to overcome the existing conflict so that it will be easier to determine the best solution, which is fitted into the principle of ”*menang tanpo ngasorake*” (Javanese) or what is called ”win-win solution”. Nevertheless, there are many conflict resolution methods, which have been developed by several parties, for example, the models of facilitating, mediation, fact-finding, and arbitrage. Javanese people have a tradition called ”*rembug desa*” as an open dialog based on good will to achieve better condition and, usually, this dialog gets facilities from the local figure for whom the people give their respect because the figure is wise and has good credibility, and it is not because of his/her position or possessions (Keraf, 2002).

5.5 Reward and Charge Schemes

The decentralization era has changed the role of community in the development process. Therefore, in this water management plan, not only the government itself acts actively but also the community should be involved in the process. In turn, both parties should receive the advantage of the new plan as well. As large low-level community will also be involved in the plan, the reward scheme becomes very important to encourage them.

This trend could also be applied to the budgeting systems of the management plan. Nowadays, there is no direct connection between the water price and charges for polluting water bodies nor there is tax cutting for the environmental friendly water users.

As previously mentioned, the existing water price in Yogyakarta is applied uniformly, no subsidy for the user of less water. The subsidy is given only for common tap in the low class inhabitant areas, but the flow rate of these taps is very fluctuating, as it is not the priority of supply. The price is put at about € 0.08/m^3 in the year of 2005.

For this plan, the scheme of reward and charge must be applied to encourage the community to apply the more sustainable water use. The main idea is to make the haves to subsidize the poor. In accordance with the charge, the act of putting more burdens to the haves is involved, and on the other hand, the action to diminish the pressure on the low class is categorized as a reward as well.

The charges could be put on clean water price for households that use more than 10 m^3/month, middle/high scale industry, industries with individual deep wells, and new constructions that exceed the limit of building coverage ratio, the ratio between sealed ground and total ground. Wastewater treatment price could be for industry without pre-treatment. In this case, it serves more as fines.

The reward in the form of lower price could be applied to clean water price of household/industries, which apply rainwater harvesting technologies or reuse technology. Wastewater treatment price is on household/industry, which has its own pre-treatment/treatment processes before diluting the wastewater into water bodies and household/industry whose land is occupied by water management projects.

By using the systems, the cost of rainwater harvesting application at the low class area could remain low, as it is subsidized by the high price of water put on the large-scale industries. The other direct effect is that the high-class populations and large industries will be forced to minimize its water use or even make a reuse for their water systems.

The reward and charge scheme could only work if the law enforcement is strong. However, the budgeting of the project could not fully rely on this system, especially in the beginning stage of the project. It is estimated in the beginning that the community participation is still low. Yet, it will grow later as the effect of intense awareness campaign.

The first step to be conducted is to adjust the water price with a subsidy system. Before it is applied, the control of water meter must be strengthened. The second step is to inspect regularly the industries that use water in the production process. The charge also can be applied directly to the industries owning individual deep wells. This latest step should be campaigns via local media as a shock therapy for other industries.

The reward scheme at first could be applied on individuals or industries that take part in the campaign. It will enlarge the support for the campaign. The next implementation is a reward for households that apply RWH, artificial recharge, or reuse technology.

5.6 Integrating Stakeholders

In developing RWH for rural and urban poor purposes, Prinz and Malik (2002) suggested that the state and scientist should intervene in order to empower rural communities and the poor who are in general poor of human resource development. Rural communities and the poor as a marginal society have to be empowered so that they can develop themselves in a sustainable basis. However, the support from the external power, i.e. intervention of state authorities, is needed in developing RWH, e.g. financing the construction of small reservoirs or other irrigation installations. Sometimes, the available knowledge is sufficient to solve such drought problem, but the support of authorities is lacking. In order to gain a success, a scientific research should then be carried out in collaboration with farmers and the poor, then the results of the applied research should be passed on to them. The sustainable traditional rainwater harvesting methods will also receive the required backing of politicians and planners to reduce water related problems and disasters in the future.

The activity of managing the vulnerable-water resource area needs a comprehensive approach. RWH is one of the elements, which is very important. Looking at the characteristics of rainfall in the study area, the rainfall potential that can be used for people's need is still very high. This rainwater can be recharged, specifically at the appropriate aquifer, or collected in certain storages, especially at the areas with critical aquifer.

