Analysis of Drinking Water Supply System Encompassing The Catchment, The Reservoir and The Treatment Facility (A Case Study of Osman Sagar Drinking Water Supply System, Hyderabad, India)

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Kurzfassung

Die Trinkwasserversorgung in Indien basierte schon immer auf einem Nachfrage - orientierten Ansatz. Hyderabad, eine schnell wachsende Stadt in Indien, repräsentiert eine hierfür typische Situation. Mit den Jahren, in denen der Wasserbedarf in Hyderabad wuchs, stieg der Bedarf, neue und damit weiter entfernte Wasservorkommen zu finden. Der Transport des Wassers von diesen entfernten Quellen bedeutete jedoch steigende Kosten bezüglich Pumpen, Wasserspeicherung und -aufbereitung. Allerdings änderte sich trotz dieser neuen Vorkommen nichts an dem unrzureichenden Angebot an Wasser, derzeit nur jeden zweiten Tag für eine Stunde zur Verfügung steht.

Ein unkontrolliertes städtisches Wachstum sowie eine nichtwissenschaftliche Herangehensweise an den Schutz der Wasservorkommen führten zu Rückgang und Verlust der Frischwasserseen in und um Hyderabad. Osman Sagar ist heute einer der wenigen Seen um Hyderabad der immer noch einen Frischwasserstatus hat. Jedoch unterlag das Reservoir in der letzten Zeit immer wieder drastischen Schwankungen bezüglich des Zuflusses, resultierend in einer Reduktion der Trinkwasserversorgung aus diesem Reservoir. Während der Bearbeitungszeit dieser Studie von 2000 bis 2005 reduzierte sich die Trinkwasserversorgung durch diesem Reservoir um 77% seiner normalen Kapazität. Da kein regelmäßiger Zufluss aus dem Einzugsgebiet mehr erfolgt, bedeutet das für das Trinkwasserreservoir Osman Sagar seinen Status als Trinkwasserspeicher zu verlieren.

Diese Studie zeigt verschiedene Wechselbeziehungen zwischen klimatologischen, geomorphologischen und anthropogenen Faktoren auf, die die Wasserdynamik in einem Trinkwasserversorgungssystem beeinflussen. Des Weiteren wird der Bedarf einer Integration von Oberflächenwasser und Grundwasserdynamik im Einzugsgebiet herausgestellt um das Wassermanagement für Trinkwassersysteme zu verbessern.

Diese Arbeit präsentiert einen möglichen Ansatz das existierende Kontrollsystem für das Osman Sagar Reservoir zu verbessern. Durch das besondere hervorheben sektoraler Konflikte (z.B. Landwirtschaft und städtischer Wasserverbrauch) zeigt die Studie den Bedarf einer Prüfung der Wasserverteilungsrechte auf und berücksichtigt

dabei auch den Wasserbedarf ober- und unterstromig des Osman Sagar. Die Arbeit hebt den Bedarf eines langfristigen Einzugsgebietsmanagements hervor, basierend auf einer Einbeziehung wissenschaftlicher Beurteilungskriterien sowie geeigneter Managementstrategien.

Anhand des Wassermangels und des steigenden Wasserbedarfs durch Klimaveränderungen, unweltbedingte und sozioökonomische Gegebenheiten, zeigt die Studie den Bedarf an Maßnahmen für ein integriertes Wassermanagement, um die Wasserverfügbarkeit und Wasserversorgung in der Zukunft zu sichern.

Abstract

Drinking water supply in India has always been a demand based approach. The situation in Hyderabad which is one of the fast growing cities in India represents the typical situation. Along the years as the water demand in Hyderabad grew, so did the need to find new and distant fresh water sources. Transfer of water from distant sources involves increasing expenditure on the pumping, storage and the treatment costs. Even with the transfer of water from new sources, supply of water in Hyderabad, still remains intermittent with one hour of supply every alternate day.

The unregulated urban growth and unscientific approach towards the source protection led to the degradation and loss of the fresh water lakes in Hyderabad. Osman Sagar is one of the few lakes around Hyderabad that still retains its fresh water status. However, in the recent times the reservoir witnessed drastic fluctuations in its inflows which resulted in reduced drinking water supply from the reservoir. Within the study period of 2000 - 2005, the drinking water supply from the reservoir has reduced to 77% of its established capacity. With no regular inflows from the catchment, the Osman Sagar drinking water reservoir is at the verge of loosing its fresh water and the drinking water status.

The study indicates various interactions (amongst climatological, geomorphological and anthropogenic factors) that affect the water dynamics within a drinking water supply system. The study emphasizes the need for integrating the surface water and the groundwater dynamics in the catchment area to improve the overall water management within the drinking water system. It presents a probable approach to improve the existing monitoring system for the Osman Sagar reservoir. Highlighting the sectoral conflicts (i.e. agriculture and the urban water needs), the study indicates the need for a review of the water allocation rights, taking into consideration the water needs and demands of both upstream and downstream activities.

The study emphasizes on the need for larger perspective of catchment management based on the integration of scientific assessment and appropriate management strategies. Recognizing the scarcity of water resources and an increasing water demand by changing climatic, environmental and socioeconomic conditions, the

study spells out the need for integrated water management measures required to secure water availability and supply in the future.

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Acronyms

APPCB	Andhra Pradesh Pollution Control Board
APUIDFC	Andhra Pradesh Urban Infrastructure Development and Finance Corporation
ARWSP	Accelerated Rural Water Supply Program
BBMB	Bhakra Beas Management Board, India
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Germany
BOD	Biological Oxygen Demand
CAMS	Catchment Abstraction Management Strategies
CGWB	Central Groundwater Board of India
CPCB	Central Pollution Control Board of India
CWA	Clean Water Act
EA	The Environment Agency, UK.
EC	European Commission
EEA	The European Environmental Agency
FAO	Food and Agricultural Organisation of the United Nations
GDRC	Global Development and Research Centre
GEMS	Global Environmental Monitoring Systems
GHMC	Greater Hyderabad Municipal Corporation
GO	Government Order
GoAP	Government of Andhra Pradesh, India
GOI	Government of India
HMWWSB	Hyderabad Metro Waterworks and Sewerage Board, India
ICRISAT	International Crops Research Institute for Semi-Arid Tropics, India
ICWE	International Conference on Water and Environment
ILEC	International Lake Environment Committee
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management

MINARS	Monitoring of Indian National Aquatic Resources
MoEF	Ministry of Environment and Forests, India
MoWR	Ministry of Water Resources, India
NGRI	National Geophysical Research Institute, India
RBC	River Basin Commission, Germany
RBO	River Basin Organisation, India
SANDRP	South Asian Network on Dams, Rivers and People
UN	United Nations
UNESCO–IHE	United Nations Educational, Scientific and Cultural Organization-International Institute for Hydraulics and Environmental Engineering, Delft, The Netherlands
UNICEF	United Nations International Children’s Emergency Fund
USEPA	United States Environment Protection Agency
WFD	Water Framework Directive, European Union
WHO	World Health Organisation
YAP	Yamuna Action Plan, India

Units

Bi m^3	Billion cubic meters
km^2	Square Kilometres
km^3	Cubic Kilometres
m^3	Cubic Meters
mbgl	Metres below Ground level
Mi m^3	Million cubic meters

1 Introduction

The study presents an integrated view of identifying and understanding various interactions (amongst climatological, geomorphological and anthropogenic factors) that affect the water dynamics within a drinking water supply system encompassing the catchment, reservoir and the treatment facility. The study is based on the Osman Sagar reservoir, one of the drinking water sources of Hyderabad, India. The reservoir is located in the semi-arid region of the southern Indian state of Andhra Pradesh. The Figure 1.1 shows the location of the Osman Sagar reservoir within the River Krishna basin.

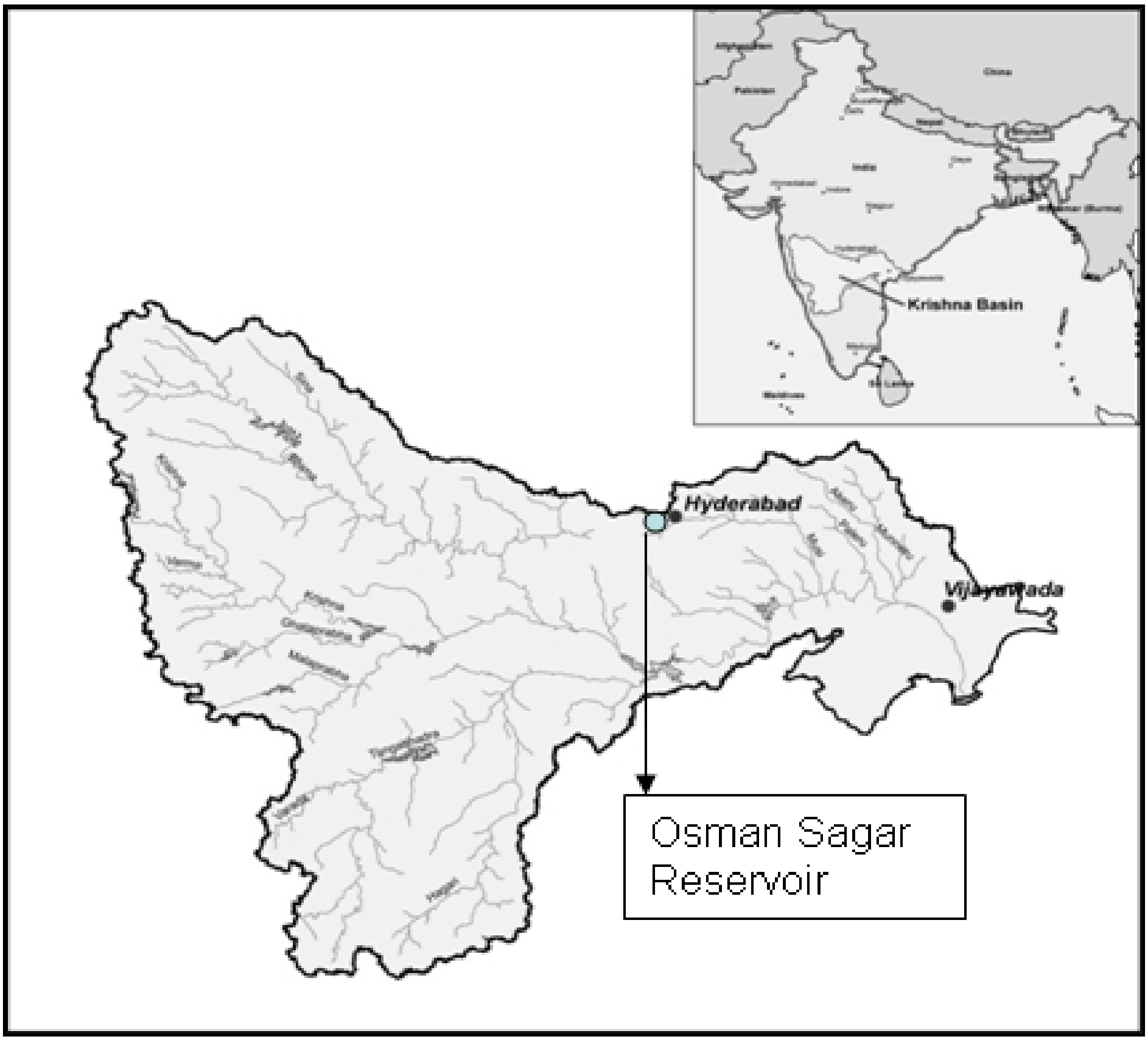

Figure 1.1: Location of Osman Sagar drinking water reservoir

The reservoir is built on the upstream of River Musi, which is one of the tributaries to River Krishna. Due to the ephemeral nature of the River Musi, the reservoir always witnessed seasonal changes in its inflows. However, in recent times the reservoir witnessed drastic decrease in its inflows which resulted in reduced drinking water supply from the reservoir to the city of Hyderabad. Scientific studies conducted by the International Water Management Institute (IWMI) (Massuel et al., 2004) and field observations conducted by Hyderabad Metro Water Works and Sewerage Board (HMWWSB) reveal that intense surface and groundwater development activities have been carried out to cover the irrigation needs upstream of the reservoir. Similar observations were presented in the reservoir of Nagarjuna Sagar (Gaur et al., 2008) which is one of the drinking water sources for the Hyderabad city. The upstream development activities in the form of land use changes and water development activities have impaired the downstream water regime resulting in the poor inflows into the reservoir. Owing to the reduced drinking water supply from the reservoir, today the Osman Sagar is at the verge of loosing its fresh water and drinking water status.

Drinking water supply in India has always been a demand based approach. Along the years as the water demand in Hyderabad grew so did the need to find new fresh water sources. The drinking water sources are located away from the urban centres to ensure good water quality. Today, Osman Sagar is one of the four drinking water sources of the city which are located within a distance of 15 km (Osman Sagar) to 150 km (Krishna River, Nagarjuna Sagar impoundment). As on the year 2008, the four sources together supply around 0.81 Mi m^3 per day of drinking water, while the water demand of the city is around 1.16 Mi m^3 per day.

The public water supply is intermittent with one hour of supply every alternate day (APUIDFC, 2003). In order to meet the growing demand, the search for new sources by the State water supply agency continues. The inconsistent and intermittent water supply through the Public water supply system pushes the consumers to source out water from other sources. Typically, these efforts include complete dependency on the groundwater resources at the individual household level, buying water from the private vendors and occasionally rainwater harvesting. However most of these practices go unmonitored.

The drinking water situation in Hyderabad is a typical case of any other fast growing city in India. Around 30% of India’s population is living in the urban centers. Major cities like Delhi, Varanasi, Calcutta and Hyderabad, which were once centers of great civilizations, flourishing on River basins, today face acute drinking water shortage (Planning Commission of India, 2002). Due to rapidly changing land use, escalating population, urbanization and industrialization, the surface water resources around these centers are under a threat of depletion and degradation. River Ganges and

River Yamuna in Northern India and River Krishna in Southern India are only to name a few.

The issues pertaining to the drinking water situation in the urban centers and the management of the drinking water sources can be categorized into three aspects:

- Resource loss.
- Resource allocation and stakeholder conflicts.
- Source conservation and management.

Resource Loss

The supply of drinking water works basically on the concept of demand and supply. The practice often caters to the escalating demands of urban population. The ideal situation is to bring water from distant sources, if the sources close by are exhausted. It is often the case, which sources once close to the city, today face the danger of not only depletion of water resources, but also degradation of the source itself. Thereby, the concerned administration brings in water from another reservoir, lake or river further away. Such a practice is not only cost-ineffective, but primarily unsustainable. Figure 1.2 represents the lake Hussain Sagar which was one of the drinking water sources for the city of Hyderabad. Today, the lake has been reduced to a cesspool.

Figure 1.2: Hussain Sagar lake - former drinking water source of Hyderabad city

Resource sharing-stakeholder conflicts

Escalating population and parallel rise in the demand for resources such as space, water and soon have a cumulative impact on one other. For instance, the need for space within the city of Hyderabad led to the encroachment of a large number of fresh water sources. Acquiring the water spread area within the development landuse is a common practice amongst the real estate developers. As the city loses its fresh

water sources, especially the drinking water sources, the attention is mostly on sourcing in water from the adjoining agricultural and rural areas. In this practice, most of the drinking water vendors bring in water from the irrigation wells and sell it across various neighborhoods in the city. This creates a water stress at within the agricultural lands. Further, addressing the same issue of increasing fresh water demand within the city, the public water supply authorities, often cut the irrigation water share and route the water to quench the city's thirst. Cumulatively, these practices pave way to the rural – urban conflict on water resource sharing.

Resource conservation and management

Drinking water reservoirs should be ideally situated in areas of minimal anthropogenic effects to ensure a good water quality. However, in lieu with the growing urbanization, finding such possibilities is difficult. Considering the complexity of the factors in managing such reservoirs, a management plan should involve an integrated approach. But, management of these reservoirs mostly involves desilting of the reservoirs, controlling the leakages in the distribution system, basic maintenance of the reservoir and the treatment facility. Minimal measures are taken towards checking the land use changes and anthropogenic activities in the catchment area. Considering the present day growth trend in India, most of these reservoirs would find themselves amidst a fast growing urbanization or intensified agricultural scenario. Either of the two situations, when unchecked, would lead to the resource depletion and source degradation. There is an ardent need to integrate the catchment area land use activities into the very core of the water resource planning, development and management.

The World Water Council's recently released vision statement (World Water Council, 2000) also makes it clear that developing new resources of water will not be sufficient to meet the challenge of escalating water demands. New sources will have to be coupled with wiser use of existing stocks of water through water conservation measures, water reuse, conjunctive use of surface and groundwater and maintenance of water quality, so that drinking water supplies and other essential uses are not compromised (WHO, 2000).

Water resources planning was once an exercise based primarily on engineering considerations. In the recent times it occurs as part of complex, multi-disciplinary investigations that bring together a wide array of individuals and organizations with varied interests, technical expertise and priorities. In this multi-disciplinary setting, successful planning requires effective Integrated Water Resource Management (IWRM) models that can clarify the complex issues that can arise (Loucks, 1995).

In India, since 2002 the National Water Policy is the guidelines for water resources development, planning and management across the country. The policy spells out clearly the need for a holistic approach integrating various sectors involved in the water resources management (MoWR, 2002). So far the IWRM approaches have come a long way in the management of water resources in agrarian setup and to an extent in the management of urban lakes in India. However, application of the same towards management of urban fresh water and drinking water sources is yet to gain the required momentum.

The study presents a plausible scenario of integrated approach in management of the Osman Sagar drinking water supply system. The study analyses:

1. The bulk movement of the water through the system, which comprises of the catchment, reservoir and the treatment plant.
2. The objective is to understand the relevance of each of the climatic, geomorphological and anthropogenic factors that affect the water dynamics within the system.
3. The study also highlights the threats from nutrient loads from the agricultural land use in the upstream of the catchment and the fast approaching threat of urbanization within the catchment.
4. Further, the study highlights the loopholes and issues relevant to conservation and management of the fresh and drinking water at the source and supply side.

2 Background

By the end of the 20th century many governments from developed countries adopted a systemic approach to water resource management, based largely upon research and policy analysis done over many years. The shift from sectorally fragmented to integrated water resource management is visible. Creation of new institutions and regulatory frameworks, more emphasis on non-point controls, demand management, and public participation and stakeholder involvement mark a deviation from traditional practice (The World Bank, 2006). General acceptance of a systemic approach has been illustrated in recent years by new water policies and themes presented in several international conventions such as the UN Declaration on Sustainability Agenda 21 in Rio de Janeiro (UN, 1992) and the Dublin Conference on Water and Environment statements made in these conventions asserted that:

- Fresh water is a finite and vulnerable resource
- Users, planners and policy-makers at all levels should participate in water development and management (UN, 1992)
- Water has an economic value in all its competing uses and should be recognized as economic goods (The World Bank, 1993)

Water policies in Europe, the United States and other industrialized countries have changed according to these new initiatives (The World Bank, 2006).

The United States' Clean Water Act (CWA) (CWA, 1972) is the major water quality framework law in the United States of America. It shifts from a program by program, source-by-source, and pollutant-by-pollutant approach to more holistic watershed-based strategies. This management approach emphasizes protecting healthy waters and restoring impaired ones on a watershed basis. The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States. The statute employs a variety of regulatory and non-regulatory tools to sharply reduce direct pollutant discharges into water bodies, finance municipal wastewater-treatment facilities, and manage polluted runoff.

The Water Framework Directive (WFD) of the European Commission (EC, 2000), promulgated in 2000 after a series of consultations from mid-1995, marks a milestone of water policy. This "river-basin-based water policy" sets up a common integrated approach and an ambitious target for the EU Member States to achieve "good water quality" by 2015 (The World Bank, 2006).

2.1 Water Resources in Europe

According to the World Bank (2006), the total renewable freshwater resource in Europe is around 3 500km³/year. This resource is unevenly distributed. France, Denmark, Sweden, Italy and the United Kingdom have the largest total fresh water resources (more than 150km³/year), whereas Malta, and Cyprus have the lowest (less than 10km³/year), In Mediterranean countries, the main issue is the high evaporation, e.g. in Spain only a tenth of rainfall reaches rivers. In addition to the uneven spatial distribution of water resources, there is variability in time both within and between years. The variability between succeeding years limits the exploitation of renewable surface water resources and justifies the construction of certain projects designed to regulate the flows (The World Bank, 2006).

In Europe, the predominant source of water is surface water, accounting for 70% to 90% of total freshwater abstraction. Groundwater is mainly used for public water supply (a little more than half of its abstraction). The most important uses, in terms of total abstraction, have been identified as urban (public water supply for households and industries), industrial, agricultural and for energy (cooling of power plants). In terms of consumption, the major "consumer" is agriculture. The demand for irrigation water shows a strong regional differentiation. 85% of the irrigated land is located in the Mediterranean countries. From a total of 332 regions, the 41 regions with the highest use of water for agricultural purposes are all located in southern Europe (The World Bank, 2006).

The use of groundwater as a source for drinking water has led to over-exploitation in many parts of Europe. Saline intrusion is frequent in coastal areas where the tourism demand increases the pressure on water resources. Therefore, some ground water resources can no longer be used for domestic use or irrigation (The World Bank, 2006).

2.2 Water Management Europe

The Water Framework Directive (WFD), promulgated in 2000, represents a fundamental reform of the EU's water policy and legislation on both environmental and administrative terms. Not only does it make integrated river-basin planning and management compulsory for member states and candidate countries, it combines the overarching theme of sustainable water-resource use with the following environmental objectives:

- Expanding the scope of water protection to all waters, surface waters and groundwater,
- Achieving a status of “good” for all waters by a set deadline,
- Water management based on river basins,
- Combined approach towards both point and non-point pollutant sources,
- Setting price right,
- More closely involving citizens and
- Streamlining legislation.

Essentially, three models of water resource institutions exist in Europe (Van, 1997). These include river-basin (watershed) based management systems in the UK and France, whose administrations are centralized, in Spain, whose administration is semi-federal; and a co-ordinate model as adopted in the Netherlands (Van, 1997).

2.2.1.1 United Kingdom

The major water institution in the UK most closely resembles that required by the WFD. The Environmental Agency (EA) is the leading central administrative body with responsibility for long-term water resource planning and the duty to conserve, augment, redistribute, and secure the proper use of water resources in England and Wales. The water resource policy is basin-based.

The Agency’s responsibilities cover a broad water-related spectrum: flood control, water quality, waste minimization in certain regulated industries, fisheries, navigation, etc. This coverage provides favourable conditions for managing water in an integrated manner.

The EA has a decisive influence on water resource policy formulation, as illustrated by some of the programs and activities under its jurisdiction (EA, 2008):

- Catchment Abstraction Management Strategies (CAMS), which set forth in 2001 the agency’s plan for managing the abstraction regime of each catchment,
- Drought plans, which set forth the agency’s role in managing droughts,
- Water resource strategies, which set forth the agency’s vision for the long-term management of water resources throughout England and Wales.

2.2.1.2 France

The Water Department in the Environment Ministry is responsible at the national level for protection, management and upgrading of aquatic environments and river systems, water quality, programming and coordination of state intervention in relevant sectors. The National Water Committee, consulted by the Water Agencies (Agences de l'Eau), plays a key role in national water policy and drafts of legislative and regulatory texts.

In contrast to the Environmental Agency in UK, the Water Agencies have no power of policy formulation or construction that relate to water or sanitation. These duties lie mainly with local governments.

The Water Agencies manage the water of six major hydrographical basins. There is a Water Agency in each basin. A River Basin Committee exists in each river basin as well. The Water Agencies work as an executive organ for managing water resources, while the committee acts as a 'Water Parliament' and is composed of between 60 and 115 users, elected representatives, specialists and state officials. Both organizations are involved in the preparation of the Water Resources Development and Management Master Plan.

The Water Agencies are public bodies responsible for balancing economic development with respect to the environment by distributing aid and taxing users. A Water Agency's sphere of influence covers all the surface water, groundwater and territorial seawaters relating to each of the river basins. The power of the Water Agencies rests on two principles:

- Solidarity: everyone has to pay charges to the Water Agencies for use of water. Everyone benefits from the construction of infrastructure.
- Decentralization: decision-making power rests upon the River Basin Committee and the Agency's Board of Directors. Both, the Chairman of the Water Agency's Board and the Director of the Agency are government-appointed.

2.2.1.3 Germany

The institutions in Germany show different features from those in the UK and France. Under constitutional law, the federal government has the right to enact general provisions concerning the framework for water resources management. The states must compile such general laws of the federal government by enacting their own laws at state level, and they may also make supplementary regulations (The World Bank, 2006).