Reducing the vulnerability of water resources needs to involve all stakeholders. It is recommended that this management be integrated to regular development programs. The introduction of rainwater harvesting has prevented and mitigated the impacts of droughts and water scarcity. Urban poor and farmers who are usually low educated have to be supported by the government and scientists to make them more powerful. Therefore, they can develop themselves without being threatened by the vulnerability.

Therefore, the recommendations developed by Prinz (2003-a) for the implementation of RWH in order to have sustainable water resources especially for managing the vulnerability areas are relevant.

These recommendations are to:

1) Integrate RWH in all water resource management plans,
2) Incorporate RWH into local, provincial and national strategies and programs of urban and rural development,
3) Integrate RWH in all watershed development plans, in agricultural development plans and land use planning,
4) Create awareness on the importance of RWH as a supply of additional water and as a chance for groundwater recharge,
5) Support all activities in schools, colleges, universities and public institutions to include education and training in RWH,
6) Support all activities and research institutions and universities to promote applied research in RWH,
7) Insure that at the national level RWH is put at high priority in development assistance talks and in domestic budgets; Insure that RWH is adequately considered in all legislations and in formulating regulations on water and land use.
8) Adopt a long term prospective in utilization of surface runoff, taking into account the growth of population and climate change.

Finally, in order to realize the development of RWH as part of IWRM, it is necessary to interconnect water resource stakeholders. The government at the central, provincial, and local levels has to be fully coordinated. The government is supported by universities. The power from universities is not only the science itself but also the number of students. In about more than 50 years since the state's independence, the number of higher education institutions in the city and its urban agglomerations has multiplied significantly, that is 127 institutions such as universities, academies, and colleges (Depdiknas, 2003). It is not to mention the lesser training courses and continuing education programs with the number of students exceeding 290,000 (Subanu, 2000). The educational sector has proven to be a strong driving force for the growth and regeneration of the area. This has a significant impact, when it is exploited seriously. Universities can be utilized as a research centre and movement or public pressure agent in developing RWH.

The Sultan as the centre of culture in DIY has a great potential to be the main supporter in mobilizing people. The role of the Palace is still significant in moving the society to be aware of imminent disasters. Commercial sectors such as industry, hotels, restaurants, etc. are also important factors in implementing RWH programs. The public, represented by NGOs, key persons, and local organizations, remains the main actor in developing RWH.

5.7 Demand Side Management (DSM)

DSM is intended to manage water in order to be efficient and effective quantitatively and qualitatively. For that reason, real steps directing to the efficient use of water are needed. These steps for example are in the form of increasing the efficiency of water usage, recycling or reusing water, and increasing the efficiency of conjunctive use.

Human’s behaviors are the most important key to increase the efficiency of water usage. Therefore, the behaviors of people in majority who are often consumptive in using water must be changed into the more efficient act in their activities. Education is the most possible way that can be expected to touch the people’s life. The education in this case includes formal and non-formal aspects. Education, supported by direct examples of using water in economical way, is the best media that can quickly awaken the people’s awareness

The economic incentive system in water cost may influence the pattern of water consumption for those who consume a little water should only pay a low cost, or even free. On the contrary, anyone who uses water in a large amount must pay bigger cost for the price of each debit unit than those who consume smaller amount of water. South Africa gives freedom to its people, so they do not need to pay for consuming water as long as their consumption is below the lowest limit in order to fulfill their daily water need, which reaches 20 litres/capita/day. The more expensive rate system directed to those who consume bigger amount of water should be followed by the increase in the quality of services from the institutions, which accommodate water supply. The subsidy system in the control of water cost/price needs to be progressively developed to establish the condition in which those who are ”water-consumptive” must give a subsidy to those who are ”water-economical”.

The water reuse and recycle are in the form of obligatory actions, especially in urban areas. In general, the water that has been used will perform lower quality than it is before. For that reason, it demands a treatment technology, which is fitted into the water quality that will be processed and based on what that water is for. This recycle/reuse is focused more on industries, hotels, universities, and/or hospitals, in which water use is in a large amount. Domestic groups can do the reuse/recycle in a simple way by reusing the wastewater of washing clothes or taking a bath to water the plants. All the time, the water is uselessly wasted, polluting the groundwater and rivers, while the people often use quality water for their plants at the same time when the groundwater quality keeps decreasing day by day.

The decreasing quality of water is, as mentioned before, mainly due to:

1) Population growth, urbanization and development of industry and other commercial activities,

2) Insufficient waste water collection and treatment: The disposal of wastewater potentially pollutes surface water bodies and groundwater. The septic tank technology, which has been used until now in Indonesia, contributes to the highest pollution of groundwater, like what happened in USA some time ago (US EPA, 2007). The garbage, likewise, contributes to the decrease in groundwater and surface water quality. For that reason, the control of waste processing, either solid or liquid waste must be managed at first, because it is essential for improving the quality of water and the environment in general.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

1. Sustainable development means preservation of the environment without neglecting the quality of economic and socio-cultural life of the community. However, the term ”development” has in fact captured the policy makers to emphasize an economy-oriented development in the name of social welfare instead of balancing the orientation aspects, including the environment. As a result, instead of a sustainable development, the opposite happens: the development of economy ”must” continue while ecology “may” be neglected. Therefore, it is necessary to reform the definition and implementation of ‘development’.

2. During the second half of the last century, a high population growth and an increasing urbanization became global trends in the developing world, including Indonesia. One of the most pressing issues of this is the interaction between land-use changes and water resources in relation to climate. No projection of the future state of water resources can be made without taking into account the past, present, and future of land-use patterns.

3. Water resources in Java, including Yogyakarta area, are in very serious conditions. Java Island, the most densely populated area in Indonesia, suffers from the hard pressure caused by the high population density and very limited natural resources, including water resources. A very ironic phenomenon is that the high rainfall during the rainy season often causes floods while during the dry season; many people find it difficult to get water, not only for the irrigation sector, but also for drinking purposes. This imbalanced situation happens almost every year. The growing number of problems due to improper water resources management has led to the adoption of an integrated water resources management approach. Its objectives are to minimize water waste, to maximize the efficiency of water use, to maximize the availability of water by limiting the degradation of water supplies and through reuse, to optimize water allocation to all competitors and to the environment as well and finally to limit the access to sustainable levels.

4. The people in Yogyakarta area depend more on groundwater because it has relatively more advantages than surface water to fulfill the domestic, industrial, and commercial needs. Because of the advantages, the amount of groundwater will be more and more reduced and will become a rare resource to get. Every house in this area commonly has got a well to access clean water. The industrial and other commercial activities often use the "deep well" to fulfill the need for clean water. Besides those two types of wells, some people living in the urban area consume the water from PDAM*, a* company for piped water supply. This company takes "deep groundwater" or "shallow groundwater" to fulfill the water supply. Unfortunately, the piped water is of disappointing quality and often in short supply. The water

quantity problem of PDAM includes a decrease in the production capacity due to clogging and in the groundwater capacity of wells. The water quality problem includes the physical, chemical, and biological parameters. In most cases, the quality and quantity of PDAM water have not fulfilled the standard of drinking water although some amount of it meets the quality requirements of clean water. Meanwhile, the water loss of PDAM is around 40%**.** On the other hand, most people (81.58%) do not have access to PDAM water; they still fully depend on non-PDAM water source especially wells. Therefore, a long-term program to establish an integrated and comprehensive master plan is set to solve the problem of operation, marketing, human resource, and finance in PDAM. The core target of this program is that PDAM can supply healthy clean water with affordable price for people without neglecting the sustainability principle of water resources and environment.

5. Generally, the percentage of population growth in Sleman Regency is relatively high, compared to the national level. The population growth in Sleman and Bantul increases steadily. Sleman Regency, in which a conservation area supposedly lies, will be seriously endangered by the rapid population growth. The function of the recharge area lying in the middle and the north of Sleman will be much disturbed by the rapid population growth and settlement area development. This condition will influence the balance of water resources quantitatively and qualitatively, not only in Sleman but also in Yogyakarta and Bantul, because the resources, groundwater, and surface water flow from Sleman to Yogyakarta and Bantul. Yogyakarta City is the most densely populated region in the study area. This area can no longer support its society's life, in term of water resources. The population growth of Bantul Regency exceeded that of DIY Province, and will surely increase because of Yogyakarta City's limited accommodation. The overflow in Yogyakarta will move to Sleman and Bantul Regencies. Meanwhile, because in Sleman the population is denser and the price of land is higher, the population growth in Bantul may be difficult to control. Therefore, a control over population growth has to be taken seriously and consistently.