Implementation of detailed water resources management regulations is solely the responsibility of the states and municipalities. Water management administration at the state level is mainly integrated within the general administration of the relevant state. Technical functions are carried out by authorities with various names (such as authorities for environmental protection, for water-resources management or for water and waste). These authorities have responsibilities in the fields of hydrology, water-resources management planning, and preparation of technical guidelines.

Germany’s strong decentralized structure of federal, state and municipality agents creates a cross-state water-resource management scheme that relies mainly on coordination through various organizations or for major river basin communities such as Weser River Basin Community, Elbe River Basin Commission are a few to name. Coordination of course becomes an even more complex problem where international water bodies are concerned, the Rhine River experience being of particular interest in this regard (The World Bank, 2006).

2.3 *Water Resources India*

India receives an average annual rainfall of 1,600mm. It is unevenly distributed both spatially as well as temporally. Levels of precipitation vary from 100 mm a year in western Rajasthan to over 9,000 mm a year in the northeastern state of Meghalaya. Most of the rainfall is during the monsoon season, from June to September. With 90% of the rainfall being concentrated over the four monsoon months and the other 10% spread over the remaining eight months, India's rivers carry 90% of the water during the period from June-September. Thus, only 10% of the river flow is available during the other eight months. Further, National level statistics for water availability mask huge disparities from basin-to-basin and region-to-region in India (CWC, 2006).

2.3.1 Surface Water Resources

India's land area can be divided into 19 major river basins. While India is considered rich in terms of annual rainfall and total water resources, its uneven geographical distribution causes severe regional and temporal shortages. The Ganga basin with only a quarter of the total drainage area has about 40% of the total population of India. The next five largest basins – Mahanadi, Brahmaputra, Krishna, Godavari and Indus cover 46% of the drainage area, but have only 30% of the population. About 75% of the people in all the river basins still live in rural areas and the livelihoods of most of them depend on agriculture. Thereby, the development and management of available water resources are crucial factors in rural development and poverty alleviation in India.

The Figure 2.1 explains the surface water dependency of various sectors in India. A major sector of agriculture is dependent on the surface water irrigation supported through the canals and large rivers in the country. In the semi-arid regions, particularly in the southern region of the country, the traditional system of using man-made lakes as means to support the dry land agriculture in the region is prevalent.

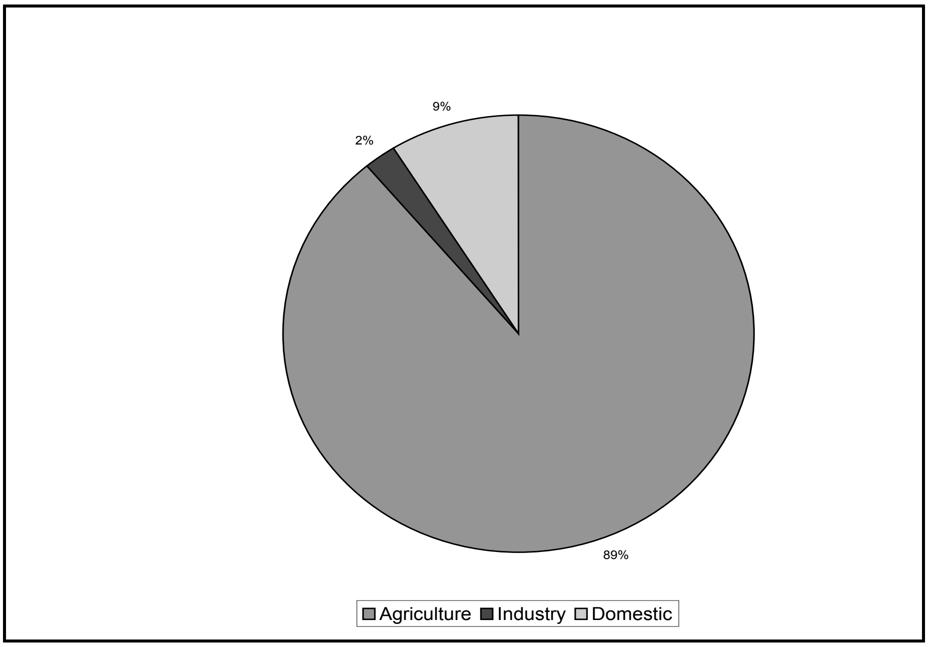

Figure 2.1: Surface water usage in India (Planning Commission of India, 2002)

Apart from the natural limitations, the pressure from growing urbanization and industrialization has led to large discharges of wastewater, both domestic and industrial into the available surface water sources. The treatment and disposal of the wastewater is a growing concern. Other problems include water quality degradation from agro-chemicals, industrial and domestic pollution, groundwater depletion, water logging, soil salinization, siltation and ecosystem impacts leading to the degradation of wetlands.

2.3.2 Groundwater Resources

Apart from the surface water available through the various rivers and their respective tributaries, groundwater also plays an important role catering to the needs of drinking water, irrigation and industrial use. It accounts for about 3% of domestic water requirement and more than 96% of the total irrigation in the country. The annual potential natural groundwater recharge from rainfall in India is about 8.56 % of total annual rainfall of the country. The total replenishable groundwater resource of the country is assessed as 43%. After allotting 15% of this quantity for drinking and industrial purposes, the remaining can be utilized for irrigation purposes (Planning commission, 2002).

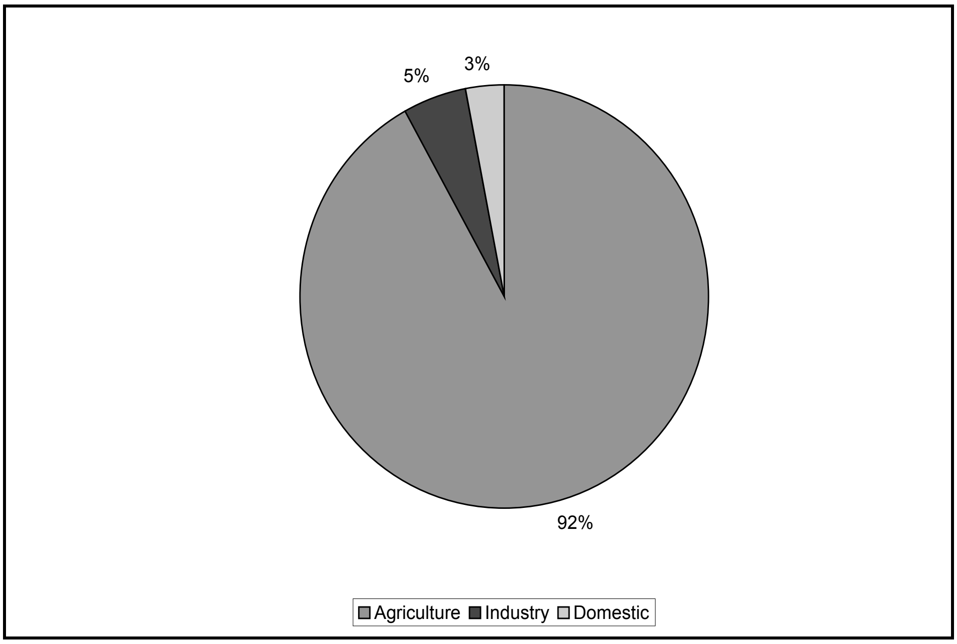

Figure 2.2: Groundwater usage in India (Planning Commission of India, 2002)

2.3.3 Drinking Water Situation in India

Traditionally, India has been an agriculture-based economy. Hence, development of irrigation to increase agricultural production for making the country self-sustained and for poverty alleviation has been of crucial importance for the government. In the five decades since independence, India has witnessed phenomenal development of water resources and has successfully met the demand of water for many of the diverse uses in the country. The rapid expansion of irrigation and drainage infrastructure has been one of India's major achievements.

However, investments made during the recent years in water related infrastructure in the country have resulted in rapid expansion in the urban, energy and industrial sectors. Infrastructure for safe drinking water has been provided to about 85% of India's urban and rural population. According to the UN (2006), five billion people are predicted to live in urban areas by 2030, smaller urban settlements of less than 500,000 people absorbing most of the growth. This transformation of rural to urban land use will have significant impact on the surface water quantity and quality. And there remains a significant challenge in providing sustainable services, especially to the poorest and areas which are difficult to reach (UN, 2006).

Drinking water supply accounts for about 5% of the total water use. About 7,000 m^3 of surface water and 18,000 m^3 of groundwater are being used for public water supply in urban and rural areas. The spatial variation of domestic demand is mainly due to uneven distribution of urban and rural populations. Water demand in urban areas is higher due to water use for flushing latrines, gardening, firefighting, etc. At present, the water withdrawal in urban areas (135 lcpd, litres per capita per day) is assumed to be more than three times higher than in rural areas (40 lcpd) (MoWR, 1999).

Data available from the Department of Drinking Water Supply shows that coverage is not uniform across the country and varies widely from state to state. For example, of the 35 states in India, only seven have achieved full coverage in rural areas (Bihar, Chhatisgarh, Madhya Pradesh, Tamil Nadu, Uttar Pradesh, Daman & Diu, Delhi, Lakshadweep, and Chandigarh) and the others to varying degrees. On the urban front, in class I cities (Class 1 city: town with population one million and above) and class II towns (town with population 50,000 to less than one million) of the country, there is a huge disparity in quantity of water supplied. Of the 393 class I cities, only around 77 cities have 100% water supply coverage. The per capita water supply ranges from as low as 9 lpcd in Tuticorin to as high as 584 lpcd in Triuvannamalai. Similarly, around 203 of the 401 class II towns have low per capita supplies of less than 100 lpcd. Figure 2.3 is a representation of the community water supply in an Indian city.

Figure 2.3: Community water supply in Indian cities (www.Indiawaterportal.org)

80% of the drinking water needs are met by the surface water sources, while 20% are covered by the groundwater sources (Planning Commission of India, 2002). The surface water sources are managed by the different government agencies, whereas groundwater is pumped by individual households. The public water supply is erratic and insufficient. For instance, in the city of Hyderabad, the present status of drinking water supply is 2 hours every alternate day (APUIDFC, 2006). Owing to this insufficiency, the consumers are bound to depend on the private groundwater wells, create storage spaces or buy water from the private vendors or markets to meet the rest of the water needs on daily basis. It is important to highlight that there is no specific or rather no monitoring of either the storage spaces nor the groundwater consumption and exploitation at the consumer end. This situation makes it complicated to assess the actual water consumption at the individual household level.

2.3.3.1 Water Supply Schemes and Government Programs

Water supply and sanitation were added to the national agenda during the first five-year planning period (1951 - 1956). In 1954, the first national water supply program was launched as part of the government's health plan (while sanitation is mentioned in the First Plan, it simply forms part of the section on water supply). Central and state administrations provided equal funding mainly for rural piped water supply schemes, with limited provision for point sources such as wells and boreholes. During the initial years, the program realized only limited achievements mainly because the states lacked qualified work forces to plan and execute projects, and materials were in short supply. During each of the subsequent five year plans, funding was allocated for the development and strengthening of state public health engineering departments. In recognition of the progress made, states were granted financial authority in 1968 to approve rural water supply schemes (subject to defined limits).

2.3.4 Water Management

2.3.4.1 Water Quality

WHO has classified inland water uses in five classes and has fixed tolerance limits of all polluting factors of water. The BIS (Bureau of Indian Standards) followed a similar classification adapted to Indian context. These standards are applied to all the surface water sources which include rivers, lakes and reservoirs. The detailed classification is presented in the Appendix 1.

The CPCB (Central Pollution Control Board) has been monitoring water quality of national aquatic resources in collaboration with concerned State Pollution Control Boards at 507 locations, of which 430 stations are under MINARS (Monitoring of

Indian National Aquatic Resources), 50 stations are under GEMS (Global Environmental Monitoring Systems) and 27 stations under the YAP (Yamuna Action Plan). The water quality monitoring results obtained in 1998 indicate that organic and bacterial contamination continue to be critical factors of pollution in Indian aquatic resources. The Yamuna River is the most polluted in the country, having high biological oxygen demand (BOD) and coliform bacteria in the stretch between Delhi and Etawah. Other severely polluted rivers are the Sabarmati at Ahmedabad, Gomti at Lucknow, Kali, Adyar, Cooum (entire stretches), Vaigai at Madurai, and Musi at Hyderabad (Figure 2.4).

Figure 2.4: River Musi at Hyderabad

These conditions prevails in the middle and lower stretches of the rivers, where the areas show dense concentrations of population and industrialization. The upper stretches of the rivers usually are still pristine (Bharadwaj, 2005).

Groundwater Resources

CGWB's studies on chemical composition of groundwater in phreatic zones have revealed that in many cases anomalously high concentrations of nitrates, potassium and even phosphates are present. In contrast, in semi-confined and confined aquifers they are of low concentration (nitrate and potassium < 10 mg/l). The inappropriate use of mineral fertilizers coupled with improper water management has affected the groundwater quality in many parts of the country. The state-wide monitoring of groundwater pollution reflects also the occurrence of high concentrations of heavy metals and fluoride at different locations across the country.

Even with strong legislative provisions such as the Water (Prevention and Control of Pollution) Act and the Environment Protection Act, 1974 and 1986 respectively, as many as 851 fraudulent industries were located along the rivers and lakes in 1997. The Water Cess Act, 1977 has also failed to act as a market-based instrument in reducing the quantity of polluted discharges (Bharadwaj, 2005).

2.3.4.2 Institutional Setup in India

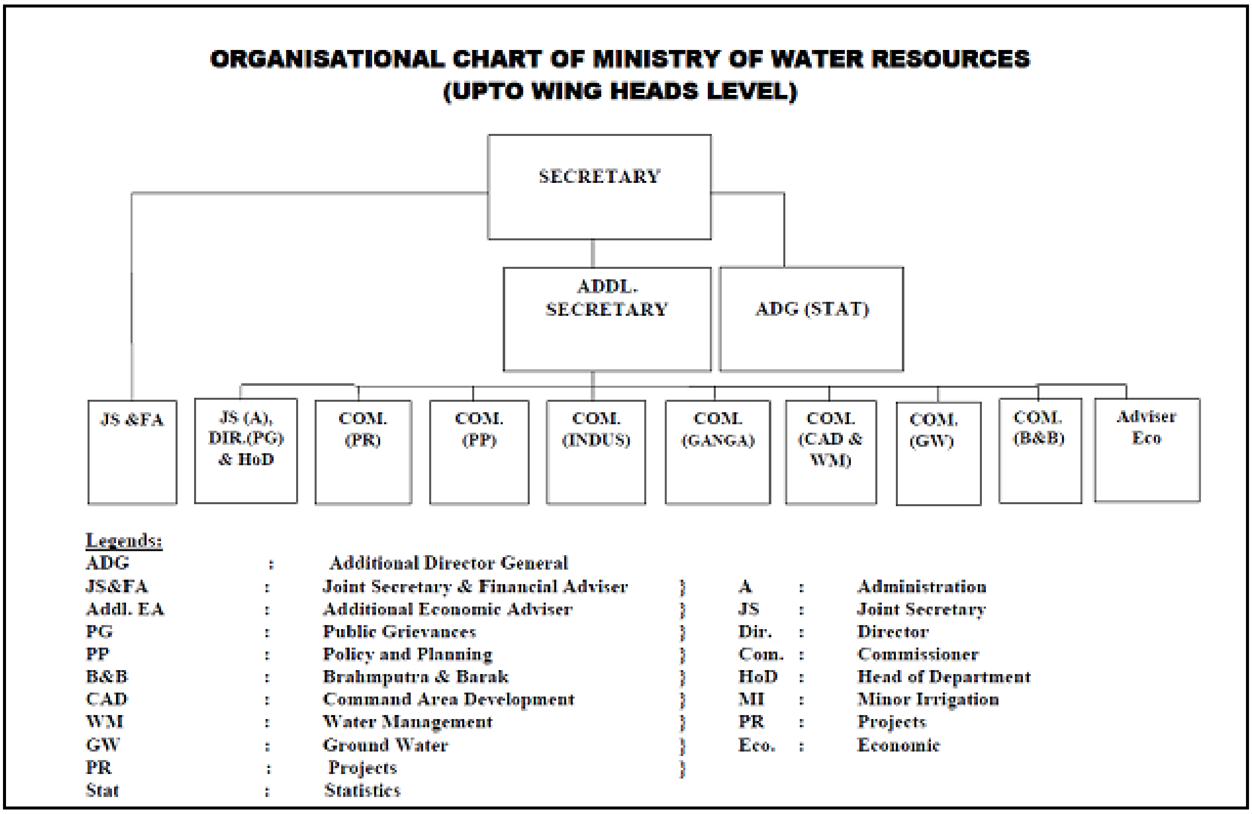

Figure 2.5: Organisation chart of Ministry of Water Resources, India (Source: MoWR, 2008)

At the central level, the Union Ministry of Water Resources (Figure 2.5) is responsible for development, conservation and management of water as a national resource, i.e. for the general policy on water resources development and for technical assistance to the states on irrigation, multipurpose projects, ground water exploration and exploitation, command area development, drainage, flood control, water logging, sea erosion problems, dam safety and hydraulic structures for navigation and hydropower. It also oversees the regulation and development of inter-state rivers. These functions are carried out through various Central Organisations. Urban water supply and sewage disposal is handled by the Ministry of Urban Development while rural water supply comes under the purview of the Department of Drinking Water under the Ministry of Rural Development. The subject of hydro-electric power and thermal power is the responsibility of the Ministry of Power. Pollution and environment control comes under the purview of the Ministry of Environment and Forests.

Water being a state subject, the state governments has primary responsibility for use and control of this resource. The administrative control and responsibility for development of water rests with the various state departments and corporations. Major and medium irrigation is handled by the irrigation/water resources departments. Minor irrigation is looked after partly by water resources departments, minor irrigation corporations, Zilla Parishads/panchayats (rural administration) and by the other departments such as agriculture. Urban water supply is generally the responsibility of public health departments and panchayats take care of rural water supply. Government tubewells are constructed and managed by the irrigation/water resources department or by tubewell corporations set up for the purpose. Hydro-power is the responsibility of the State Electricity Boards (MoWR, 2008).

In addition, there are agencies that are involved in various aspects of river basin management, through wasteland development, promoting drinking water and sanitation, agricultural development, pollution control and others. Though a National Water Resource Council was setup in 1983 for better cooperation amongst the various organisations and agencies involved in water resources development and management, much needs to be done for it to be more effective and to coordinate their actions. There are no formal institutional mechanisms that consider the different sectoral demands for planning and management of water (SANDRP, 1999).

2.3.4.3 National Water Policy

The Ministry of Water Resources (MoWR) drafted a National Water Policy in 1987 to guide the planning and development of water resources throughout the country. The policy included several recommendations, which were subsequently adopted by the states. The recommendations focused on the need for introducing:

- give water resource management and domestic water supply the highest priority,
- design standards for groundwater structures to protect groundwater sources,
- water quality monitoring and mapping as well as
- Data management and evaluation.

The 1987 policy has been recently revised and the National Water Policy 2002 has now been adopted, once again according primacy to drinking water. The National Water Policy 2002 recognises the need for well-developed information systems at the national and state levels, places strong emphasis on non-conventional methods for utilisation such as inter-basin transfers, artificial recharge, desalination of brackish or sea water, as well as traditional water conservation practices such as rainwater harvesting, to increase utilisable water resources. It also emphasis on watershed management through extensive soil conservation, catchment area treatment, preservation of forests and increasing forest cover and the construction of check dams. The policy also recognises the potential need to reorganise and reorient institutional arrangements for the sector and emphasises the need to maintain existing infrastructures (MoWR, 2002). Under the National River Action Plan (NRAP), certain stretches of major rivers with high or intermediate levels of pollution have been identified by the Central Pollution Control Board and action is underway to reduce the pollution load. Many other similar measures are underway.

73rd Constitutional Amendment is a constitutional act in India that is meant to provide constitutional sanction to establish democracy at the grassroots level (lower administrative units like villages, towns and city administrations) as it is at the state level or national level. In line with this act, increasing recognition that centralised, government-controlled and supply-driven approaches need to be changed to more decentralised, people-centric and demand-responsive approaches has led to the revamping of the Accelerated Rural Water Supply Plan (ARWSP) and the inception of the sector reforms programme. This major paradigm shift in thinking and policy started in 1999 and incorporates the principles of: (a) adoption of demand responsive approaches based on empowerment, to ensure full participation in decision making, control, and management by communities, (b) shifting the role of governments from direct service delivery to that of planning, policy formulation, monitoring and evaluation and partial financial support and (c) partial capital cost sharing, in either cash or service or both, and 100% responsibility of operation & maintenance by users. Sector Reforms are currently being undertaken in 67 districts across the country and is likely to increase to 75 districts soon (MoWR, 2001).

While states have been asked to formulate state water polices based on the National Water Policy within the next two years, some states such as Karnataka, Madhya Pradesh, Orissa, Rajasthan and TamilNadu have already drafted state policies based on the new national policy. The national policy guiding the water and sanitation sector in India is contained in the Eighth Five-Year Plan (1992-97), which states "Safe drinking water and basic sanitation are vital human needs for health and efficiency [given that] death and disease, particularly of children and the drudgery of women are directly attributable to the lack of these essentials." High priority was given to serving villages that did not have adequate sources of safe water and to improving the level of service for villages classified as only partially covered. The Eighth Five-Year Plan also identified several points of emphasis including management of water as a commodity, delivery of water services based on principles of effective demand, standards of service corresponding to the level that users are willing to maintain, etc. The Ninth and Tenth Plan broadly follow the directions set by the Eighth Plan (Planning Commission of India, 2008).

National policy guiding India's approach to water supply and sanitation in the Eighth, Ninth and now the Tenth Five-Year plan broadly follow the guiding principles of the New Delhi declaration, adopted by the United Nations General Assembly in December 1990 (Planning Commission of India, 2002). These include: (a) protection of the environment and safeguarding of health through the integrated management of water resources and liquid and solid waste; (b) organization of reforms, promoting an integrated approach including changes in procedures, attitudes, and behavior, and the full participation of women at all levels; (c) community management of services, backed by measures to strengthen local institutions in implementing and sustaining water and sanitation programs; and (d) sound financial practices, achieved by better management of existing assets and extensive use of appropriate technologies.

2.3.4.4 Water Management Practices and Approaches

Many of the River Basin Organisations (RBOs) in India were either subject-oriented or project-oriented organisations (Chitale, 1992). Organisations that were confined to construct and operationalise a specific engineering project were Damodar Valley Corporation (DVC), Bhakra Beas Management Board, Tungabhadra Board, and Narmada Control Authority, Betwa River Board and Bansagar Control board. The objectives of some of the RBOs in India are mentioned below:

Brahmaputra Board: The Brahmaputra Board was set up in 1980 to prepare a master plan for flood control in the Brahmaputra valley, taking into account the overall development and utilisation of water resources of the valley for irrigation, hydropower, navigation and other beneficial purposes. The Board is headed by a chairman appointed by the Government of India (GOI) and has members from governments of the basin states. The main functions include (a) preparation of plans for flood control and utilisation of water resources for various uses; (b) preparation of detailed designs and cost estimates for proposed projects; and (c) construction, maintenance and operations of multipurpose projects with the approval of the Government of India (GOI).

Bhakra-Beas Management Board (BBMB): The Bhakra-Beas Management Board was constituted through an executive order in accordance with section 79 of the Punjab Reorganisation Act 1966 to regulate the supply of the Sutlej, Ravi and Beas rivers to the state of Punjab, Haryana, Rajasthan, and the National Capital Territory of Delhi. The Board is headed by a chairman appointed by GOI and has members from basin states. The BBMB is responsible for the operation and maintenance of the projects under its jurisdiction and to allocate water for irrigation based on inflows to the reservoirs. In addition, it will distribute energy in consultation with beneficiary states. BBMB, like DVC, functions under the control of the Union Power Ministry, and not the Water Resources Ministry.

Upper Yamuna River Board (UYRB): The Upper Yamuna River Board was constituted for (a) Regulation and supply of water from all storages and barrages up to and including Okhla Barrage; (b) maintenance of minimum flows; (c) monitoring of return flow quantities from Delhi after allowing for consumptive use; and (d) providing coordination for maintenance of water quality, and conservation. The Board is headed by a member of the Water Planning & Projects of Central Water Commission and also has members from the basin states.

Ganga Flood Control Board (GFCB) and Ganga Flood Control Commission (GFCC): The Ganga Flood Control Board was set up in 1972 by a resolution of the Government of India. The Ganga Flood Control Commission was set up according to the clause 5 of the resolution to undertake specific works in the Ganga Basin and for assisting the Ganga Flood Control Boards. The GFCC is expected to prepare a master plan for the basin to deal with problems emerging from flood erosion and water logging in the region. The implementation of these will be carried out by the appropriate riparian state. A chairman appointed by the GOI heads the Commission. GOI also appoints two full time members. Basin states appoint part-time members of the commission.

Other Organisations: Betwa River Board was constituted under the Betwa River Board Act (1976) for efficient, economical and early execution of the Rajghat Dam Project. The Bansagar Control Board was constituted in 1976 for efficient economical and early execution of Bansagar Dam and connected works, across river Sone. Mahi Control Board was constituted for Mahi Bajajsagar Project across river Mahi. The Narmada Control Authority is in charge of overseeing the implementation of the award of the Narmada Water Dispute Tribunal for planning and management and sharing of benefits from Sardar Sarovar project

What is clear from the origin, functions and constitution of these RBOs is that they are all structured for planning, design and implementation of large projects. Proper river basin management encompassing the needs, resources and priorities of the entire river basin has not been done in a single river basin in India (SANDRP, 1999).

Lake Management in India

Apart from the river management, there has been considerable effort involved in conservation and management of fresh water lakes. There is no specific definition for Lakes in India. The word “Lake” is used loosely to describe many types of water bodies – natural, manmade and ephemeral including wetlands. The manmade (artificial) water bodies are generally called Reservoirs, Ponds and Tanks though it is not unusual for some of them to be referred to as lakes.

The lakes and reservoirs, all over the country without exception, are in varying degrees of environmental degradation. The degradation is due to encroachments eutrophication (from domestic and industrial effluents) and silt. The anthropogenic pressures in the catchment itself have resulted in degradation of the catchment area posing a threat to the quality of water stored in the lakes. This is a common threat to both the urban and rural lakes. Some of the basin level problems that pose a threat to the reservoirs and lakes can be listed as follows:

- Silting of lakes on account of increased erosion as a result of expansion of urban and agricultural areas, deforestation, road construction and such other land disturbances taking place in the drainage basin:
- Diversion of rivers feeding the lakes leading to the reduction in the inflows and also the size of the lakes.
- Conflicts over using lake water such as for drinking, irrigation, hydropower etc.,
- Untreated or inadequately treated domestic and industrial effluents from point sources located all over the basin

The degree of the problems varies from lake to lake, but is more pronounced in urban lakes. Experiencing these threats are lakes such as Osman Sagar reservoir in Hyderabad, Udaipur lakes in Rajasthan, Nainital lakes in Uttaranchal, India. The (Figure 2.6) shows the sewage inflows and solid waste in one of the feeder inlets of an urban lake in Hyderabad.

Figure 2.6: Sewage inflows in one of the inlets of Hussain Sagar lake, Hyderabad (Source: CRE, Hyderabad)

National Lake Conservation Plan:

Addressing these issues, some of the restoration plans and management measures taken up across the country are:

Source protection: Soil conservation measures, bank/slope erosion control measures, afforestation, drainage improvements, diversion of silt carrying channels away from the lake, control of sewage wastes, sewage interceptions and diversions and participation of people in watershed management measures have been widely adopted as effective management tools in all the lake restoration projects.

In lake treatment: The following are several palliative measures under taken to remove eutrophication and improve quality of lake water:

- Dredging and de-silting – as in the Bhoj wetlands, Dal and Nagina Lakes, the Sukna Lake, the Ropar lake, and the Renuka Lake.

- De-weeding/hyacinth control or removal (biological, chemical, mechanical and manual measures, bio-composting) – as in the Loktak, Bhoj Wetlands, Harike and Kanjli lakes.
- Bio-remediation (Clean up with bio-products - natural bacteria breakdown, and aerators to churn the lakes) as in the Powai Lake in Mumbai, Ooty and Kodaikanal lakes in Tamil Nadu, and Mirik Lake in West Bengal.
- Introduction of composite fish culture/larvivorous fish species to control mosquitoes (Sasthamkotta lake, Ashtamudi lake, etc)
- Engineering measures (hydraulic) to improve flow of seawater into the lake to maintain salinity levels in coastal lakes e.g opening of lake's outer channel into the sea ensured better exchange of salinity level in Chilika Lake.
- Revival of traditional drainage system to replenish lake storage and drain out flood waters to improve rabi cultivation of Tals, Chaurs, and Oxbow lakes.
- Lake water supplementation through irrigation canal systems in the area as in the case of Nalsarovar bird sanctuary and the Keoladeo National Park

Restoration and management plans of the fresh water lakes in India have a exclusive involvement of the neighbourhood communities, NGOs through various awareness and educational programs. The Figure 2.7 shows the dredging being carried out in a fresh water lake in the city of Hyderabad.

Figure 2.7 Dredging being carried out in Hussain Sagar Lake, Hyderabad (Source: CRE, Hyderabad)

2.4 Water Resources in Hyderabad

Hyderabad, the capital city of the state of Andhra Pradesh, is one of the fast growing mega cities of the country and of the world. The water woes in the city represent a typical situation of any other urban centre in India. Hyderabad is a classical example of an exploding urbanisation. Located in the semi-arid region of the country, the city has a geographic coverage of 1,547 km² and a population of over 6.1 million (2001 Census). Its population displays an annual growth rate of 3.4% (GHMC, 2008). The city experiences the typical features of resource crunch and degradation at an alarming rate.

2.4.1 Historical Overview

The city is known to have around 300 lakes and the famous River Musi. Being situated in the semi-arid region, the city is historically known for the man-made lakes which have been supporting both the agricultural and the urban needs. Many big lakes were built in and around Hyderabad city by the Qutub Shahi rulers (1534-1724 A.D.) and later by the Asaf Jahi rulers (1724-1948). Some of the big tanks built during those periods are Hussain Sagar, Mir Alam, Afzal Sagar, Jalpalli, Ma-Sehaba Tank, Talab Katta, Osman Sagar and Himayatsagar (Rekha Rani, 2000). Most of the big tanks were constructed by the former rulers or ministers, whereas the minor tanks were built by zamindars (landlords).

The Hussain Sagar was built in 1575 by Sultan Ibrahim Kutub Shah as a source of water for the city and suburbs north of Musi River. When the lake did not fill with water even after four years of completion, a channel has been made from the Musi River to bring water to the lake (Alikhan, 1990).

The Mir Alam tank is another fresh water lake. From these two tanks (Hussain Sagar and Mir Alam tank) there was plenty of drinking water supply to the city and the suburbs. Since the 1950's, Hussain Sagar and Mir Alam tank are no longer used as sources of drinking water to the city. The lakes have lost their fresh water status due to the sewerage inflow from Hyderabad city. Today these two lakes remain as sewage pools. In order to bring back the oligotrophic status of the lake, there are ongoing efforts to treat the water (Rekha Rani, 2000).

2.4.2 Water Requirement

The average per capita consumption of water is estimated at 0.14 $m^3/c/d$ (145 lpcd), while the supply is around 0.12 m^3/d (120 lpcd) (Reddy, 2007). According to the HMWWSB, the current water demand for the city is estimated at 1.16 Mi m^3/d, but the water supply is only 0.81 Mi m^3 per day. The deficit is made worse by frequent droughts and is expected to rise in the future, due to urban expansion and changing lifestyle. The Figure 2.8 indicates the trend in the water demand and the supply in the past and in the projected changes in the near future.

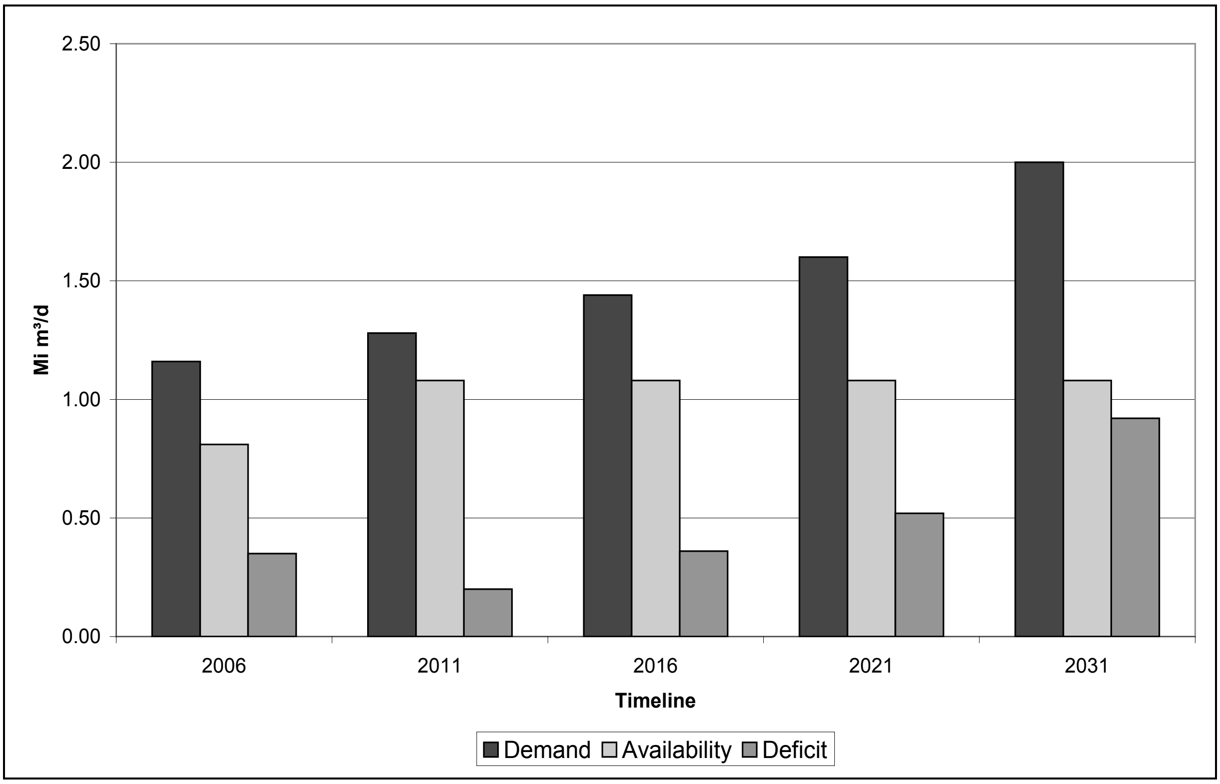

Figure 2.8: Estimated water demand in the city of Hyderabad (HUDA, 2006)

2.4.3 Water Supply

The Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB) is a statutory authority in charge of providing and maintaining water supply and sewerage facilities in Hyderabad as well as surrounding municipalities. The board is an autonomous body under the Water Supply and Sewerage Act (1989) and is responsible for supply of potable water including planning, design, construction, implementation, maintenance, operation and management of water supply and sewerage system. The board is stipulated to run on profit making lines by generating surplus through tariffs in order to meet the operational costs, capital expenditure and debt servicing (APUIDFC, 2006).

2.4.4 Drinking Water Sources

Today, Hyderabad city receives its drinking water from the five impoundments of the following four rivers (
Table **2.1**):

- Osman Sagar on River Musi
- Himayat Sagar on Esi River

- Manjira River
- Krishna River

The different phases indicate different dams that have been created at various stretches of the river.

Table 2.1 Drinking water sources of Hyderabad (HMWWSB, 2007)

Drinking water Source	River	Year	Reservoir	Distance from city (km)	Drawls Mi m³/d
Osman Sagar	Musi	1920	Osman Sagar	15	0.06
Himayat sagar	Esi	1927	Himayat Sagar	10	0.04
Manjira-Phase I	Manjira	1965	Manjira Barrage	58	0.06
Manjira-Phase I	Manjira	1981	Manjira Barrage	59	0.12
Manjira-Phase I	Manjira	1991	Singur Barrage	80	0.15
Manjira-Phase I	Manjira	1993	Singur Barrage	80	0.15
Krishna Phase I	Krishna	2005	Nagarjuna Sagar Dam	116	0.23

Note: Phases mentioned in the table above refers to different sections of the dam commissioned in different years.

The total quantity of water that can be drawn from the above sources is 0.81 Mi m³ per day. In addition, 0.1Mi m³ per day of groundwater is also drawn through bore wells. Due to considerable reduction in the inflows to the impoundments and immense growth of population, the Phase-I Krishna Drinking Water Supply Scheme was commenced in the year 2005 and Phase-II in the current year of 2008. These efforts, however, could not meet the escalating water demand of 250 lpcd and the deficit continues. To improve the present conditions plans are to bring in water from the Godavari river, from a distance of 119 km (Saleth and Dinarl, 1997).

2.4.5 Distribution Network and Coverage

The public water supply system of Hyderabad covers over 90% of the inner city`s population and 65% of the surrounding municipalities. Access to piped water in Hyderabad area is around 70% and is much lower in surrounding municipalities, averaging to around 43%. For those who cannot afford individual house connections, especially the weaker section of the society, they rely on the 8353 public stand posts for water. 95% of connections are metered, but the majority of meters are not working. Water is supplied for 30 minutes to 2 hours every alternate day in the inner city and 1 hour every third day in surrounding municipalities (APUIDFC, 2006).

The transmission mains carry water from the source to the water treatment plants and subsequently towards the master balancing reservoirs. The total length of the distribution system is 1727 km, comprised of pipes with diameters ranging from 75mm to 700mm of different materials. The trunk distribution mains transmit water from the balancing reservoirs to the reservoirs within the city. The total length of the transmission mains is about 286 km^2 and the trunk mains is about 265 km^2 (APUIDFC, 2006).

The water distribution system for the inner city area is divided into 20 water distribution zones. The zones are further divided into 20-30 sub-zones based on operational convenience. The sub-zones are operated using control valves thereby making the operation of the system very complicated. There are 118 reservoirs in total, both ground and elevated, supplying water to all the localities in the city. The total storage capacity of the balancing reservoirs available within the city is about 0.39 Mi m^3. The present storage capacity is inadequate for the quantity of water supply available (APUIDFC, 2006).

2.4.6 Water Management

While the city undergoes spatial and population explosion, the city’s water resources are shrinking at equal rate. This leads to limited supply of drinking water and at some places absolutely no supply of the same. As a result, the residents depend heavily on the groundwater sources, pumped individually. Groundwater resources in recent years are also turning out to be unreliable, in terms of both quantity and quality.

At the consumer level - both domestic and non-domestic – counteract the water deficit of the public water supply by complementing it with other sources. Depending on their economic status, these options range from investment in an in-house storage (cistern) to the installation of individual groundwater wells in their backyard. Other options are to purchase water from private tankers (Figure 2.9) joint supply arrangements by neighbourhood groups and inter-household sharing including local water markets (Saleth and Dinar, 1997).

Figure 2.9 Drinking water supplied through tankers in Hyderabad

2.5 *The Study Area*

The Osman Sagar drinking water reservoir (Figure 2.10) was built on the upstream of River Musi primarily to control floods on River Musi and secondly to utilize the water for the drinking water needs to the city of Hyderabad. The catchment area is still predominantly agricultural and rural in its characteristics.

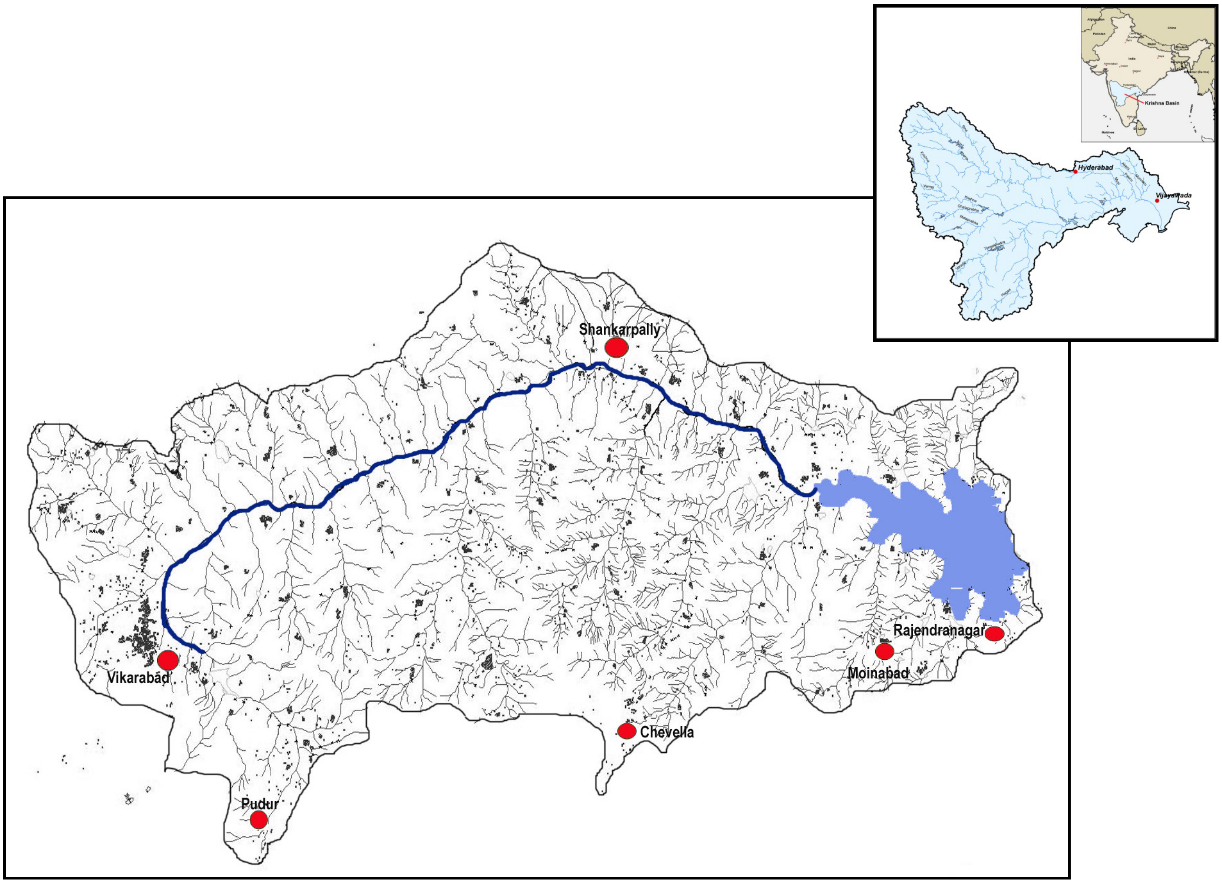

Figure 2.10: Location map of the Osman Sagar reservoir

2.5.1 The Catchment

The catchment area of Osman Sagar reservoir is spread over an area of 738.15 km². The area comprises the political divisions of six mandals (administrative units) in the west division of Ranga Reddy District in the state of Andhra Pradesh (Rajendranagar, Chevella, Shankarpally, Vikarabad, Pudur and Moinabad).

Figure 2.10 shows the location of the political regions within the catchment.

The catchment hosts a population of over 221,000 (CPO, 2000), living in 80 villages and 6 towns. The settlements within the catchment are predominantly rural with agriculture and allied activities as dominant income source.

2.5.1.1 Topography

The catchment is bound by the surrounding districts of Mahaboobnagar, Medak and Sangareddy respectively. The Ananthagiri hill range straddles across the district from Mahaboobnagar District border in the south to Dharur Mandal in Vikarabad Revenue Division in the North. The catchment has a flat topography of mean slope less than 1% (Massuel et al., 2004).

2.5.1.2 Climate

The catchment area is in the semi-arid climatic region. The climate of the region is characterized by hot summers and mild winters. It is generally dry, except during the monsoon season. The year may be divided into four seasons: March to May is the summer season, June to September constitutes the south-west monsoon season, October to December from the north-east monsoon season and January to February is the winter season. The Figure 2.11 represents the annual temperature variation in the study area.

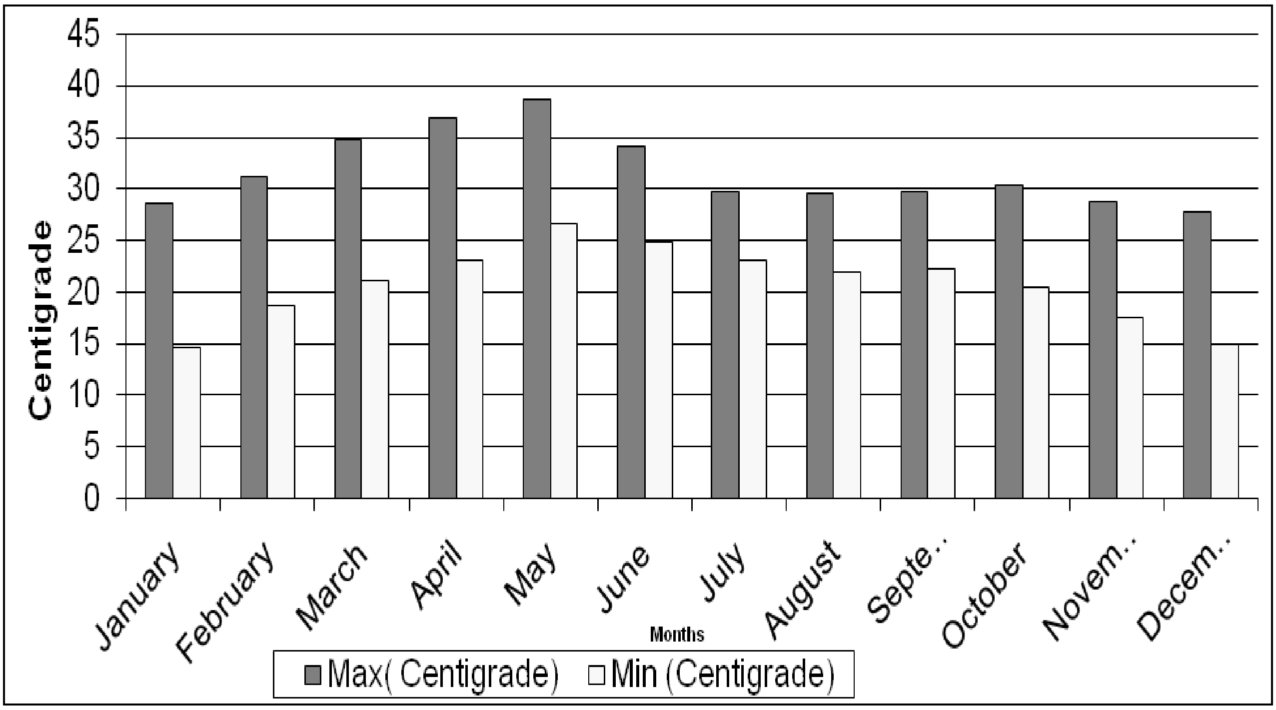

Figure 2.11: Annual temperature variation in the study area

The mean maximum temperature begins to rise from the middle of February and reaches a maximum of about 35°C in May. With the onset of the south-west monsoon into the region early in June, there is appreciable drop in temperatures. In the beginning of November, the decrease in both day and night temperature is rapid.

December is the coldest month with the mean daily maximum temperature at 28.6°C and the mean daily minimum temperature at 13.6°C (CPO, 2001).

The region has a mean average rainfall of 780 mm/yr, the bulk of which is received through the south-west monsoon during the period from June to September. During the south-west monsoon season the relative humidity is generally high, ranging between 70 and 80%. Humidity decreases from the post-monsoon season onwards. The driest part of the year is the summer season when the humidity is between 30 and 35% in the afternoon.

Winds are generally light to moderate with some increase in force during May and south-west monsoon season. Winds from westerly direction begin to blow from May. In the south-west monsoon season winds are mainly from western to north direction. During the post-monsoon season winds are light and variable in direction (CPO, 2005).

2.5.1.3 Geohydrology

The catchment is predominantly under the Deccan trap basalt and lateritic geology. The common ground water abstraction structures are dug wells and bore wells. Their yields depend mainly on the recharge conditions in the area. In this region, groundwater occurs in joints, fractures and crevices of massive and jointed basalts. In vesicular basalts, open vesicles pave the way for groundwater occurrence and movement. Groundwater in these formations occurs under water table and semi-confined conditions. Its exploration carried out in the district indicates the presence of about 2 to 4 aquifer zones to a depth of about 100 m. The average groundwater depth to water level ranges from 10 to 20 meters below ground level. The average specific yield of the weathered basalt and laterite is 0.01% to 0.02% respectively (CGWB, 2007).

2.5.1.4 Soils

The study area is predominantly vertisols (black soils) and lateritic soils with a thickness ranging between 90 - 180 cm. Black soils are very dark and have very high montmorillonitic clay content. They have a high moisture retention capacity. They become extremely hard on drying and sticky on wetting. Hence, they are very difficult to cultivate and manage. Under rain-fed conditions, they are used for growing cotton, millets, soybean, sorghum, pigeon pea. Under irrigated conditions, they are used for a variety of other crops such as sugar cane, wheat, tobacco and citrus fruits.