6. Based on the fact relating to the existing land use development, there are inappropriate land uses as residential areas rapidly replace conservation areas in Sleman. The same condition also happens to irrigated farmlands, the main source of agricultural products, especially rice, which have been narrower due to the development of settlement areas. Although a regulation has been legislated to protect irrigated farmlands especially in a suburban area, the number of farmlands, especially irrigated farmlands, keeps decreasing. The average decrease in farmlands per year was 1.41% during which the average settlement growth was 1.47%/year. Moreover, there is an interference disturbing the balance of water resources, besides the decreasing number of farmlands. The change of land use from agriculture to settlement area basically means the hardening of the land surface, which in turn will hamper the process of rainwater absorption into the ground. The more the buildings are built, the less the water can be absorbed and the more the runoff water will flow to rivers and be potential to cause floods, especially in downstream areas. Another problem is the decline of

groundwater surface not only in Yogyakarta but also in Sleman and Bantul. In addition, the increasing intensity of settlements is generally correlated to the emergence of pollutants which does threaten river water and groundwater. If there is no concrete step to control the settlement development, the food production may decrease, the river water and groundwater may be more polluted, the groundwater level may more decline, and the flood at the downstream will be worse. A suggestion that every building, either for settlement or not, should have a well to absorb the rainwater is crucial, besides the renovation of the drainage system, which at present is only able to flow the rainwater to the sea. The new drainage system should be able to catch the rainwater and absorb it into the ground. In fact, the model of land resource management needs a reform to be more consistent. A commitment to protect the conservation area and productive farmland must be consistently adhered. The government should give many alternatives as a service to the public without sacrificing the conservation area and productive farmland. Hence, there has to be an evaluation on the implementation of the existing regional planning and regulation system. Subsidy system for farmers, the main victim of urban development, can also be implemented. Overlapping authority of related institutions should be minimized in order to have an effective workflow and coordination. Moreover, encouraging education development can increase the commitment of all stakeholders to land resource development. Ultimately, the stakeholders' involvement in the preliminary plan is very important because a bottom-up public participation model will build sense of belonging to the development program.

7. There are generally three basic patterns of climate, i.e. wet months – dry months – wet months. The first wet months happen from January to June, dry months are from July to September, and the second wet months happen from October to December. The maximum monthly rainfall of 409 mm/month is in January in Sleman and Bantul Regencies, while the minimum monthly rainfall is 15 mm/month in August in Bantul. Sleman has the highest average rainfall, the next is Yogyakarta, and the lowest is Bantul. The whole mean of 15-year rainfall of Sleman is 2,320 mm/year. Yogyakarta has the average rainfall of 2,046 mm/year. The mean of rainfall in Bantul is 1,785 mm,/year. In term of water balance, Sleman and Bantul Regencies have surplus of water resources, however Yogyakarta City suffers in deficit water balance. The whole area of Yogyakarta, Bantul and Sleman has about 70% surplus of potential rainwater that can be managed properly by develop RWH rather than wasting the runoff into rivers or finally the ocean.

8. The original CN value from US SCS cannot be applied directly to the study area. Different test results between observed and predicted CN show that optimization is needed to reduce the differences. The optimization develops a trial and error method that includes increasing the value of CN for each land use and decreasing the criteria for soil hydrology. Paired sample t-test is developed for the differed test of observed and predicted CN. Relatively different variables are also utilized in order to have a significant result. The total amount of runoff in urban areas in general is larger than that in rural areas.

9. The vulnerability levels of water crisis in the study area vary from extremely high to very low level of vulnerability. In general, the areas having the extremely high vulnerability are in the centre of Yogyakarta and its surrounding. Suburban areas can also be a critical area. The area with extremely high vulnerability is 2% of the total extent while that with high vulnerability covers 9% that with moderate vulnerability covers 59%, that with low vulnerability covers 26%, and that with very low vulnerability level covers 4%. The whole location is dominated by moderate vulnerability criteria, except the urban areas which are so vulnerable to water crisis event that prevention is urgent to do. The natural vulnerability areas are in the zone of minor, poor, and/or non-aquifer formation. For the social economic analysis, the vulnerability area is divided into 3 categories: (1) recharge area, (2) urban-anthropogenic vulnerability area, which consists of five categories of anthropogenic vulnerability, and (3) natural vulnerability area.