Lateritic soils are deeply weathered red soils with high kaolinitic clay content, having low base and silica owing to pronounced leaching. The major limitations posed by these soils are a deficiency in phosphorous, potassium, calcium, zinc and boron. They also show high acidity and hence toxicity of aluminium and manganese (FAO, 2005).

2.5.1.5 Land use

The catchment constitutes the rural background for Hyderabad city, feeding the powerful metropolis with various raw materials and agriculture produce. The land use is classified according to the classification set up by the Ministry of Food and Agriculture. The classification is given in the Table 2.2.

Table 2.2: Land use classification (Ministry of Food and Agriculture, India)

Forests	Forests
BAUCL	Barren and uncultivable land
LPNAU	Land put to non-agriculture use
PP	Permanent pastures
Misc. Tree	Miscellaneous tree cover
Cul Waste	Culturable waste land
Current Fallow	Agricultural land left fallow for the present year
Other Fallow Land	Fallow land other than the current fallow
Net Area Sown (NAS)	Agricultural land in use in the present year

Note: Fallows lands are the agricultural lands left uncultivated either due to limited access to the irrigation or no access at all.

Based on the above classification the land use for the study period has been represented in the Figure 2.12.

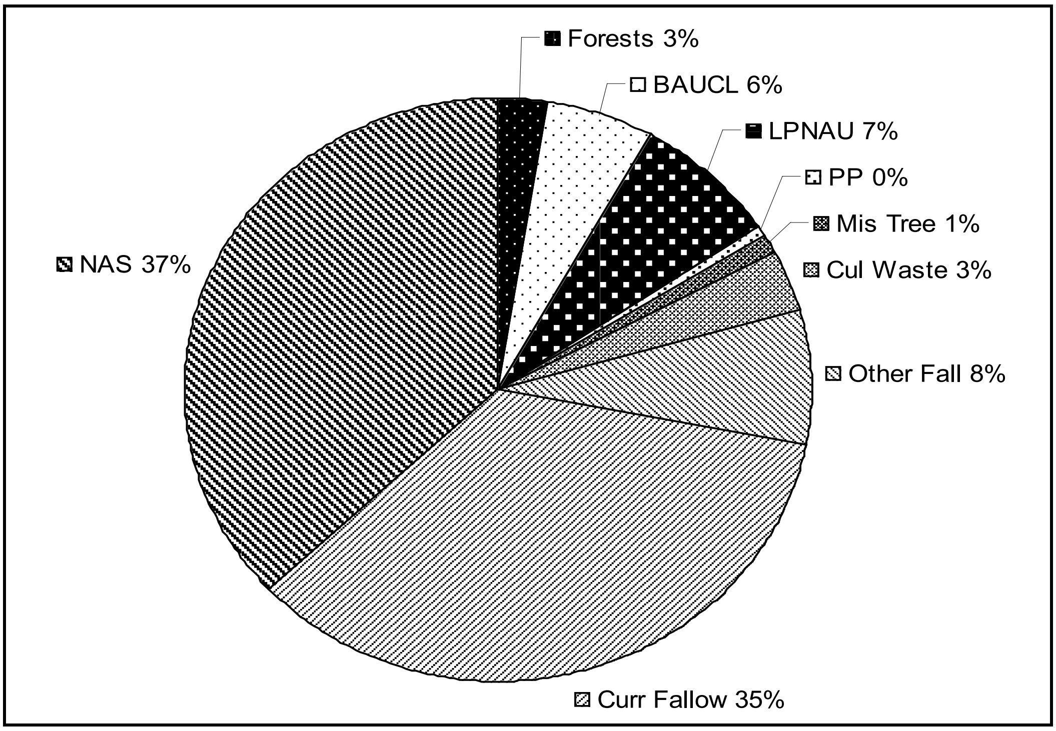

Figure 2.12: Land use within the catchment (CPO, 2005)

The area has a very small percentage of forest area, mostly restricted to the Ananthagiri hills of the catchment. 37% of the region is under agricultural activity and an equal percent of land under current fallow (35%). The current fallows (Figure 2.13) are the agricultural lands which are left fallow due to drought or no access to irrigation. The fallow lands are agricultural lands which are dependent mainly on the rain for irrigation. Most of these lands are owned by the small and marginal farmers who do not have access to a private groundwater well. Thereby, under the drought and low rainfall conditions, these agricultural lands are left fallow by the farmers.

Figure 2.13: Fallow land within the catchment

2.5.1.6 Agricultural Production

Amongst the lands that are under regular cropping conditions, food crops account for 80.3%, while non-food crops for 19.7%. The principal food crops are sorghum, castor, pulses and rice (Figure 2.14). Agricultural activities in the area are dependent on the monsoon. There are two main cropping seasons, namely kharif (April - September) and rabi (October-March). The major kharif crops include sorghum, rice, sorghum, pearl millet, maize, cotton, sugarcane and groundnut. The rabi crops include castor, pulses, linseed, rapeseed and mustard (CGWB, 2007).

Figure 2.14: Rice cultivation in the catchment

In the year 2004 and 2005 around 10,440 ha and 10,351ha of area was under cultivation. Around 60 to 65% of the area was cultivated with sesame, sunflower, castor, groundnut and cotton. Crops such as pulses, vegetables and sugarcane form around 16% of the total land under agriculture. Cereals include rice, sorghum and wheat which comprise around 19–24%. The area under the cereal production depends on the rainfall and also the availability of irrigation. Therefore, the year 2005 recorded 5% more area under the cereal production than 2004. 2005 was a wet year with rainfall above the mean average of the region.

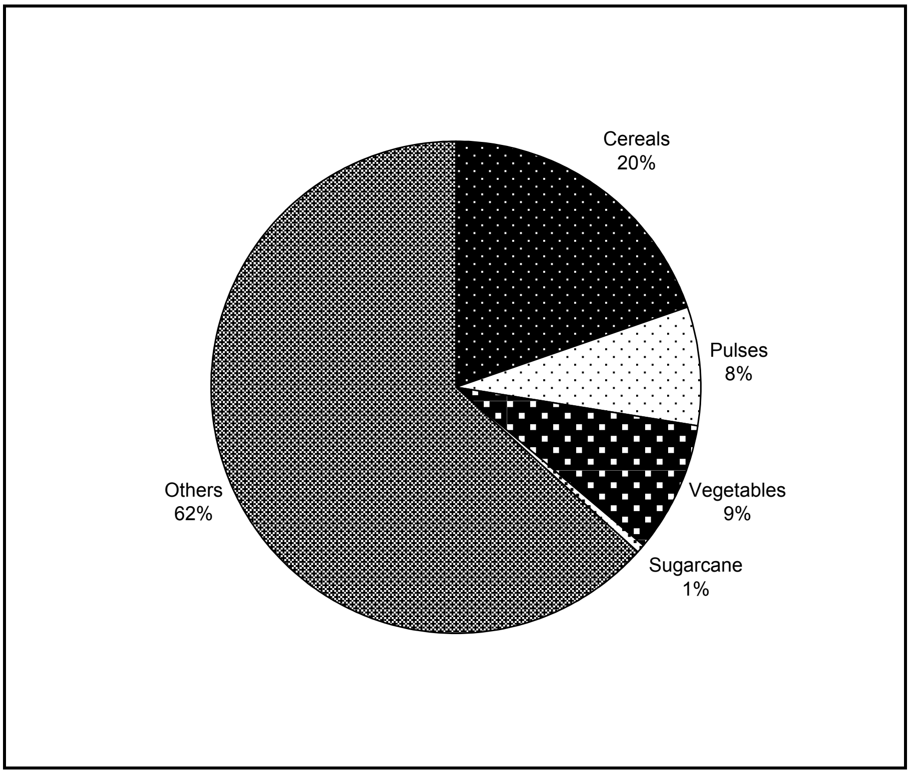

Figure 2.15: Agricultural area under various crops in the catchment, 2004 (CPO, 2004)

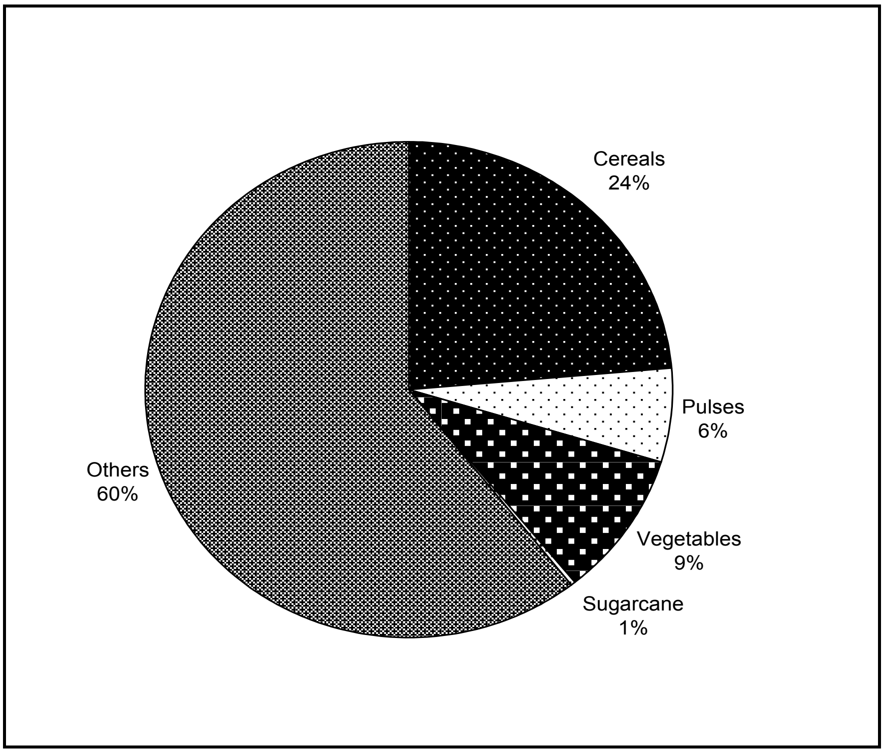

Figure 2.16: Agricultural area under various crops in the catchment, 2005 (CPO, 2005)

Sugarcane is mostly grown in the northern region of the catchment (Shankarpally Mandal) which has the highest number of bore wells for irrigation. The use of surface water from River Musi (upstream of Osman Sagar reservoir) for irrigation purposes has been banned. This measure is to protect the drinking water rights for Hyderabad city. Thereby major dependency for irrigation purpose is on groundwater (Figure 2.17) (CPO, 2005).

Figure 2.17: Groundwater wells within the agricultural lands in the catchment

2.5.1.7 Status of Groundwater Resources

The region is mainly dependent on groundwater for its irrigation due to scanty rainfall and little surface water resources. Adding to this, the River Musi, which is the principal source of surface water in the region, is under conservation law, stating that any activity aimed towards utilization of the water from the river is forbidden in the region. This explains the dependency on groundwater for domestic and irrigation purposes.

According to the district census of 2000 the region has around 6,700 dug wells with an average depth around 20 meters below ground level (mbgl) and 4,800 shallow tube wells (10-15 mbgl) for irrigation purposes. The Figure 2.18 indicates the different irrigation sources in the catchment. Although there is a ban of surface water use the region, around 33 surface flow schemes have been recorded in one of the downstream mandals (Moinabad). This is a gross surpass over the conservation law of the osman sagar. This situation also states the presence of strong stakeholder conflict on the distribution and usage of the common water resource. And also the differences between the regional administrative decisions and that of the Hyderabad drinking water supply authority.

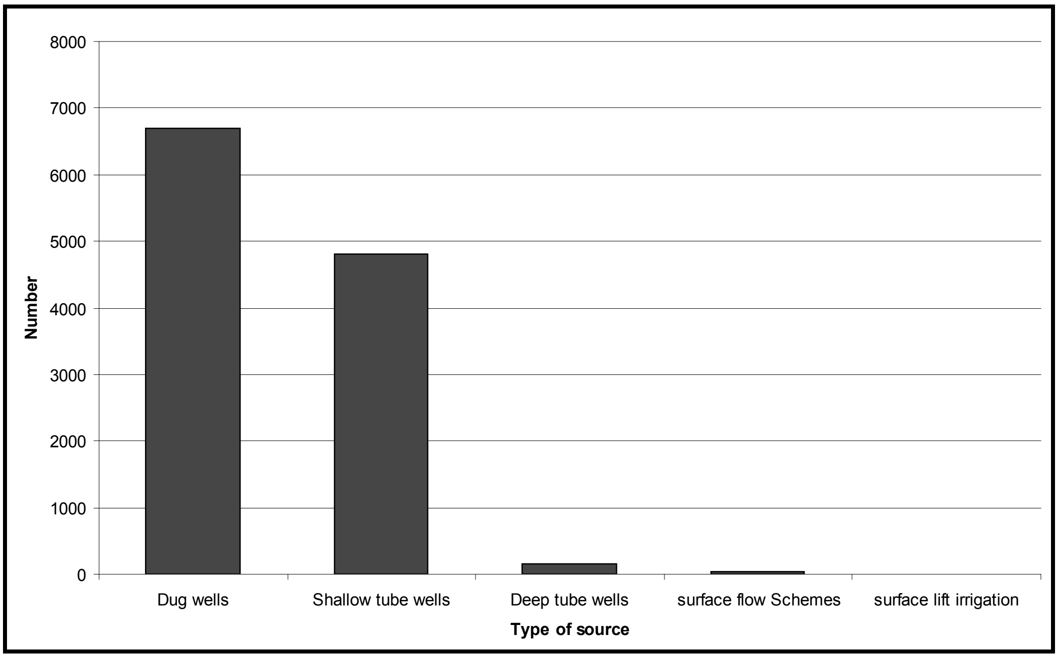

Figure 2.18: Sources of irrigation in the catchment (CPO, 2000)

The greaterr part of the catchment depends also on the groundwater sources for their drinking water needs. In total for all the six regional blocks, a total of 1,773 bore wells for drinking water have been recorded (Figure 2.19).

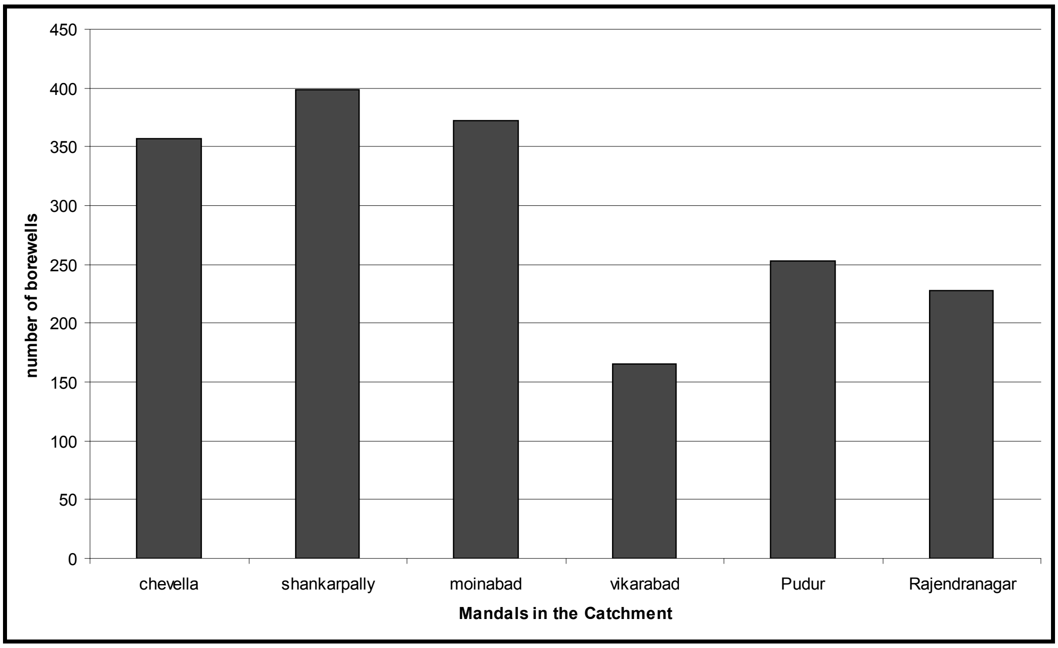

Figure 2.19: Drinking water wells in the catchment (CPO, 2000)

The use of groundwater has gained momentum from the early 1970s since drilling technologies improved. This was followed by the progress made in pumping equipment. In place of surface pumps, submersible pumps that can be installed at greater depths have been developed. This proved to be counter-effective. The advent of higher capacity drilling rigs capable of drilling to deeper depths, even in crystalline basement rocks, eventually results in drying up of wells located in weathered zones.

The indiscriminate drilling of boreholes and subsequent development of the resources has caused a decline in water levels and reduction in yields (Rao et al, 1998). The mean average groundwater levels within the catchment range between 10 mbgl – 20 mbgl (CGWB, 2007). In the catchment more than 70% of the available groundwater resource has been used up. Based on the groundwater exploitation, the central groundwater board has classified the mandals as safe (<70% exploitation of available net groundwater resource), semi-critical (70 – 90% exploitation of available net groundwater resource) and critical (>100% exploitation of available net groundwater resource). The mandals of Shankarpally and Moinabad have been declared over-exploited while the rest of the four mandals have been observed to be safe (CGWB, 2007).

The increasing exploitation of groundwater during the last two decades and deficit in the rainfall for the last few years has driven the farmers to a distress situation. In order to monitor the changes in groundwater, the central groundwater board established a network of observation wells and collects data four times a year, mainly in pre- and post-monsoon period (January, May, August and November).

2.5.1.8 Industrial Activity

As the catchment is in the conservation zone to safeguard the water quality of the drinking water, there is a restriction on the industrial norms. Thereby no heavy industries are being allowed to operate within a 10 km radius of the reservoir. Also the activities of the industries are being monitored by the State Pollution Control board (CPO, 2002).

2.5.1.9 River Musi

River Musi is an ephemeral river, which flows during the monsoon and is dry during the rest of the year. The River Musi emerges from Anantagiri hills in Vikarabad district situated at 661 meters above mean sea level. It flows for 70 km before reaching the reservoir of Osman Sagar. From there on, the river continues to flow east through Hyderabad city (**Figure 2.10**).

Figure 2.20: River Musi during monsoon season

Figure 2.21: River Musi during the summer season

On entering the city, the river changes its role to a mere receiver of urban runoff and wastewater, thus exhibiting a dual function. River Musi runs across the city of Hyderabad, dividing the city into the north and south division. Downstream of the city, the river has 24 diversion weirs, primarily built as irrigation structures, supporting the agriculture in the suburbs of Hyderabad. The Musi finally joins the River Krishna at Wazirabad, 40 km southwest of Hyderabad. That makes the total length of Musi to be 256 km (Ramachandriah et al., 2007).

2.5.2 Osman Sagar Reservoir

Reservoirs are man-made lakes, created for a specific purpose or multiple purposes. This creation makes reservoirs different in many aspects than lakes, thus, several aspects of their management are different (ILEC, 1991). Ecologically, reservoirs are considered as a transition between rivers and lakes, as most of them are built on a river by building a dam. Osman Sagar Lake is a typical example of such a reservoir.

Osman Sagar drinking water reservoir is one of the drinking water sources for the city of Hyderabad. Being located around 15 km from the Hyderabad city limits; it is also the nearest drinking water source. The reservoir was built in 1920 primarily as a flood mitigating structure and only secondarily as a drinking water source to the city. The reservoir was constructed after the devastating floods in 1908 during the regime of Mir Osman Ali Khan. The technical inputs for its construction were provided by Sir Mokshagundam Visvesvarayya, a renowned civil engineer (HMWWSB, 2007).

Figure 2.22: Osman Sagar drinking water reservoir in 2000

The reservoir is located between the coordinates 1723’ N and 7818’ E. It has a storage capacity of 124 Mi m³. It is spread across over 5 – 10 km², with a maximum depth at 32 meters (HMWWSB, 2005). The reservoir is a gravity based system, where the raw water withdrawal and supply to the treatment plant is only through gravity. This avoids energy consumption for pumping.

According to its installed capacity, the reservoir has been supplying an amount of 0.027 Mi m³ of water per day. However, the sedimentation rate into the reservoir of apprximatly around 2% annually has reduced the installed storage capacity of the reservoir. There has been very little effort in checking the sedimentation in the reservoir (Ramachandriah et al., 2007).

The installed capacity has been established to serve a population of 300,000 to 500,000. Hyderabad city has reached now a population of 6,100,000. On top of that, there has been a decline in water supply over the years due to reduced inflows (Ramachandriah et al., 2007).

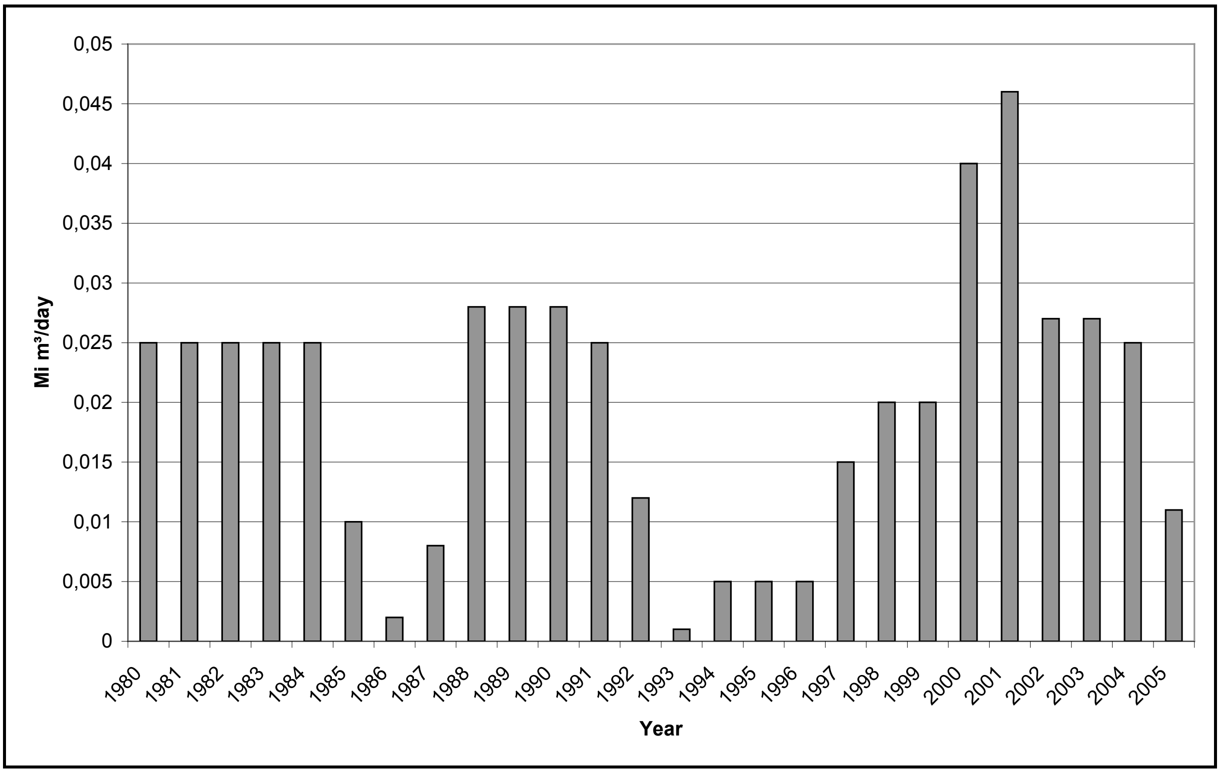

Figure 2.23: Year-wise drinking water withdrawal from Osman Sagar reservoir

The reservoir is mainly fed by River Musi and 19 other small streams. However, over the past years, the major inflows from the River have reduced drastically, resulting in slow depletion of the reservoir and also reduced drinking water supply (Figure 2.23) A study found that there has been a progressive decline in the percent of rainfall converted into inflows into the reservoir during 1961 to 1996, even though the rainfall patterns have not changed much. The Osman sagar area has recorded a mean of

694.50 mm of annual rainfall. The Figure 2.24 represents the rainfall trend over the reservoir since the year 1976.