10. People who live in recharge area are in general less commitment in developing RWH than people who live in urban-anthropogenic vulnerability area and or in natural vulnerability area. Therefore, either the efforts to urge awareness or the form of command is still possible to complete with the development of recharge wells or conservation ponds. The social conditions support that chance. The RWH facilities suitable for the recharge zone are ‘recharging well’ and ‘conservation pond’, but not rainwater storage. The priority in the development of RWH facilities is given to naturally functioning resources, such as conservation pond, because of the lower costs and minimal land availability. As a result, the society can participate more and the speed of land conversion can be controlled. A different condition occurs in the urban anthropogenic vulnerability area, where more respondents do not have RWH facilities due to a limitation on land-ownership. However, there is only one kind of RWH facilities only in this area; it is recharge well (6.67%). A very good opportunity is shown by the fact that a small number of RWH facilities are made based on people’s self-awareness, 75% of respondents have understood the advantage of storing rainwater, and 73.33% of respondents are willing to manage RWH. Similar to the recharge zone, the urban anthropogenic vulnerability area has inappropriate rainwater storage due to the high investment cost and limited land. Moreover, the physical condition of the area is good for absorbing water effectively and sufficient for managing the recharge well, and conservation pond. This area is mostly urban area with limited space but good economy condition; therefore, the development of RWH facility will focus on the making of flexible and highly valued recharge well. At the natural vulnerability area, only 26.67% of respondents own a rainwater storage although 50% of them understand the importance of storing rainwater and about 90% are willing to manage RWH. Ultimately, according to the physical conditions of environment and the analysis result, the most possible facility for this area is rainwater storage. However, it is important to implement a gradual-development strategy, considering the economic problems, low ATP (ability to pay) value, supply of soft loan facility, and stimulus/incentives or others.

11. RWH is expected as is one of the best solutions to overcome the water resources problems. However, the development of RWH at the study area is still hampered by several factors, and they are:
    (1) Especially those who live in the recharge zone or the urban areas, are able to develop RWH, but most of these people still consider RWH as hardly feasible, specifically the build a recharge well or a rainwater reservoir. For those people RWH is still considered as a secondary or even a tertiary alternative to have covered their water needs.
    (2) On the contrary, at the natural vulnerability area that naturally has a bad water resources, the people must face the economic problem in developing a rainwater storage because this system needs a quite high investment, although if it is calculated, it will be cheaper than if they spend money to buy water from a tank, as what they do all the time.
    (3) The society actually has understood the importance of conserving rainwater, but all this time the people still have not considered it as an urgent need.
    (4) Most people have a pragmatic assumption that they tend to neglect the long-term need, especially if they cannot get the benefits immediately. As mentioned before, the benefit of developing RWH cannot always be enjoyed directly by the people themselves; it is also for other people and for a long period of time, except the model of rainwater storage.
    (5) The main factor that hampers the development of RWH in urban area is the limited space, considering that this area has been crowded with population and buildings.
    (6) The government's effort to activate its people to developing RWH is far from being optimum. All this time, the government only appeals the society, and in fact even this is still not massive enough in its application.
    (7) The government so far tends to conduct incidental programs; such as distributing clean water to the NVA while this act does not overcome the problem emerged in the future.
    (8) The laws and rules available in Sleman Regency and Yogyakarta City have not been enforced yet; an evaluation system is lacking.
    (9) The rules have not been written explicitly and strictly to urge people to develop RWH, so that the making RWH is more for saving the water resources, instead of only for fulfilling the need to increase the regional income at each region.
    (10) The construction of a recharge well done by the government so far seems to be only as top-down effort without trying to involve the society. Besides this, the number is still far from being sufficient.
    (11) The society's awareness to develop RWH has still not yet changed sufficiently to become a real move in the field.

12. The proposed RWH developments comprise two main groups. The first one is proposed for domestic, commercial, and government or state sectors, i.e. (1) RWH recharge well, (2) RWH storage, (3) conservation pounds. The second group is proposed to develop especially by the government or related state agencies, i.e. (1) river polder and (2) eco-