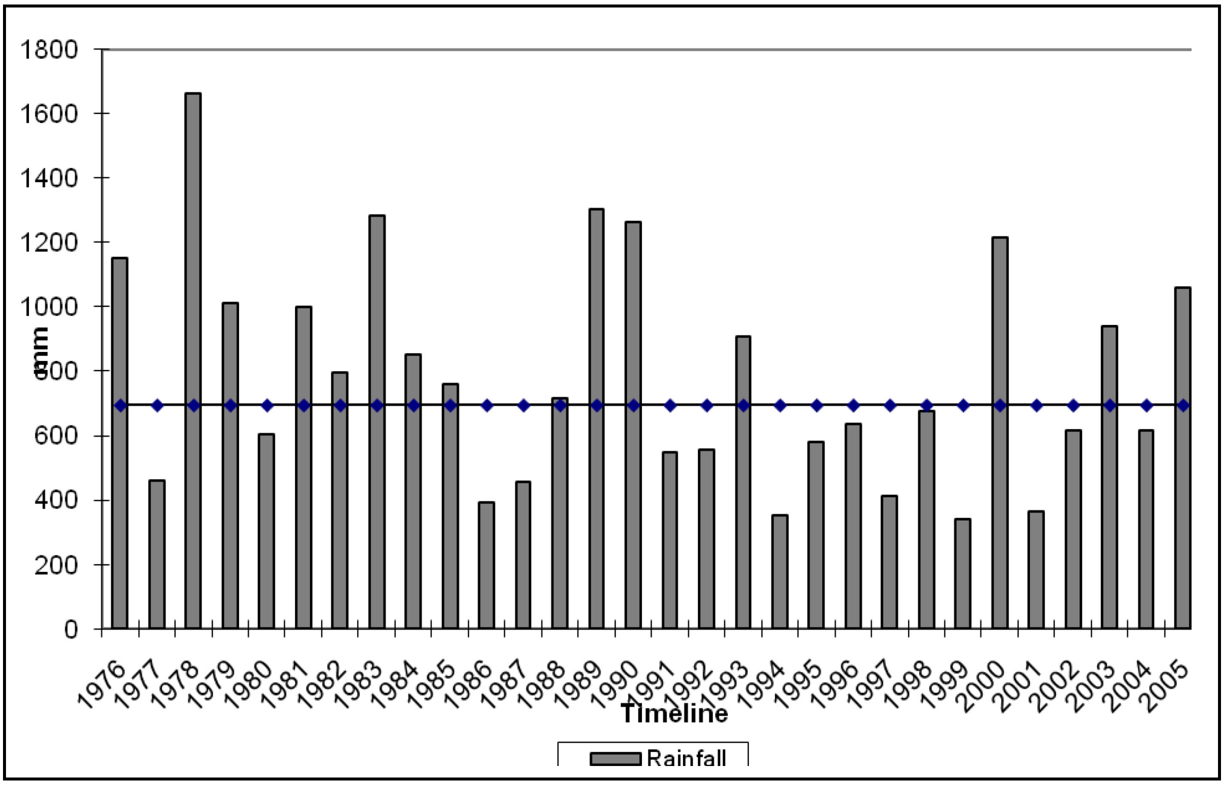

Figure 2.24: Annual rainfall trend over Osman Sagar reservoir

The frequency of surplus outflows from the reservoir (Figure 2.25) has reduced drastically in comparison to earlier decades. In the present decade, there has been no surplus spill from the reservoir, leading to the drying up of the river downstream the reservoir.

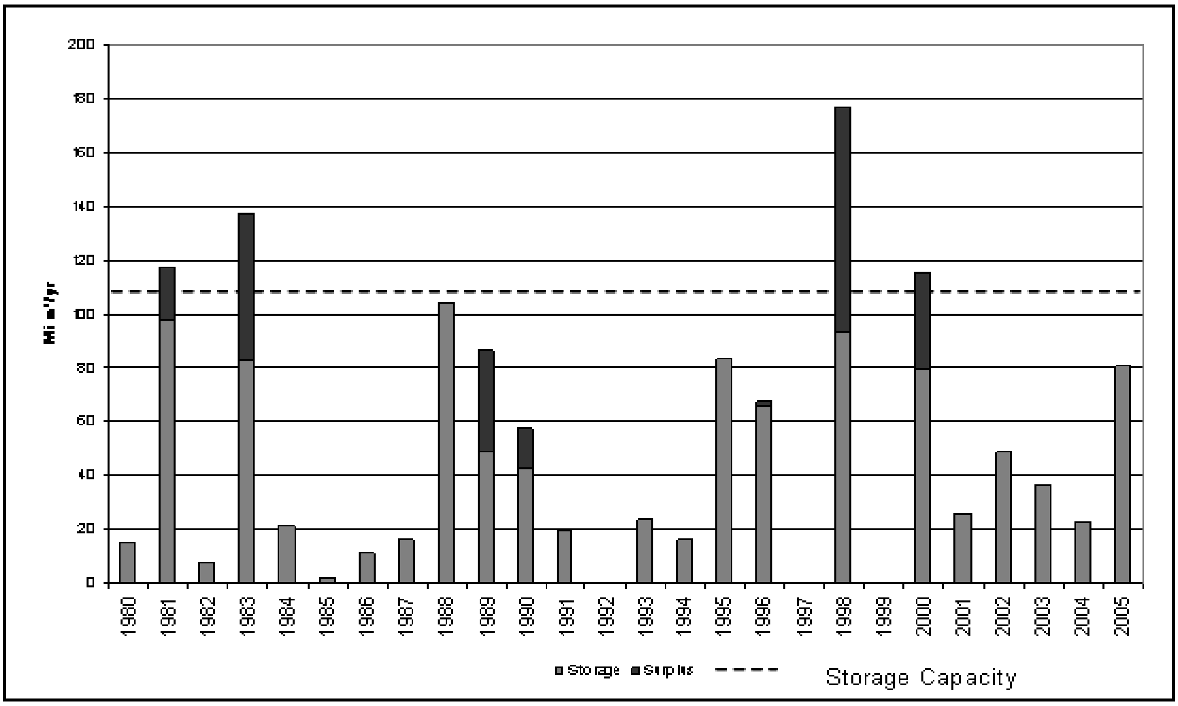

Figure 2.25: Surplus overflow from the Osman Sagar reservoir (HMWWSB, 2007)

Between the years 1980-2005, the reservoir has reached its full reservoir levels more number of times in the first years of the period compared to the second half. Based on this trend, a study projects that the reservoir may dry up completely by 2040 (Ramachandriah et al., 2002). Further, according to a world bank study, not only has the reliability of water withdrawal from Osman Sagar has declined but also there has been a loss of gross decline in its storage capacity due to siltation. According to the study, it is estimated that since the year 1988, the gross storage of the reservoir has been reduced to 12% (Saleth and Dinar, 1997).

Figure 2.26: Osman Sagar in the Year 2005

Additionally, there is the threat of urbanization within the catchment, the result of which would be increased wastewater inflows into the dried-up reservoir. The entire stipulated scenario is similar to the fate faced by the other 300 odd fresh water lakes around the city.

2.5.2.1 Water Quality Reservoir

Osman Sagar reservoir falls under category 'C' of the Primary Drinking Water Quality Standards, given out by the central pollution control board. The categorization of the primary water quality in India, is represented in Appendix 1. Category 'C' is the classification of a drinking water source which has the conventional treatment facility (i.e. sedimentation and filtration) and disinfection process (Ramachandriah et al., 2007).

It is important to highlight the fact that the standards do not specify the nature of the water body, as a lake or river. The reference is quite different from the regular European standards, where the water quality is more specific according to the type and kind of the water body i.e. surface water body and groundwater quality (EU, 2000). Thereafter, the utility factor of the source is decided. It is essential to understand that the water quality is largely dependent not just on the land use dynamics within the respective catchment, but also the very nature of the water body.

2.5.2.2 Conservation Measures: GO 111

In view of the importance of Osman Sagar for drinking water needs of the city, the HMWSSB constituted an expert committee to suggest ways and means to monitor the quality of water in the reservoir. After detailed discussions and field visits the expert committee submitted two reports making certain recommendations for the protection of the lakes.

In 1994, the state government issued a government order, the (Government Order) GO MS 192, prohibiting various developments within 10 kms radius of the lake. In 1996, after the second expert report, the government issued GO 111, modifying the earlier GO MS 192. Based on the satellite maps, an area of about 140 km^2 was recognized as a dangerous zone in the catchment area (GoAP, 1996).

The GO 111 stipulates prohibition of industries, major hotels, residential colonies and other establishments that generate pollution in the catchment of the lake. However, the GO permits residential developments in the zones identified as earmarked for residential purposes, subject to certain conditions to protect water flowing into the lake. Two such important conditions are to restrict the floor space index (FSI) to 105 and to keep 60% of total area as pen spaces in the notified 84 villages. The HUDA (Hyderabad Urban Development Authority) has been directed to take action for classification of 90% of the catchment area as recreational and agricultural which is inclusive of horticulture and floriculture. The HMWSSB has been directed to periodically monitor the levels of different fertilizers and pesticide residues carried into the lakes and review the results once in 6 months (GoAP, 1996).

Further, the connected respective agencies, such as APPCB (Andhra Pradesh Pollution Control Board) and the local government agencies were directed not to undertake any construction work, check damns, lift irrigation and storage reservoirs across the streams in the catchment area. The industries department does not allow industries to operate within the catchment area, according to the catchment conservation plans. Unfortunately none of the organisations and departments has acted upon various measures to protect the lakes (Ramachandriah et al., 2007). With the projected urban developments, such as the outer ring road development, international airport, the land use around the close vicinity of the lake has been permitted to change.

2.5.3 The Drinking Water Treatment Facility

The raw water from the reservoir runs through the raw water conduit for a distance of 15 km and reaches the drinking water treatment facility at Asif Nagar. The treatment plant is located at a distance of 14kms from the Osman Sagar reservoir. The raw water travels the distance through a raw water conduit, which is based on a gravity system. The treatment facility is designed to treat 0.2 Mi m^3/day of water and consists of three raw water treatment plants.

1. Pneumatic water treatment plant,
2. Paterson treatment plant,
3. Candy Treatment plant.

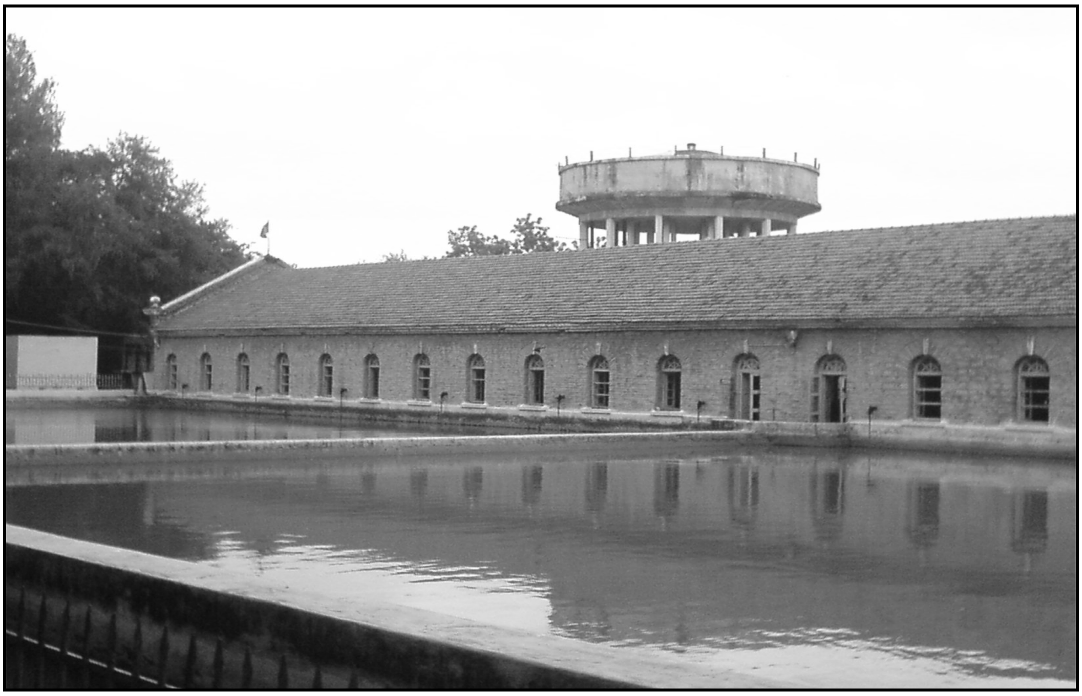

Figure 2.27: Raw water treatment facility downstream of Osman Sagar reservoir

Out of the three plants, the pneumatic treatment plant is not in use anymore. The treatment facility runs the Paterson and Candy (named after their manufacturer) treatment plants. The two treatment plants are designed to treat 0.04 Mi m³/day and 0.03 Mi m³/day of raw water. At present, the treatment plants are utilized under their capacities, water treatment is according to the reduced withdrawal.

The Patterson and Candy treatment plants include the following components (Figure 2.28):

- Alum dosing equipment,
- Settling tanks,
- Rapid gravity filters,
- Post chlorination.

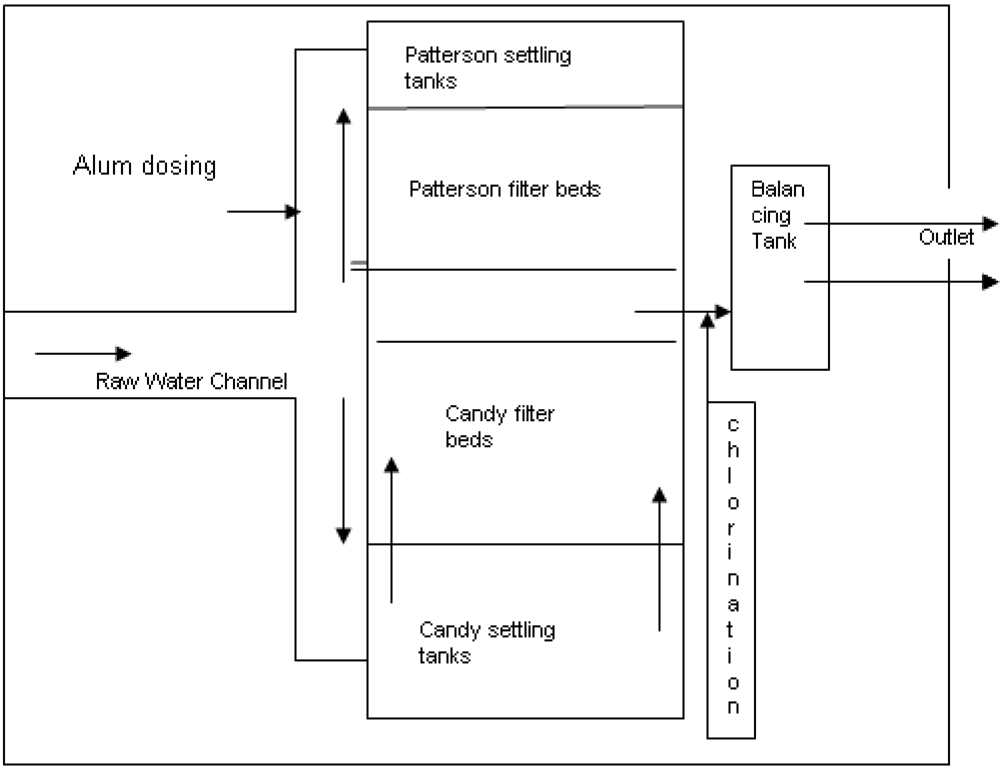

Figure 2.28: Schematic representation of the treatment facility

The raw water enters the treatment facility through the raw water channel. Before channelling the raw water to the primary settling tanks, the raw water is run over the slabs of alum at the inlet of the settling tanks. The raw water is then channelled towards the Patterson settling tanks and Candy settling tanks. Thereafter, the water is channelled into the rapid gravity filters (Figure 2.29). The treatment facility has a post-chlorination equipment, from which the dissolved chlorine is mixed with the filtered water. The treated water is then sent to the balancing tank before let into the distribution network of the city.

Figure 2.29: Rapid Gravity Filters at raw water treatment plant

The treatment facility has a water quality testing laboratory which runs raw water and treated water quality testing on a daily basis. The comprehensive monthly report is then sent to the main administration of the HMWWSB. The raw water quality testing is according to the primary water quality standards set by the central pollution control board (Appendix 1) and the treated water quality testing is according to the drinking water quality guidelines given by the WHO (WHO, 2006).

The primary water quality standards (Appendix 1) do not consider phosphorous. Phosphorous is not a drinking water parameter according to the WHO drinking water standards. However, it is an important parameter for surface water bodies, especially for lakes, as it is one of the decisive factor for eutrophication. Considering that the catchment is dominated by agricultural activity, measuring the phosphorous load from the catchment is essential.

3 Aim and Methodology

3.1 Problem Statement

Over recent years, Osman Sagar reservoir has been receiving reduced inflows from its catchment which lead to decreased potential drinking water withdrawals from the reservoir. There has been almost complete dependency on the storage of the reservoir. On the treatment side, the plant has been under utilized by 50% of its established capacity. Upon conducting field studies and expert interviews with the management and administration to understand the probable factors for reduced inflows into the reservoir, the following assumptions were brought up:

- Change in the rainfall trend,
- Increased groundwater development activities within the catchment,
- Increasing groundwater consumption in the catchment.

At this point, the role of the changes within the catchment and its impact on the reservoir needs to be identified. There is a need to carry out a scientific study to identify the probable causes for the present situation of reduced inflows.

Assuming a continuum of reduced inflows, the lake is heading towards stagnation, which could lead to a drastic change in its chemical-biological dynamics. The Osman Sagar reservoir faces a major threat of loosing its status as a fresh water source and its utility factor as a drinking water source.

3.2 Aim and Objectives

Scientific and practical experience on lake conservation reiterates time and again, that preventive measures are not only economical but also sustainable on long term basis. It is important to recognize the inter-linkages of the catchment, lake and treatment plant and view the whole as a single system. It is essential to understand the changes that precede lake degradation to ambitiously halt the process of fresh water degradation.

This study aims at identifying the factors, both natural and anthropogenic, affecting the water regime of the Osman Sagar drinking water supply system - beginning from the catchment up to the treatment plant.

The following objectives have been stated:

1) To understand the water regime of the entire water supply system and establishing the probable linkages amongst the climatic, geomorphologic and anthropogenic factors.
2) To give an overview of the nutrient loads in the catchment and in the reservoir as a quality perspective.
3) To develop a scenario of inflow pattern with respect to the land use changes.

3.3 System Specification

A system-level analytical approach has been adapted to realize the aim and objectives of the study. Thereby, the entire water supply system has been categorized in three sub components, based on their role within the system. Each component has been studied individually in order to identify and highlight the significant inter-linkages. The categorization is as follows:

I. Source-side analysis: The catchment
II. Storage-side analysis: The reservoir
III. Supply-Side analysis: The treatment plant

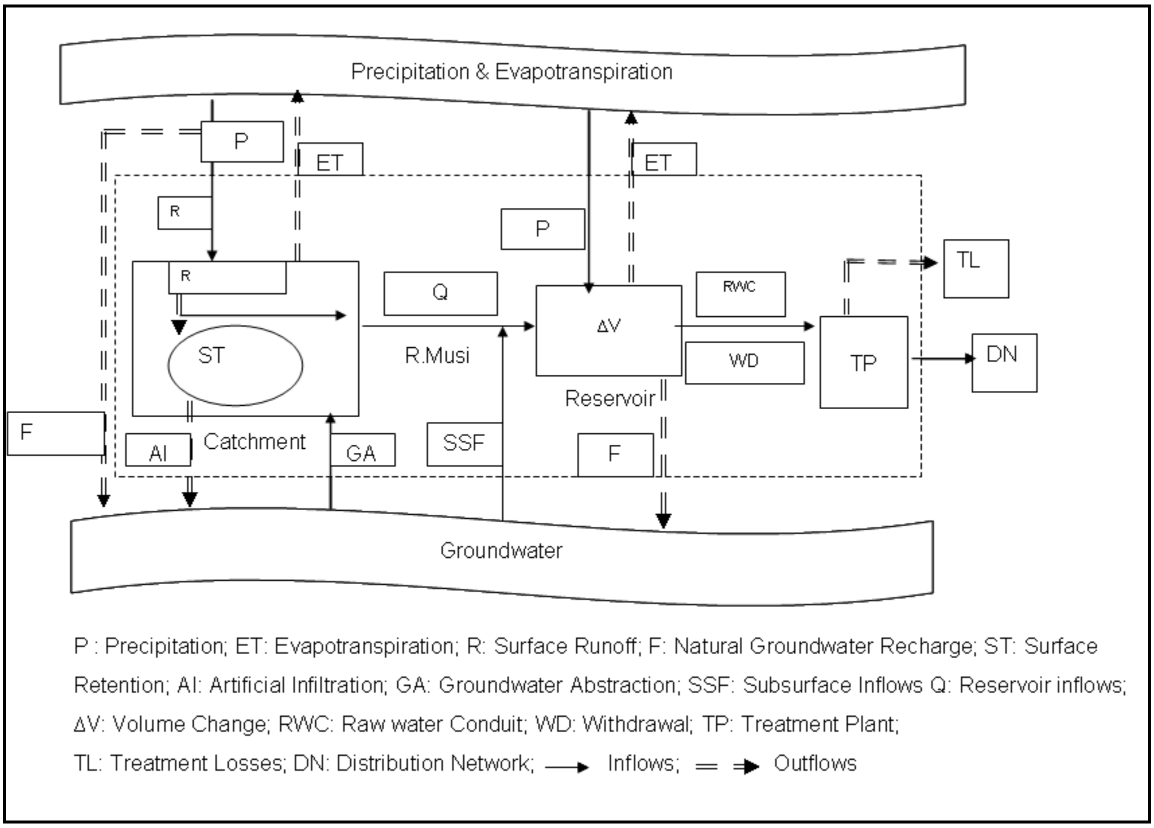

Figure 3.1: Schematic representation of the study area

Figure 3.1 represents the existing water flow convergences and divergent points within the Osman Sagar drinking water supply system. The straight arrows inwards represent the inflows, while the double lined arrow moving outwards represent the outflows. The River Musi carries the surface runoff to the reservoir as inflow, while the raw water conduit supplies the raw water to the treatment plant downstream. The different carrier channels (River Musi, raw water conduit) have been integrated within the respective sub-system (catchment, reservoir.)

The surface retention indicates the bulk volume of the potential fresh water that is retained within the catchment either through various surface storage structures or through artificial groundwater recharge activities. Field observations, expert interviews and secondary data analysis were carried out to arrive at the water balance for the supply system. However, considering the lacunae in the data availability for the groundwater interaction, the features such as the groundwater abstraction, artificial infiltration and subsurface inflows haven’t been included in the water balance.

3.4 Methodology

3.4.1 Hydrological Analysis

A simple water balance like any other water audit tool, determines the amount of water lost from a supply system due to both measurable and undefined reasons (CWC, 2005). The water balance in the present study aims at understanding the bulk movement of water through the system. The main effort is to identify the plausible linkages that affect the inflows into the reservoir. Further, it is an attempt to bring out a realistic understanding and assessment of the present performance level of the Osman Sagar supply system.

Advanced hydrological and water resources models rely on many of the same relationships as robust water balances. Sophisticated models are significantly more data Intensive than the basic water balance. These models strive for accuracy and spatially and temporally explicit output data (USAID, 2003). The water balance attempted in this study is primarily to understand the gross water regime within the system.

The water balance accounts for the stocks and flows of water in a geographic area. While the water balance is a mass balance model, temporal variability is the basis for the approach. Water balances are extremely useful in examining inter-seasonal and inter-annual trends in water availability.

I. Source-Side Analysis: Catchment

S = (P – ET – R – F – Q) **Eq. 3.1**

S	Surface Retention (m^3/yr)
P	Precipitation (mm/yr)
ET	Evapotranspiration (mm/yr)
R	Surface Runoff (m^3/yr)
F	Infiltration (mm/yr)
Q	Reservoir Inflows (m^3/yr)

II. Storage-Side Analysis: Reservoir

∆V = (Q + R- ET-WD) **Eq. 3.2**

∆V	Volume change of the lake (positive or negative m^3/yr)
Q	Total reservoir inflows (m^3/yr)
R	Precipitation over the lake (mm/yr)
E	Evapotranspiration from the lake (mm/yr)
WD	Water withdrawal (m^3/yr).

III. Supply Side Analysis: Treatment Facility

S = (WD – TL) **Eq. 3.3**

S	Supply to the distribution network. (m^3/yr)
WD	Raw water withdrawal from the reservoir (m^3/yr)
TL	Treatment and distribution losses (m^3/yr)

The parameters were equated to the units of Mi m3 per year. The water balance was carried out at two temporal levels: annual and monthly. The annual water balance has been carried out for the time period of 2000-2005, while the monthly balance highlights the trends in the years 2004 and 2005.