drainage system. The priority of RWH development is based on the vulnerability criteria and the urgency of development completed by RWH types. Priority 1 is in the recharge area, which is important to sustain water resources system, especially groundwater, not only for Sleman but also for Yogyakarta and Bantul. This recharge area is the part of Merapi Aquifer system in northern Sleman, where rich people are attracted to build houses. The main attraction of the fast housing development in this area is the comfortable environment such as clean water, cool weather, and beautiful view. Therefore, the RWH model alternatives that can be developed in this area based on social economic and physical aspects are: (1) recharge well, (2) conservation pond, and (3) eco-drainage system re-development. Priority 2 is in the areas categorized as extremely high vulnerability of water resources. This area is mostly in Yogyakarta and its surrounding urban areas. The high population and settlement density in this area can trigger the water resources degradation, qualitatively and quantitatively. The recommended RWH development alternatives are: (1) recharge well, (2) conservation pond, and (3) eco-drainage system redevelopment. Priority 3 is for the high second category of anthropogenic water resources vulnerability. This area is still mostly at the urban areas. The recommended RWH developments are: (1) recharge well, (2) conservation pond, and (5) eco-drainage system redevelopment. Priority 4 is proposed for the natural vulnerability. The areas usually face serious drought in every dry season. The recommended RWH development alternatives are (1) recharge well, (2) conservation pond, (3) eco-drainage system redevelopment, and (4) river polder. Priority 5 focuses on the medium vulnerability area as the major category of water resources vulnerability in the study area. Finally, priority 6 and 7 are in the low vulnerability and very low vulnerability areas. The recommended RWH developments for priority 5, 6, and 7 are (1) recharge well, (2) conservation pond, and (3) eco-drainage system redevelopment. Besides the mentioned alternatives, river polder is suitable to be developed at the areas of Priority 5 and 6.

13. An ineffective rule to be reformed is IMB (license to build a building). IMB should be the main means of control on the development of settlement area. Through a requirement of balance between the land use and the regional planning, IMB must be the priority for reviewing and evaluating the development system. Up to this moment, IMB is only a means of collecting taxes in the name of regional income and merely for fulfilling the requirement of license. The evaluation and examination of IMB process have hardly been done in practice. The obligation of having a recharge well on the blueprint is just a formality that has rarely been examined whether the recharge well is actually made as planned.

14. In the new era of decentralization in Indonesia, local government has much more authority in the governance management than it has before. The changes in decentralization significantly affect the environmental management including water resources sector. Water resources management that often covers cross-administrative border of several local governments should adopt a system approach to ensure that every important factor has been taken into account. Usually, the local government has a strong interest in its own jurisdiction. As a

result, there are difficulties in utilizing the system approach to manage properly the water resources in a cross-border system and more conflicts among local governments occur recently. To respond such issue, the Joint Secretariat KartaManTul (JSK) is established and completed with KartaManTul water commission and relevant regional laws. The three local governments are used to work together coordinated by the provincial government. Each local government has different interest. Located in the upper part of the province's watershed, Sleman is the recharge area that has to preserve its environment and needs the lower region for disposal. Yogyakarta municipality is the locomotive of economic activities in the region, however, it does not have more space for disposal. Located in the lower part, Bantul is considered the best place for disposal. Moreover, Bantul and Yogyakarta need Sleman as the source of water, surface water and groundwater. The different interests seem to have nothing in common, but with organized efforts, they can actually be orchestrated as intertwining, coherent pieces of mutual interest.

15. Traditionally, people put water at the very high and prestige portion. *Mamayu Hayuning Bawono* or living harmoniously with the nature is a Javanese philosophical concept that prevails until today, where there are harmonious relations amongst individuals in the society, between human beings and the universe, and between the servant and God. In other words, it means to conserve the beauty of the world for the welfare of its inhabitants and the safety of the universe. This philosophy is closely relevant to the context of conserving water resources through the rainwater harvesting. In terms of religion, where Muslim forms the majority, rainwater is an important part of religious belief. The rain is given by the nature and so is the dry season. However, the flood and drought disasters are forced to occur not only by the natural factor but also by the unsuitable environment management. God delivers rain from the sky to create life for the dwellers of the earth. In other words, if there is no rain, there will not be any life. This element rain is so important that God the Almighty repeatedly gives explanation in at least 35 verses of Qur'an. It is stated explicitly and implicitly that the falling rain is meant to give life to creatures on the earth instead of a disaster as long as human beings living on the earth, the caliphs of God, know how to read the implicit meaning of this universe, to be grateful, and to act towards the components of this universe.

16. In order that the water resources management can be successfully conducted, especially the RWH development, the social communication relating to cultural aspect is very important to develop. The social instruments that can urge the community to develop RWH for the sake of the sustainable water resources are, for example: (1) water education, (2) better communication, (3) campaigns, and (4) the expansion of public participation. For this plan, the scheme of reward and charge must be conducted to encourage the community to apply a more sustainable water use. The main idea is to make the haves to subsidize the have-nots.

17. Reducing the vulnerability of water resources needs to involve all stakeholders. It is recommended that this management be made integral part of regular development

programs. Urban poor and farmers who are usually low educated have to be supported by the government and scientists to make them more powerful. Therefore, they can develop independently without being threatened by the vulnerability.

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