3.4.1.1 Source-Side Analysis: Catchment

The following sections presents the assumptions used in calculating different parameters of the hydrological equation (Eq. 3.1).

Surface Retention

The surface retention in the present study is assumed to be the part of the surface runoff that has been retained within the catchment. The entire catchment is under the State Watershed Development Program, which involves development of check dams across streams, small-medium scale surface storage structures and contour bunding. The development of these structures helps in reducing the rate of flow of surface runoff. The arrested surface flow is then made to either percolate into the groundwater or stored in the farm ponds. This results in reduced surface flows into the respective surface water streams and the river Musi in turn. Considering the relevance of these developments to the flow regime in the river Musi, it is essential to understand the volume of potential runoff that was retained within the catchment (USAID, 2003).

To cross-check the theoretical analysis, field observations, involving expert interview on watershed development and management in the study area, data on the storage spaces, have been carried out. In expert interviews with the Deputy Commissioner of Andhra Pradesh State Rural Development Department, the role of watershed development within the study area was discussed. The outcome of the discussion was classified information of the watershed development, in terms of the surface storage structures, check damns and other. The details will be discussed in the results section of the study.

Precipitation

The monthly rainfall data from the various rainfall gauge stations in the study area has been compiled for 5 years (2000-2005) to study the spatial and temporal distribution of precipitation. The data was gathered from the Indian Meteorological Department, Hyderabad division, which is responsible to record and compile the precipitation data at various rain gauge stations across the state of Andhra Pradesh. In reference to the study area, data was compiled for six rain gauge stations located within the catchment area. **Figure 2.10** shows the location of the rain gauge stations within the catchment.

Evapotranspiration

Evapotranspiration can also be determined by measuring the various components of the soil water balance. Fluxes such as subsurface flow, deep percolation and capillary rise from a water table are difficult to assess for short time periods. Data on these parameters need in depth and continuous field monitoring, which was out of scope for the present study. Therefore, these fluxes have been excluded from the equation. The methodology (FAO, 1998) has been modified to a simple mass balance equation as follows:

ET = (P - R – F) **Eq. 3.4**

ET	Evapotranspiration (m^3/yr)
P	Precipitation (mm/yr)
R	Surface runoff (m^3yr)
F	Natural groundwater recharge (m^3/yr)

Methodology as this can only give evapotranspiration estimates over long periods of time (FAO, 1998). Literature reviews on the study region and the field level experiments and observations conducted by respective hydrologists, geophysical research institutions, reveal that the potential evapotranspiration ranges from 1,600 mm to 1,700 mm, exceeding the rainfall over 100 % (Massuel et al., 2004).

Surface Runoff

The surface runoff is assumed to be the effiective runoff into the river Musi. The surface runoff for the catchment has been analysed using the Rational Method. The Rational Method is usually expressed in terms of the following equation (Hayes et al., 2005):

R = (CIA) **Eq. 3.5**

R	Peak flow in m^3/yr
C	Runoff coefficient (dimensionless)
I	Average rainfall intensity (mm/yr)
A	Area in km^2

Assumptions associated with the use of the Rational Method in the present study are that there has been no great difference in the land use changes within the study period. The characteristics of the land use have been therefore considered the same for the entire study period.

The runoff coefficient has been calculated by weighted average or different land use types with reference to the runoff coefficients relevant (Table 4.1).

The water balance was calculated for monthly and annual timeline. For annual balance, the surface runoff has being represented in Mi m³/ year; while on monthly lines it has been represented as m³/month.

Natural Groundwater Recharge

In the present study, natural infiltration from the precipitation has been considered. Under the monsoon type of climatic conditions prevailing in most parts of India, natural groundwater recharge, comprising percolation of a portion of the rainfall, is the major component of total annual recharge of the groundwater (Rangarajan et al., 2000). The catchment area falls under the semi-arid region, characterized by seasonal rainfall of a highly fluctuating nature, in both space and time.

The National Geophysical Research Institute (NGRI) conducted natural recharge measurements using tritium injection method. Results from 35 study areas located in different climatic and hydrogeological conditions suggest a linear relationship between rainfall and natural recharge for all the four major hydrogeological units of granites, basalt, sediments and alluvium. According to the regression analysis of the study the natural infiltration due to precipitation for the basalt region ranges from 8 to 10% (Rangarajan, 2000). The International Water Management Institute (IWMI) conducted a groundwater modelling for the catchment region and the study indicates that 9% of the annual rainfall dissipates as natural infiltration (Massuel et al, 2004)

3.4.1.2 Storage-Side Analysis: Hydrological Balance of the Reservoir

The amount of inflow from all sources and the water losses determine the water balance of a lake or reservoir. The water balance for the reservoir has been adopted from methodologies for lake studies of the International Lake Environment Committee (ILEC) (ILEC, 1991).

3.4.1.2.1 Parameters and Data Generation

Precipitation directly on the surface of the lake is especially important for the water balance of large lakes. For example, the equatorial Lake Victoria receives more than 90% of its water from the direct precipitation (ILEC, 1991).

The amount of surface water runoff to a lake is highly variable and depends on the morphometry, nature of the soil and vegetation cover of the drainage basin. Most important are the rainfall patterns. A high surface runoff can be caused by heavy rains in a relatively short time together with a heavy inflow of nutrients as a result of soil erosion.

The data on the reservoir inflows, evapotranspiration and the withdrawals have been gathered and compiled from the HMWSB, which is the key agency in regards to the ownership and maintenance of the Osman Sagar drinking water supply system. The water quality information of the reservoir has also been gathered from the same department.

3.4.1.3 Supply Side Analysis: Treatment Plant

The drinking water treatment plant of Osman Sagar drinking water supply system is the oldest treatment plant of the city of Hyderabad. The plant has been designed to treat a volume of 0.027 Mi m^3/ day. At present, the plant runs at only 50% of its installed capacity.

The water balance for the treatment plant has been carried out based on simple input and output analysis, considering the losses to the system, through the raw water conduit and within the treatment plant. According to the expert interviews with the Managing Director of HMWWSB, the losses within the supply and treatment plant have been considered as 20% (Reddy, 2007).

Extensive literature review was carried out prior to the field visits to the reservoir and its respective treatment plant. The field visits were essential to validate the aspects brought up by the literature review. The field visits included complete survey of the treatment plant, expert interviews with the General Manager and the Chief-engineer of the treatment plant. Considering the age of the treatment plant, around 80 years, there were a lot of questions posed to understand the conditions and functioning of the treatment plant across the time.

3.4.2 Nutrient Load Analysis

In regards to the changing land use dynamics and the intensity of the agricultural activities upstream of the reservoir, there was a need-felt to highlight the water quality scenario at the catchments and also present the corresponding water quality picture at the reservoir level.

As the catchment area is predominantly rural, with agriculture as primary anthropogenic activity, analysis of the nutrient load is essential to understand the probable influences on the water quality and the health of the reservoir at two different contexts. They are:

At present context

- Considering the present context of reduced or no inflows from the catchment, it is assumed that any amount of nutrient load from the catchment will be retained within the catchment. This phenomenon may not pose an immediate threat to the reservoir, however would influence the soil quality and the groundwater quality.
- In the event of storm of high intensity rainfall leading to sudden increase of surface runoff, the reservoir may at once receive a high amount of soil nutrients that may pose a threat to the water quality and alter its trophic status.

As a future perspective

- In the context of improved catchment management and thereby improved inflows from the same, the analysis of the nutrient loads would specify the probable sources and loads of nutrients and other harmful substances like the pesticides that pose a threat to the reservoir and its water quality. In this context, the nutrient load would help us in understanding the essential measures, deterministic towards choosing the right technological and management strategies.
- Further, the near future threat is indicated as the urban push factor from the continual urban expansion of Hyderabad city. This would alter not just the land use changes within the catchment, but also the corresponding water regime and the quality aspects of the same. For instance, increased use of water, leading to increased wastewater discharge and its respective safe disposal would be of high importance.

Towards these assumptions, the case study highlights the nutrient loads and their corresponding sources within the catchment. Based on the FAO methodology on Assessment of Soil nutrient analysis, case study of Andhra Pradesh was adapted to this study and was carried out for the years 2004 and 2005. According to the FAO methodology (FAO, 2003), the following equation was considered:

Nutrient Load = (A x EF) + (B x 0.10) – TR **Eq. 3.6**

A Total fertilizer nutrients used in the zone for all the crops (kg/year)
EF Fertilizer use efficiency factor (N = 0, 45, P = 0, 25, K = 0, 70)
B Nutrient addition through organic manures
TR Total nutrient removed by crops.

Considering the non-availability of data on the organic manures, the nutrient addition through farm manure was not considered in this study. Further, the nutrient load presents the agricultural contribution to the soil nutrient content within the catchment. The role of input factors such as the atmospheric deposition, biological fixation and their corresponding outflows require a detailed scientific nutrient flow analysis. As this methodology is out of the scope in the present study, information from other scientific studies and other literature studies carried out within the catchment region have been mentioned in this study.

The primary information on the crop production and the harvest data was gathered from State Department of Statistics (CPO, 2004 and CPO, 2005), where the relevant data from the study region was compiled. The mineral fertilizer input data was taken from the FAO data on the fertilizer usage and consumption for India (FAO, 2005). The mineral fertilizer usage for different crops, in the state of Andhra Pradesh, has been taken into account (Table 3.1).

Table 3.1: Mineral fertilizer usage (FAO, 2005)

Crop groups	Crops (kg/ha)	Fertilizer use (kg/ha)	Average fertilizer use (kg/ha)
Cereals	Rice	103.50	89.65
	Wheat	105.50	
	Maize	59.60	
Pulses	Soghum	58.50	36.2
	Pigeon pea	20.90	
	legumes	15.30	
Sugarcane		207.10	207.10
Vegetables	Potatoes	10.00	34.50
	Tomatoes	24.50	
Others	Oil seeds	70.00	70.00

Typically, a mineral fertilizer is a combination of binders, fillers and the actual nutrient. The percentage combination of the three differs from product to product thereby enumerating the nutrient uptake by the plant a gross estimate. In regards to the output, the nutrient uptake through the harvest is considered as a major output. The nutrient output from various crop produce was estimated according to the nutrient removed by respective crop (FAO, 2005). Different crops were grouped under the categories of cereals, pulses, vegetables, sugarcane and others. Cereals include paddy, wheat and maize. The leguminous crops have been grouped under the category pulses. As the nutrient removal is dependent on the yield from different crops, the annual harvest production details were gathered from the Chief Planning Officer (CPO) of the region. Further, the data was also crosschecked with other research findings in the same area and short span discussions with the farmers, in certain areas of the study area. Table 3.2 represents the nutrient removal by different crops that was considered in the present study. Please refer the Appendix 2 for the detailed nutrient removal by different crops.

Table 3.2 Nutrient removal by different crops (FAO, 2005)

Crop	Nitrogen (N) Kg/ha	Phosphorous (P) Kg/ha	Potassium (K) Kg/ha
Cereals	64	13	35
Pulses	105[2]	7	35
Sugarcane	60	22	125
Vegetables	60	22	125
Others	74	9	40

3.4.3 Scenario Development

During the course of expert interviews with the administration of the HMWWSB, scholars from the scientific and research institutions in Hyderabad, questions were posed as to the fate of Osman Sagar reservoir with an assumption of the continuum of the present state of affairs. Towards this, two major answers were given:

- The lake being used as storage tank, for the fresh water being pumped from other distant surface water sources and continues being a drinking water source.

- Considering the cumulative effect of escalating urban expansion and the massive infrastructure projects taken up by the city, that the reservoir would face the same ill fate like the rest of the fresh water sources, that surround the city of Hyderabad, which are either going dry or eutrophic due to nutrient inflows.

In either of the two options, thereby, there is a need to understand the systems behaviour, in terms of water regime, under the changing land use conditions. Evidently there is a need to highlight the corresponding change in the water quality dimension too.

Supply augmentation by tapping new, distant and multiple use water sources often disturbs sectoral allocation and causes intersectoral water conflicts (Saleth and Dinar, 1997). To avoid these costly and unsustainable options, it is important to review and scientifically analyse the probable options to revive the reservoir. The study carries out a scenario development with different intensities of surface retention, under present climatic and land use conditions. Land-use and land-cover changes may have four major direct impacts on the hydrological cycle and water quality. They can cause floods, droughts, and changes in river and groundwater regimes, and also affect quality (Rogers 1994). On this basis, the following scenarios were developed, with respective assumptions:

- Analysing water regime, at different surface retention intensities, under present state of land use conditions (represented in terms of runoff coefficient) and similar rainfall pattern (the rainfall pattern within the study period has been considered.)
- Analysing the water regime within the study system, under higher extent of urbanized land use conditions (represented by the runoff coefficient as 0.6), under same rainfall patterns as in the study period.

The various scenarios will be discussed in the discussions section of the report.

4 Results and Discussions

4.1 Hydrological Analysis

4.1.1 Source-Side Analysis: The Catchment

The surface runoff from the catchment is one of the main sources of reservoir inflows. Any influences on the water regime within the catchment influences the reservoir inflows. The parameters in the classical hydrological balance equation (Eq. 3.1) were analysed individually before arriving at a water balance for the catchment. The water balance is a volumetric analysis indicating the bulk movement of water across the system. The balance is represented in Mi m^3 in the report.

4.1.1.1 Precipitation

Precipitation is the primary natural supplier of water to a basin. Its characteristics describe the supply of water to a basin, a portion of which reaches the basin outlet as surface runoff. Amount and duration of the precipitation are the most important to describe intensity and frequency of the precipitation (Hayes et al., 2005).

The precipitation data was gathered from the rain gauge stations from all the 6 regions to understand the spatial distribution of the rainfall. The precipitation data was gathered from the Indian Meterological Department (IMD) for the years 2000 to 2005. The rainfall data is recorded for every day. As the present study focuses more on the timescale of monthly and annual, corresponding data has been considered.

The overall average precipitation within the study period has been recorded to be around 780mm. The minimum rainfall (average within the study period) was recorded in the Moinabad region, while the maximum was recorded in Shankarpally region. The Figure 4.1 shows the rainfall trend across the study period.

The available water from rainfall for the catchment has been calculated by multiplying the precipitation by its corresponding area of the political region where the respective rain gauge station is situated in. The available water through precipitation for the catchment is represented in the Figure 4.2

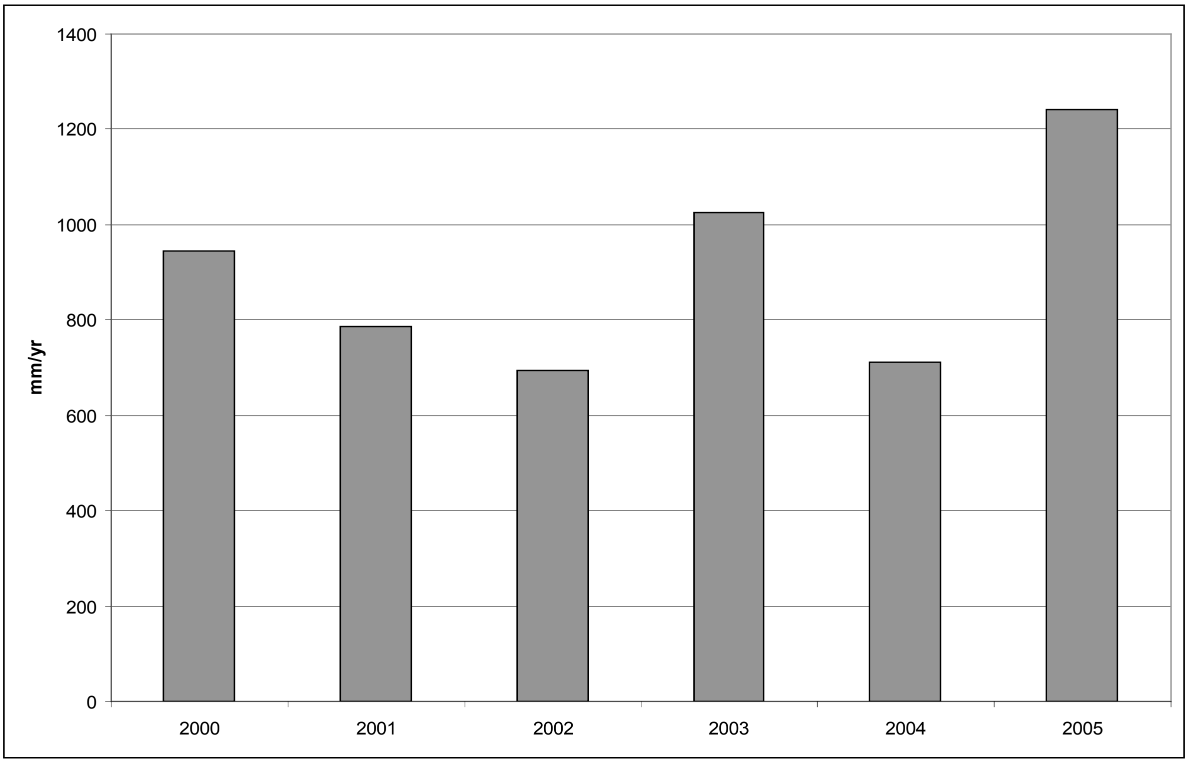

Figure 4.1: Inter annual rainfall variation within the catchment

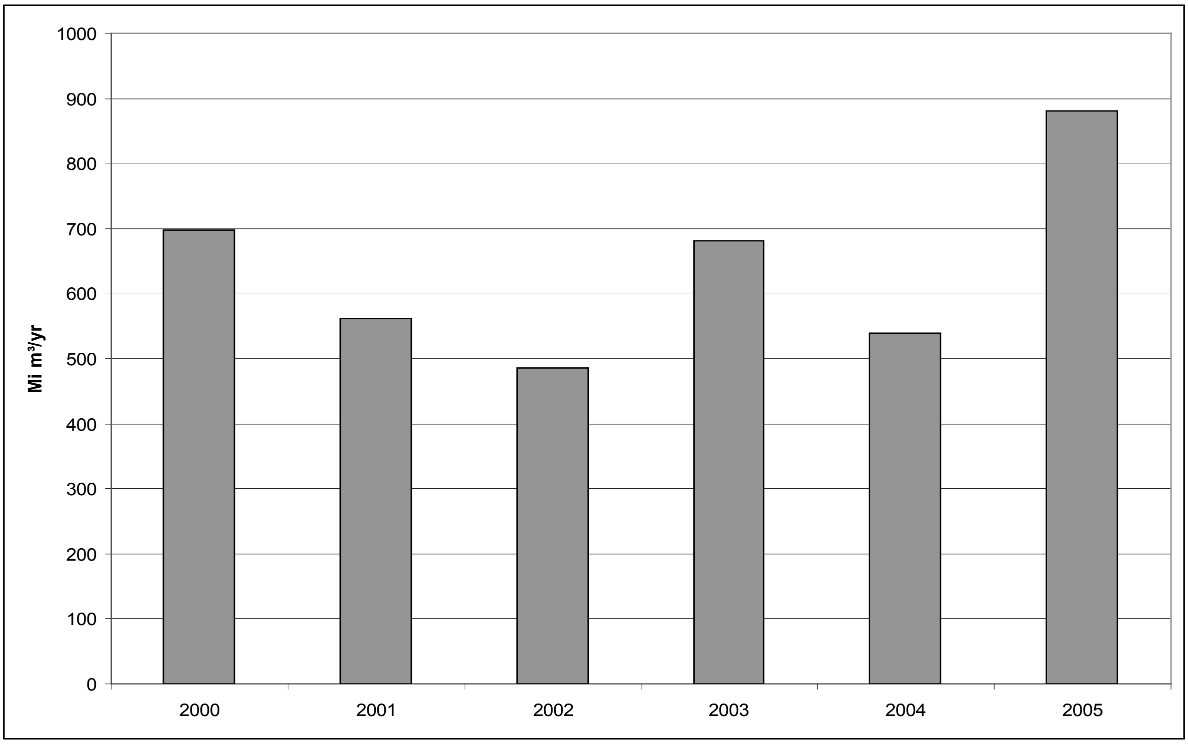

Figure 4.2: Volumetric estimation of precipitation in the catchment

Frequent droughts and wet years of high intensity rainfall are characteristics of this region. The IMD classifies rainfall as surplus, normal and deficit, if rainfall deviations from mean average rainfall are >+20, ±19 and < -20% respectively (Gaur et al, 2008). Based on this categorization, the rainfall trend within the study period has been analyzed accordingly.

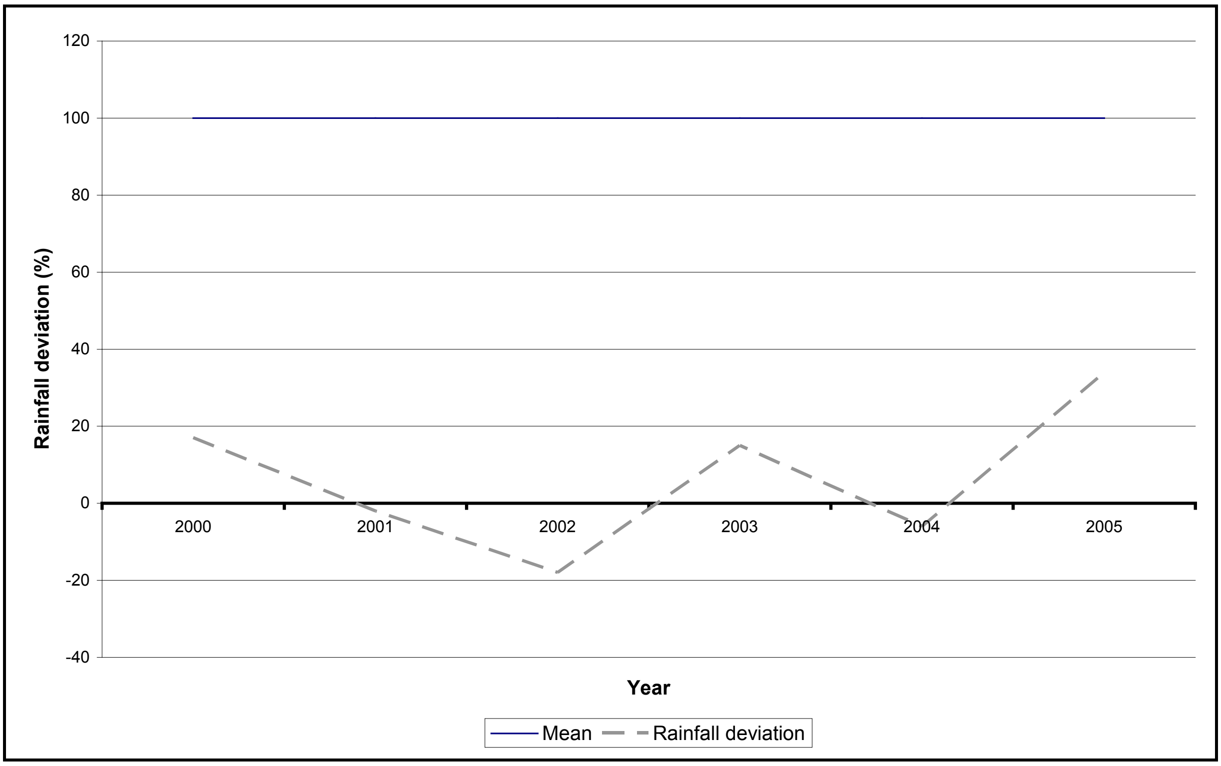

Figure 4.3: Precipitation deviation during the study period (2000 – 2005

The catchment area does not show a large variation from the mean average rainfall during the study period. The year 2000, 2003 are considered normal rainfall years, with rainfall showing a positive deviation of 17%, 15% from the mean average rainfall, while the year 2005 was a surplus year with a positive deviation of 34%. The years of 2001, 2002 and 2004 were considered lean periods, exhibiting a negative deviation of 2%, 18% and 6% from the mean annual rainfall. This is a similar trend to the rainfall trend across the State of Andhra Pradesh, where the period of 2002 - 2004 was declared drought year with a negative deviation of 34% from the mean average rainfall (CGWB, 2007).

It is the distribution of the rainfall within the year determines the corresponding availability of water in the region. The region receives rainfall from the south-west monsoon, mostly during the months of July to September (70 – 80%). The retreating monsoons from the North-East winds, deliver around 20-30% of the total annual rainfall (Figure 4.4)

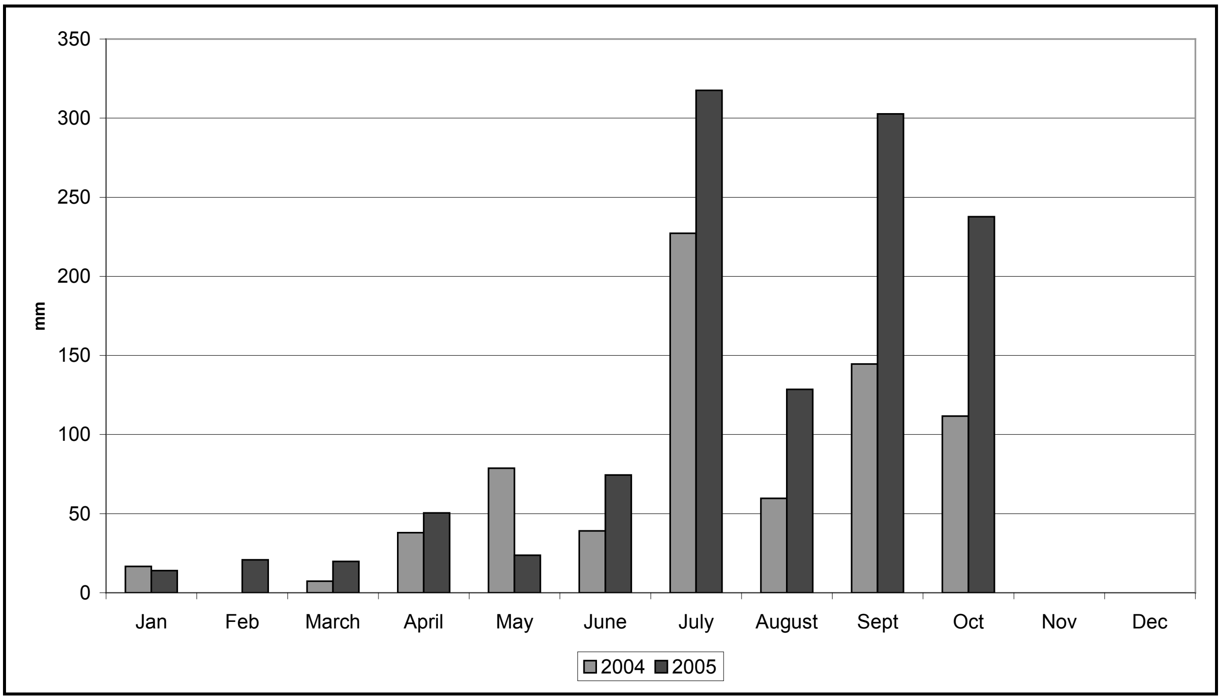

Figure 4.4: Monthly variation in precipitation in the catchment in 2004 and 2005 (CPO, 2004 and 2005)

The ephemeral behaviour of the River Musi (the principle channel for the reservoir inflows) is largely dependent on the very distribution of the rainfall across the year. The monsoon period is also the priority period to harvest the available precipitation either through infiltration or through surface retention activities across the catchment.

4.1.1.2 Evapotranspiration

Acording to the equation 3.2., the annual evapotranspiration for the study area has been estimated and is presented in the Figure 4.5. The average annual evapotranspiration has been estimated to be around 47% of the total precipitation.

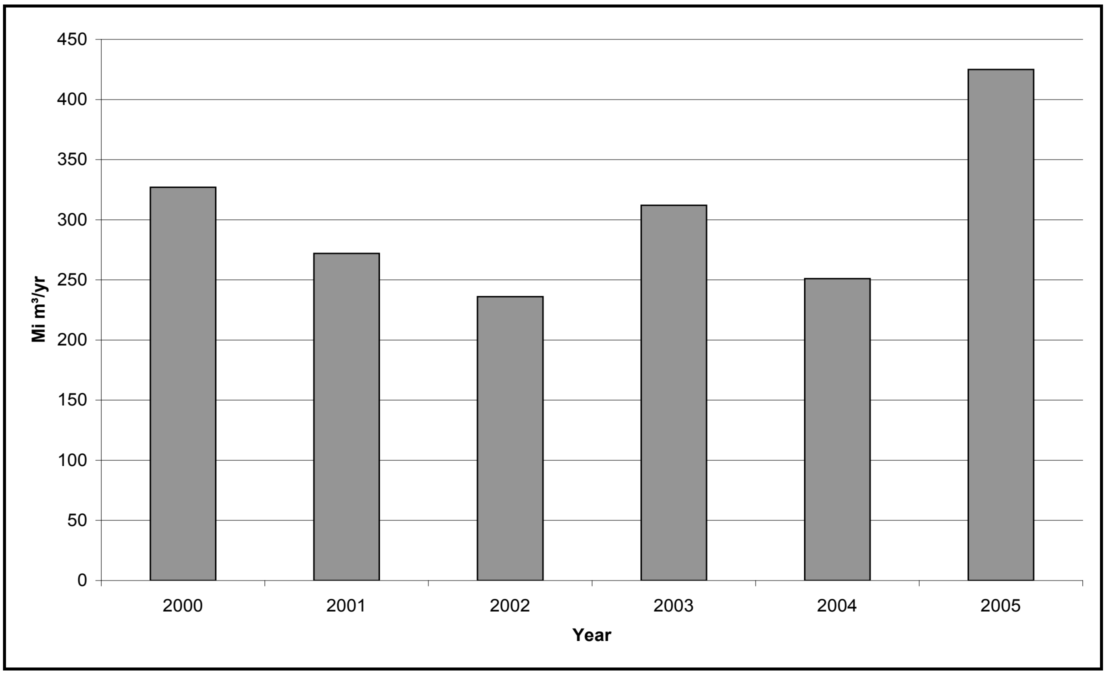

Figure 4.5 Estimated evapotranspiration for the catchment within the study period (2000-2005)

The catchment being in the semi-arid climatic area, experiences potential evapotranspiration 1600mm to 1700mm per year.

4.1.1.3 Surface Runoff

Runoff is that part of the precipitation that reaches the reservoir as stream flow at a concentrated point. Two broad categories of factors affect runoff precipitation characteristics and basin or watershed characteristics. Precipitation characteristics include type, duration, amount, intensity, frequency, and distribution. Basin characteristics are size, shape, topography, soils, geology and land use.

Catchment shape and topography are key basin characteristics controlling the routing of runoff to the basin outlet, and primarily control the timing of the peak, and to a lesser extent, the magnitude of the peak flow. Soil properties determine to a large degree the infiltration rate, storage, and release of the precipitation from the overburden. Soils affect the amount and type of vegetation, which also influence the infiltration rate. For instance, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types.

Land use and modifications to the natural surface by practices such as deforestation, mining, and farming, as well as structures such as dams, bridges, channels, and pavement also can have a significant effect on the runoff from a basin.

In the present study, the surface runoff is assumed to be the effective runoff into the river Musi, which is the primary feed to the Osman Sagar reservoir. Further, the surface runoff has been estimated with the assumption that no significant land use changes have taken place within the catchment. This was cross checked with the land use records with the respective government agencies, which verifies that the changes have been seen only within the net agricultural area, where the changes were seen mostly between fallow and Net Area sown. The reason being, that in the absence of groundwater irrigation, the small and medium scale farmers left the agricultural land as fallow land, especially during the lean rainfall period. The runoff coefficients for different land use catergories has been represented in the Table 4.1 With these aspects into consideration, the weighted average runoff coefficient for the region has been calculated to be 0.4. The runoff coefficient was calculated not considering the existing check dams within the catchment.

Table 4.1: Land use categories and their corresponding runoff coefficients (USDA, 1986)

Land use type		Runoff Coefficient
Forests	Forests	0.16
BAUCL	Barren and Uncultivable land	0.40
LPNAU	Land Put to Non-Agriculture use	0.45
PP	Permanent Pastures	0.25
Misc. Tree	Miscellaneous Tree cover	0.25
Cul Waste	Culturable Waste land	0.16
Current Fallow	Agricultural land left fallow for the present year	0.40
Other Fallow Land	Fallow land other than the current fallow	0.40
Net Area Sown (NAS)	Agricultural land in use in the present year	0.65

According to the rational equation (Eq. 3.5), the surface runoff has been estimated to be around 43% of the total precipitation available. The Figure 4.6 represents the annual runoff for the region, during the study period.

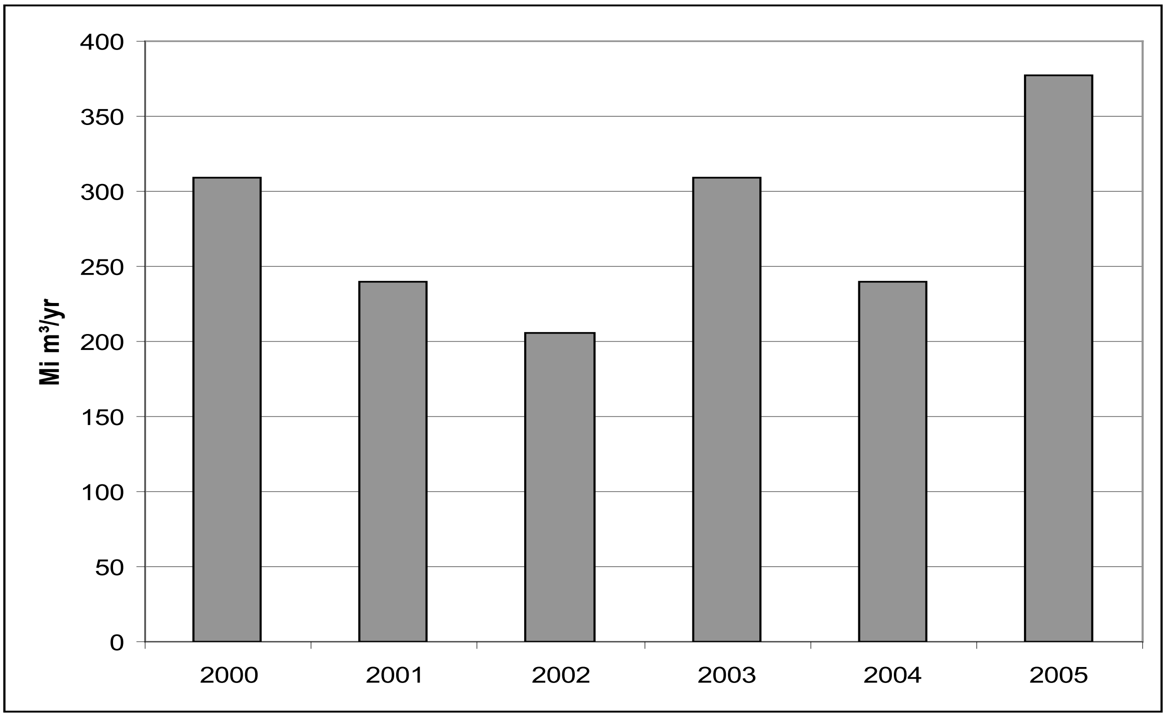

Figure 4.6: Annual surface runoff in the catchment

In terms of volume, maximum surface runoff in this period was recorded in the year 2005, as 377 Mi m³, while the least was in the year 2002, as 206 Mi m³.

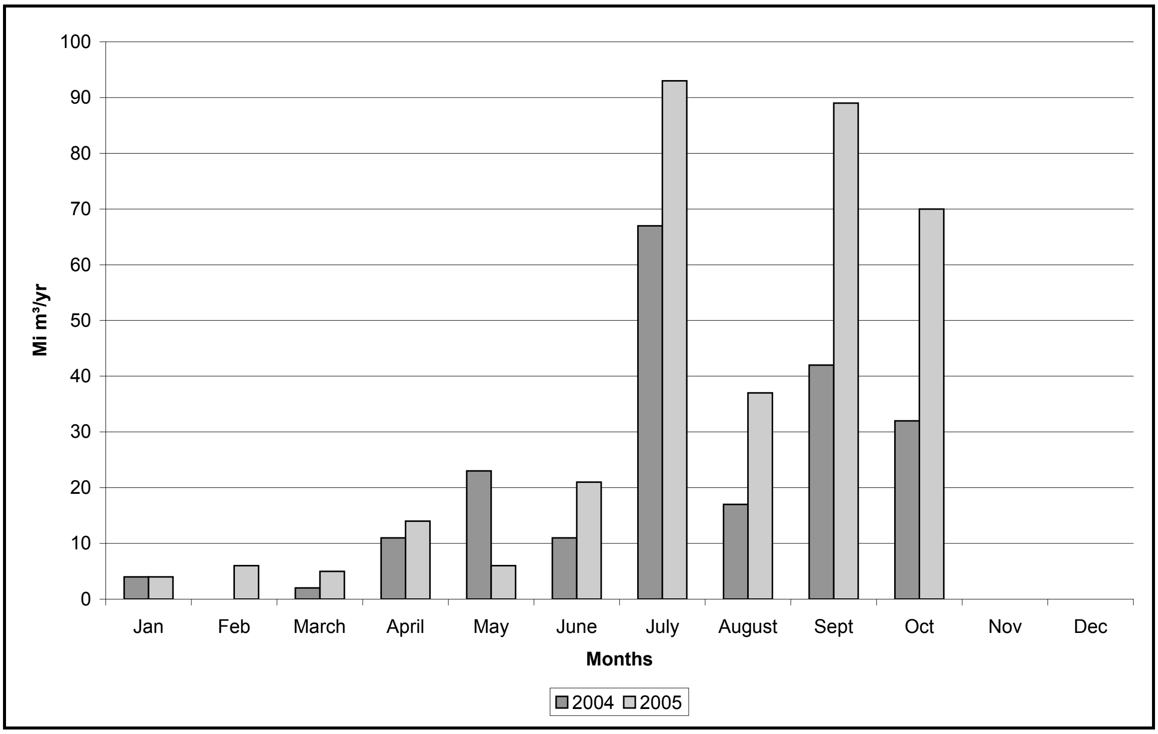

Figure 4.7: Monthly variation of the surface runoff in the catchment in 2004 and 2005

Figure 4.7 represents the monthly variation of surface runoff within the catchment. It has been observed that almost 80% of the annual runoff is met during the monsoon period of July-October. The 20% of the annual rainfall received during the dry season is lost to the evapotranspiration, due to high temperatures.

The period soon after the dry season, experiences poor soil moisture conditions. The field level studies and observations conducted in one of the micro-watershed within the catchment reveal that the first few monsoon rainfall events during the months of June, July did not cause any runoff. The runoff events start during the month of August and the runoff is dependent on the intensity of the rainfall event (Wani et al., 2006).

High intensity short duration rainfall leaves less scope for infiltration and more runoff. Efforts towards reducing the runoff and utilizing these sudden rainfall events are being carried out through effective watershed development programs. According to a study conducted in one of the micro-watersheds in the catchment area in the year 2000, it has been observed that there is a significant reduction in runoff from the treated area (area with the watershed development) over the untreated area (area without the watershed development) (Wani et al., 2004). In a normal rainfall year (2000), significant reduction in runoff from the treated watershed (45% less than the untreated portion) was observed. Even during the sub-normal rainfall year (2001) significant reduction in runoff volume (29% less than the treated area) was recorded.

The monsoon period is marked by high intensity rainfall and at times the region can receive almost 30% of the total annual rainfall, in a single spell of rain, which is mostly for a day or two. At such events, the area witnesses a heavy surface runoff, which would bring about a sudden increase in the reservoir inflows. It is essential to study and include the daily rainfall events in the reservoir management plans.

4.1.1.4 Natural Groundwater Recharge

The monsoon period is characterized by high intensity rainfall. The first few spells of rain, during the month of June do not yield any potential surface runoff. The rain is usually lost of the soil moisture or to the infiltration. As the frequency and intensity gears momentum from the months of July to September, the area witnesses frequent flash floods. According to the field study conducted by ICRISAT in the year 2000 at one of the micro watershed within the catchment, the area received 30% of the total annual rainfall in a single day (Wani et al., 2006).

The natural groundwater recharge process from the precipitation for the catchment has been analysed according to the studies conducted by NGR on the natural recharge process for various geological provinces in India. It has been observed that a linear relationship between rainfall and natural recharge exists for all the four major hydro geological units of granites, basalt, sediments and alluvium. According to the study, a certain minimum rainfall requirement is required to initiate groundwater recharge the minimum value for basalt has been mentioned as 355mm/year (Rangaranjan et al., 2000).

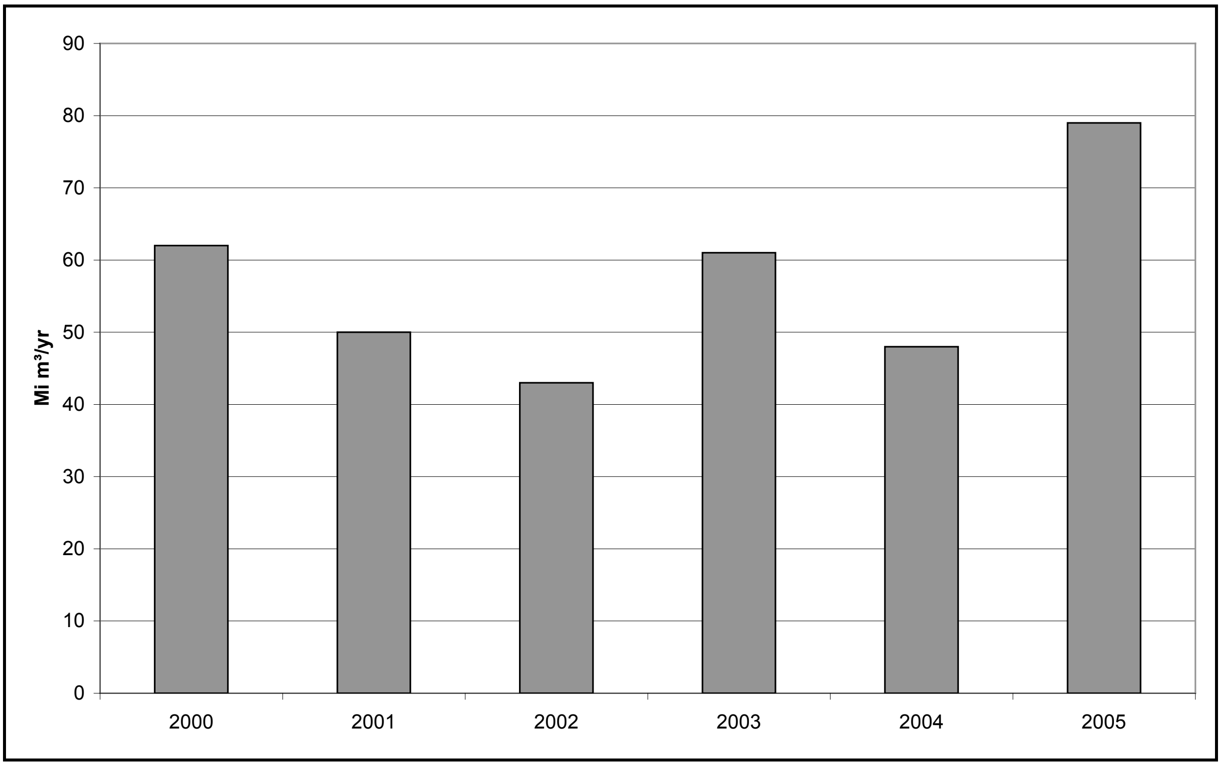

Figure 4.8: Trend in annual natural infiltration in the catchment

In order to monitor the groundwater recharge process the Central Groundwater Board established a network of observations wells and collects data four times a year, in the months of January, May, August and November. According to the their data and observations, the fluctuation in groundwater levels is a combined affect of meteorological, geomorphic and lithological characteristics coupled with exploitation by human intervention (Rao et al., 1989). The water level during the pre-monsoon and post-monsoon periods ranges from 19.13 and 13.01 mbgl (meters below ground level) (CGWB, 2007).

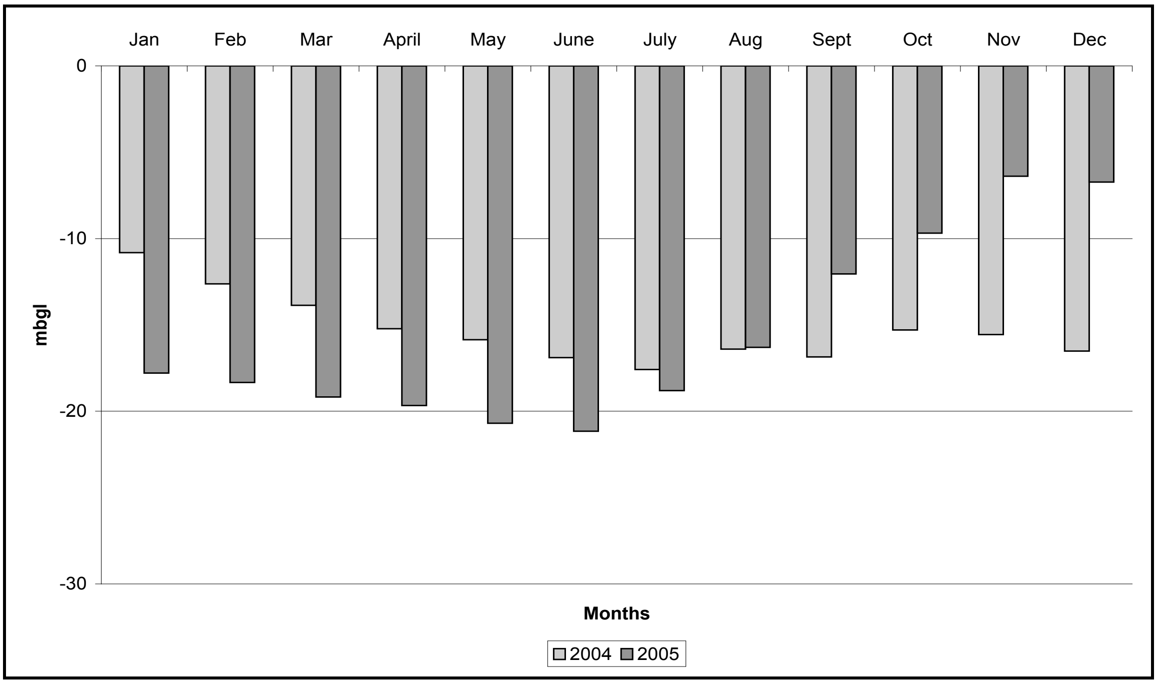

Figure 4.9: Monthly variation of the groundwater levels in the catchment in 2004 and 2005 (CGWB, 2007)

During pre-monsoon period (May) of the year 2005, depth to water level varied between 2.78 and 26 metres with general depth to water level range of 10 to 20 metres below ground level.

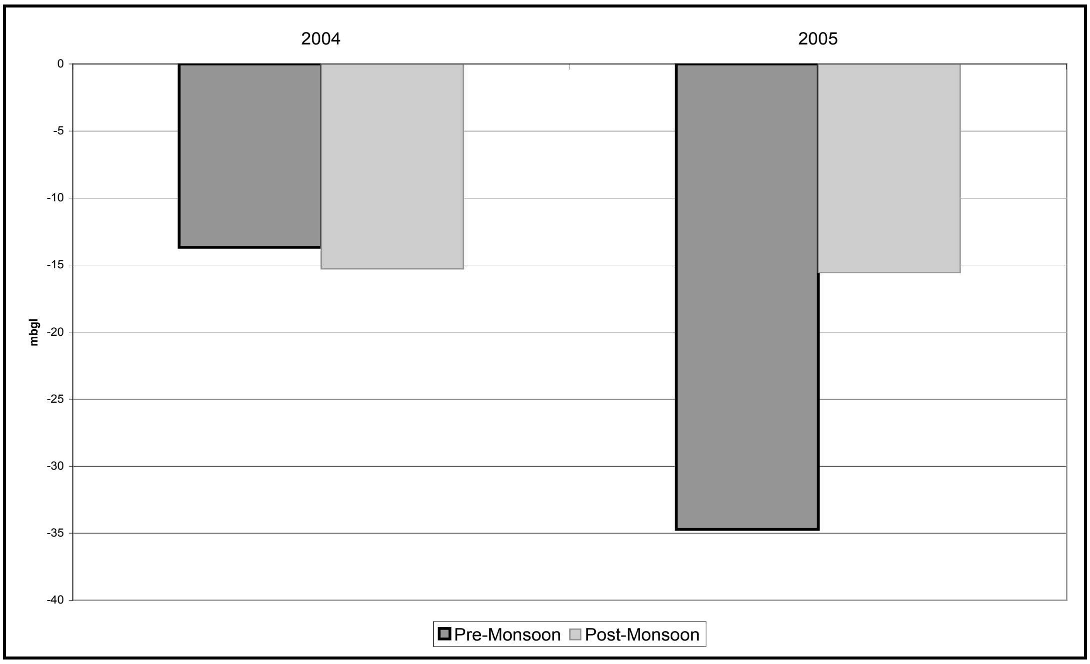

Figure 4.10: Seasonal trend of the groundwater levels in the catchment (CGWB, 2007)

Around 30% of the observations wells in the catchment region lie within this range. A small percentage of the wells recorded levels more than 20 metres below ground level. In the post-monsoon, the depth to water level ranges from a minimum of ground level (G.L.) to maximum of 19.76 m.

4.1.1.5 Surface Retention

The surface retention indicates a percentage of water that has been retained within the catchment. Considering the ongoing watershed activities within the catchment, the surface retention is considered as the cumulative impact of the process involving the increasing the groundwater recharge within the catchment through the surface storage structures (that have been built as part of the watershed activities).

The catchment region is significantly agricultural in its land use. Agriculture is mainly supported by groundwater irrigation and partly by the direct rainfall. According to the surface water conservation law within the catchment, the use of water from the surface water streams and the river Musi is not permitted. Thereby, the dependency is completely on the groundwater sources. The over dependency on the groundwater resources over a period of time has led to a drastic fall of the groundwater table within the catchment. In the recent years, addressing this issue, extensive watershed activities are being carried out to improve the groundwater sources through the integrated approach of watershed development came into focus through various Rural Development Programs within the State of Andhra Pradesh.

It has been observed that a major part of the geomorphologic, hydrological, rainfall and land use pattern in the region provides ample scope for locating suitable locations for the construction of various types of artificial recharge structures like the farm ponds, check dams and percolation trenches.. As part of the District Poverty Alleviation Program, the state government of Andhra Pradesh had taken up extensive watershed development program.

The development of watershed activities within the catchment region of Osman Sagar is a clash with the surface water conservation law (GO 111). To understand the impact of the watershed activities on the surface runoff into the river, the surface retention was analysed to be a product of the hydrological equation (Eq. 3.1). The surface retention within the region in the last 5 years has increased from 65% to 100% of the surface runoff.

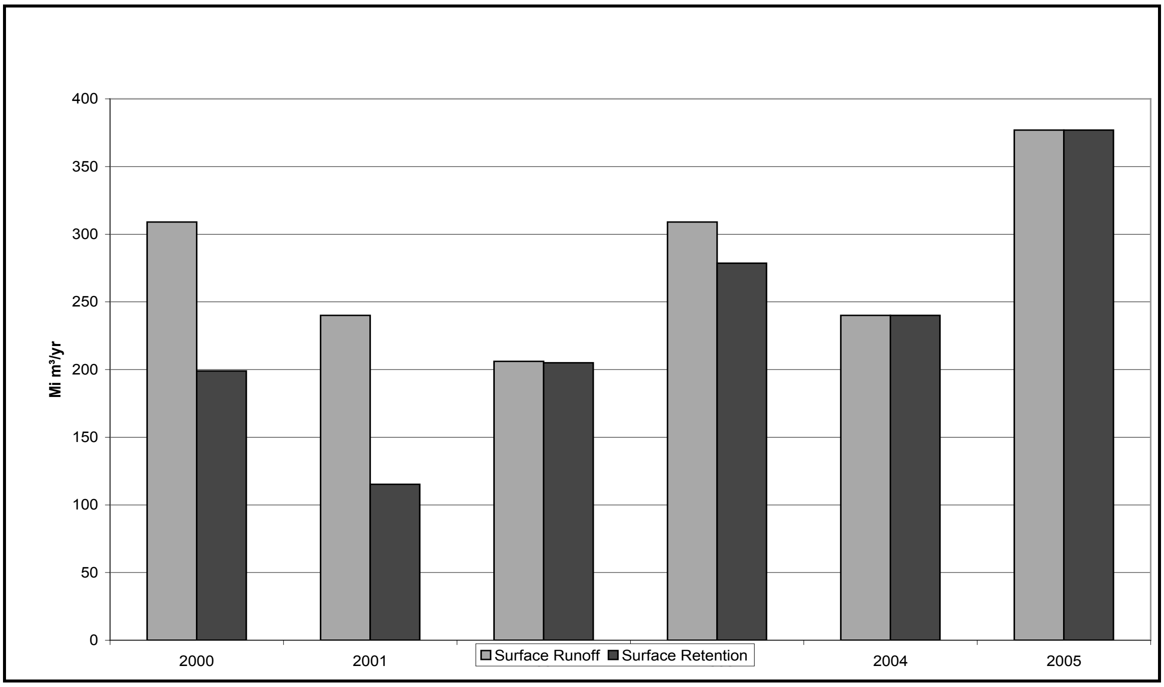

Figure 4.11: Annual trend of the surface runoff and surface retention in the catchment

In the continuum of the programs, a series of integrated watershed development activities have been taken up as branch of the rural development programs, extensively since the year 2000 (Das, 2008).

Figure 4.12: Check dam in the catchment (Wani et al., 2003)

The watershed development, recharge works have been taken up by the District Water Management Agency under the government run program called NEERU-MEERU (Water–You). The structures constructed under these schemes are percolation tanks, check dams (Figure 4.12) and farm ponds. Expert interview reveal that the for a standard watershed unit of 500 ha, around 20 surface storage structures and gully plugging structures are a nominal figure. The capacity of the surface storage structure ranges from 128 M^3 to 3000 M^3. So far, in the entire administrative region of Ranga Reddy district (which is the grosser part of the catchment area) about 2385 structures are under execution (Das, 2008).

Increasing surface retention: Impact of watershed development within the Osman Sagar catchment

Due to variations in seasonal rains during the crop growing period, crops may face drought and sometimes water logging due to torrential downpours causing runoff. In order to conserve rainwater, minimize land degradation, improve groundwater recharge, increase crop intensity and crop productivity a watershed management approach was adopted

The watershed development has led to significant changes in land use. 1160 artificial percolation tanks built on the seasonal stream network were listed within the catchment, in the year 2000. Now, nearly 70% of the basin cultivated of which 45% is irrigated. Around 60% of the water for irrigation is supplied by groundwater extraction (Massuel et al., 2004). The groundwater extraction is mostly during the monsoon (July - August) and the post –monsoon season (October – December).

The soil and water management measures in the treated watershed included field bunding, gully plugging and check dams across the main water course, along with improved soil, water, nutrient and crop management technologies. Untreated areas represent farmers' practices without any technological intervention.

According to the field level studies conducted by Institute for Crop Research in Semi-Arid Tropics (ICRISAT) in a micro watershed present within the catchment, It has been observed that, runoff volumes from watershed development area was significantly lower during all the runoff events (small, medium and large storms). It has been observed that from the micro-watershed (treated) runoff was 50% lower than from the area of conventional agricultural practices or without any watershed development (Pathak et al, 2002).

In general, during low runoff years the differences between the treated and untreated watersheds are very small. During a good rainfall year, i.e., 2000, a significant difference in runoff was observed between treated and untreated watersheds. Soil loss was measured from treated and untreated watersheds during 2001, and a significant reduction in soil loss (only 1/3) was found from treated compared to untreated watershed.

The region is also marked by events of high intensity rainfall (Wani et al., 2003), where a single spell of rain can cause higher amounts of surface runoff in shot span of time. For instance, the rainfall on 24th August 2003 alone accounted for about 70% of the total annual runoff (Pathak et al., 2002). Events such as these would leave less scope for infiltration process.

The high intensity agriculture and escalating demand for groundwater irrigation over a long period of time has led to depleting groundwater levels within the catchment area (CGWB, 2007). The watershed development activities taken up in the catchment area worked towards harnessing the runoff, for artificial groundwater recharge. According to the scientific study conducted by IWMI on the Osman Sagar catchment region, the simulated data for artificial recharge suggest around 11%, while the natural recharge from rainfall accounts for 9% (Massuel et al., 2005).

Studies conducted by ICRISAT also indicate that the watershed development activities have improved the groundwater level and yield in the wells significantly. Often runoff events during the early part of the rainy season recharge the groundwater level in the wells near the check-dams. The availability of water from the well enables farmers to plant on time without reducing the growing period and also encourages them to increase the area under cultivation due to availability of additional water for irrigation (Wani et al., 2003).

Field studies conducted at the micro-watershed within the catchment by ICRISAT reveal that the watershed development practices could improve the rainfall contribution to the groundwater up to 27% of seasonal rainfall (taking the specific yield of the aquifer material as 4.5%) (Wani et al., 2004). Owing to the success of improvement in the groundwater levels around 60% of the water for irrigation is currently supplied by groundwater extraction (Massuel et al., 2004).

4.1.2 Storage-End Analysis: Reservoir Water Balance

Within the study period, the reservoir witnessed a drastic decrease in the inflows, thereby making the reservoir mostly depend on the direct rainfall it receives. Under the normal rainfall conditions, the reservoir is fed 80% by the river inflows and 20% by the direct rainfall (Ramachandriah et al., 2007). It has been observed that the reservoir inflows have decreased from 54% in the year 2000, to 27% in the year 2005. Thus, exhibits a thorough 50% reduction within a span of 5 year period.

The water balance for the reservoir has been conducted through the hydrological equation given out by the guidelines from the ILEC (Eq. 3.2). Accordingly, the Table 4.2 represents the water balance for the Osman Sagar reservoir for the period between 2000-2005.

Table 4.2: Water balance for the Osman Sagar Reservoir

Year	Q	R	ET	WD	Δ V
2000	110	42	32	40	80
2001	124	12	37	47	54
2002	0	13	9	27	-23
2003	30	22	13	27	13
2004	0	15	10	25	-20
2005	0	25	25	11	-11

Note the values are in Mi m³

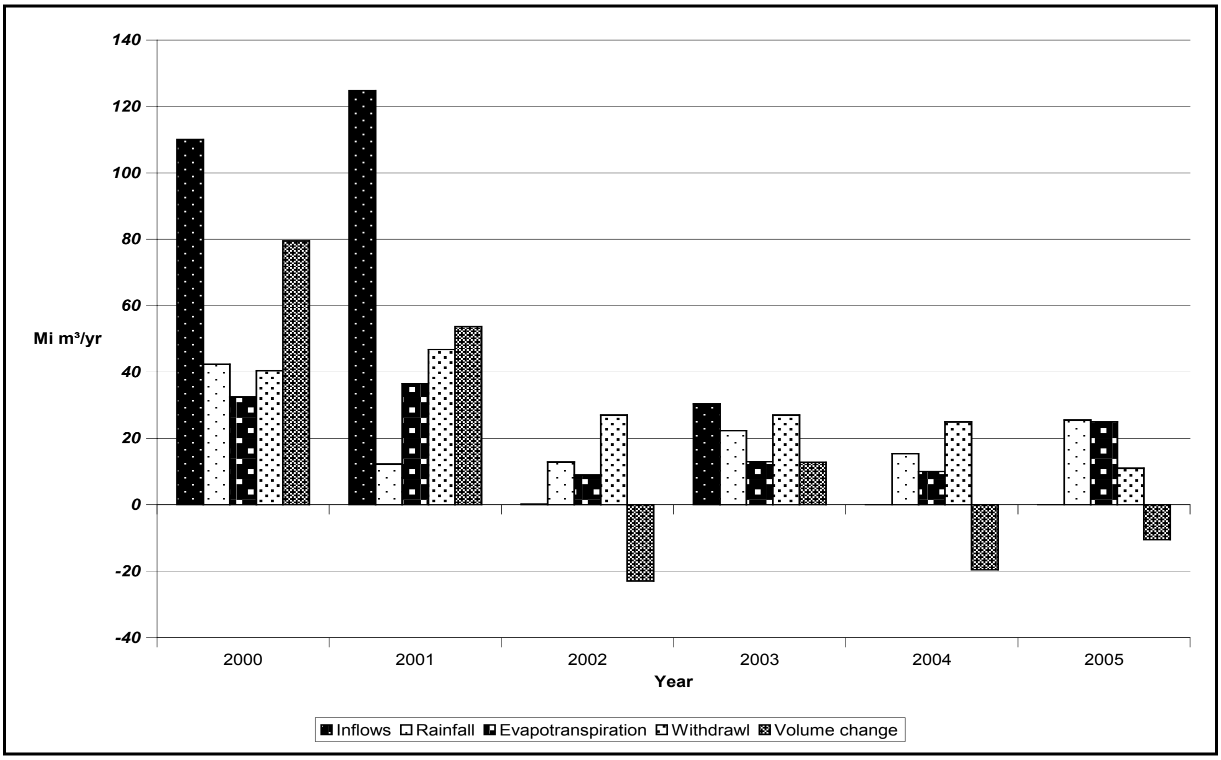

Figure 4.13: Annual water balance of the reservoir

The study period witnessed a normal year and a continuous drought period from the year 2002-2004. In this period, the reservoir was completely dependent on the inflows received in the previous years of 2000-2001 and direct rainfall that it received in the years 2002 and 2004.

Though the year 2005 was a year of surplus rainfall, the reservoir did not receive any inflows from the River Musi. Thus the reservoir was completely dependent on the on the direct rainfall it received. The monthly variation was studied for the years 2004 and 2005. The Figure 4.14 and Figure 4.15 show the water input (inflows and the direct rainfall) and the volume change for the Osman Sagar reservoir for the years 2004 and 2005.

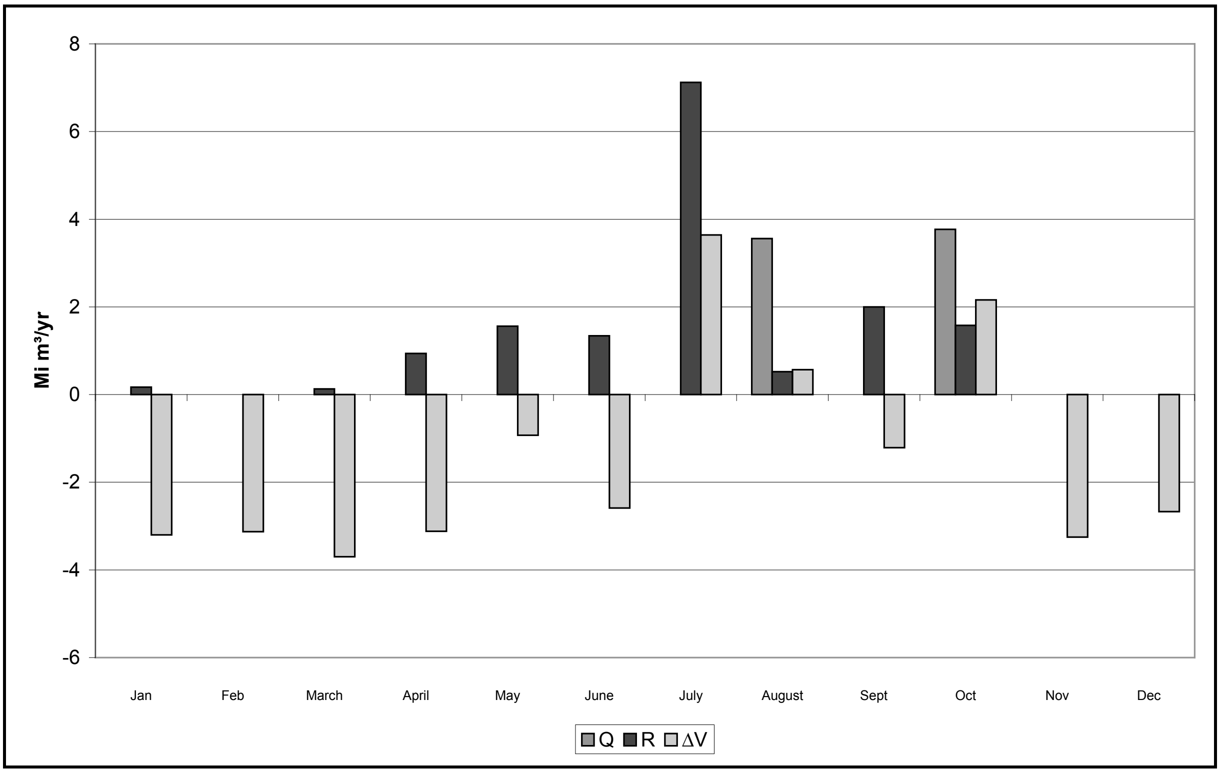

Figure 4.14: Monthly water input and volume change in Osman Sagar for 2004

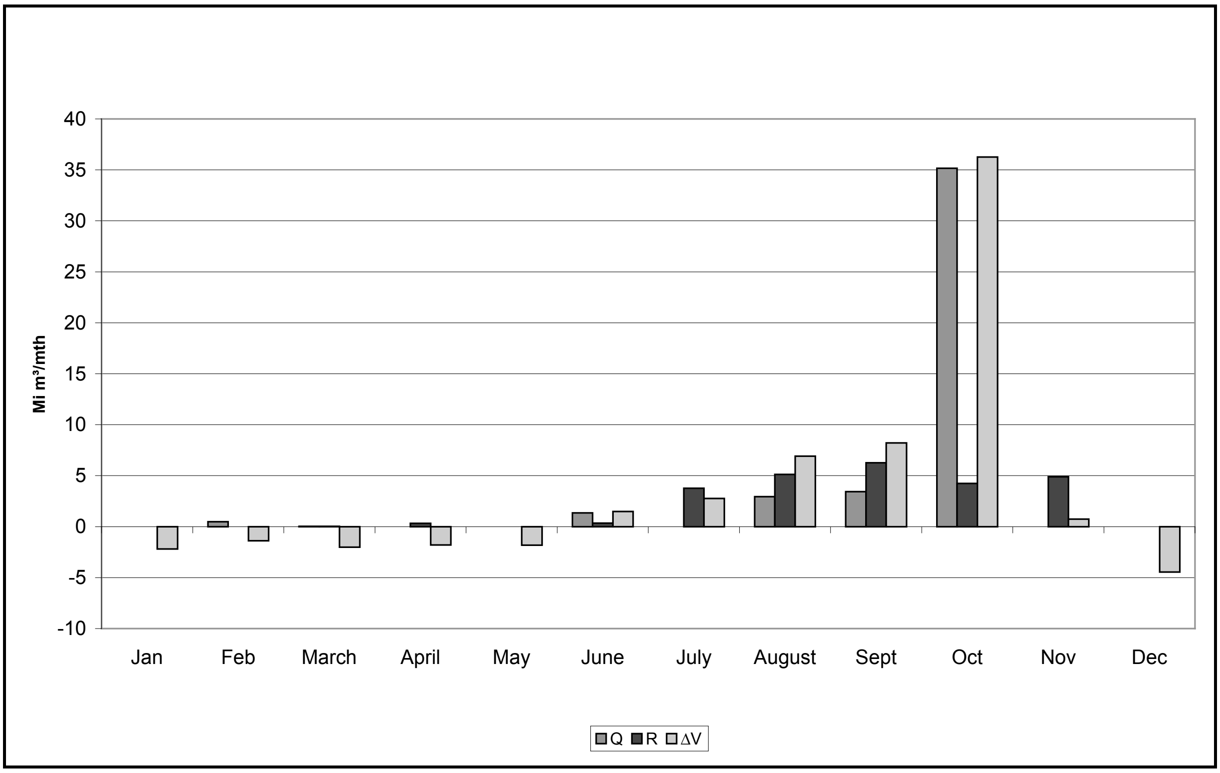

Figure 4.15: Monthly water input and volume change in Osman Sagar for 2005

The water balance also indicates that as the inflows reduced, the reservoir depends completely on the direct rainfall it receives during the year. This makes the water supply to be totally dependent on the available storage in the reservoir. The Figure 4.16 refers to the cumulative volume change of the reservoir within the year 2005. The volume change indicates that the reservoir has been mostly stagnant throughout the year except for the period of July to November. This trend is a normal behaviour of the reservoir considering the ephemeral nature of the River Musi which is the primary source of inflows.

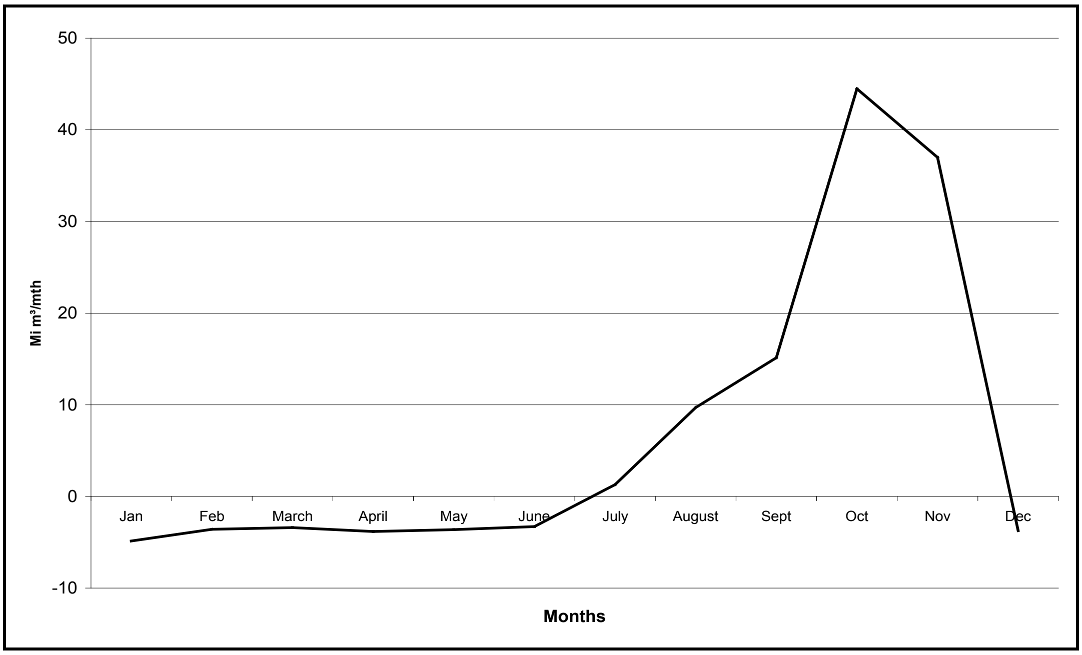

Figure 4.16: Changes in the available water in the reservoir storage in the year 2005

The Figure 4.17 exhibits the cumulative volume change of the reservoir within the study period. The negative volume change in the water balance represents that the additional water that was drawn from the reservoir than it received as inflows.

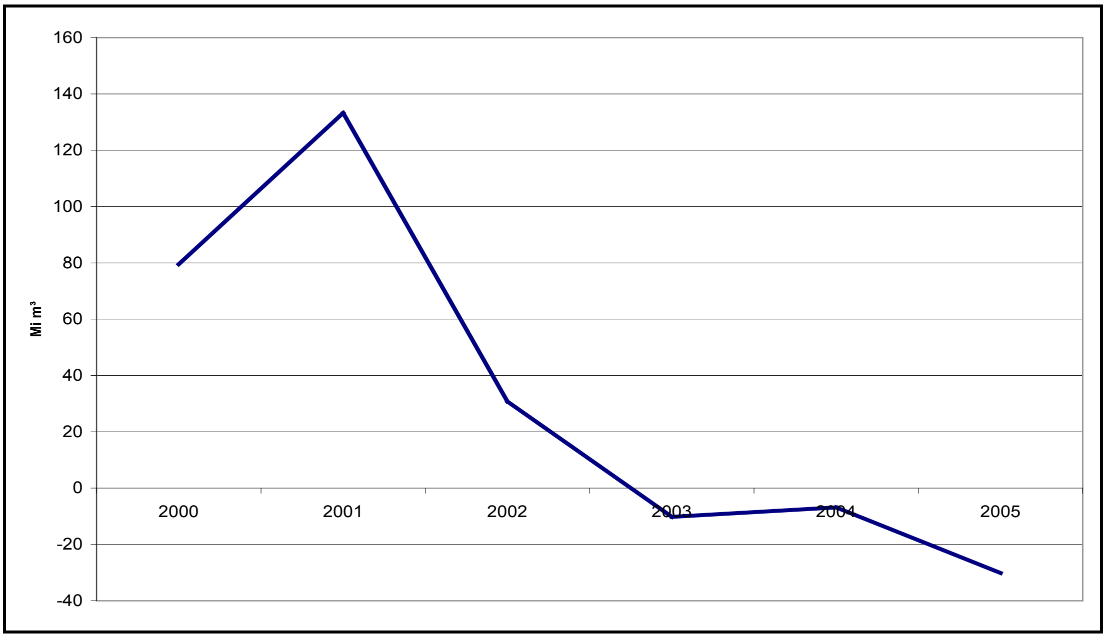

Figure 4.17: Cumulative change of the available water in the reservoir storage within 2000-2005

4.1.3 Supply-End Analysis: Raw Water Treatment Facility

A simple input-output analysis was carried out to arrive at the water balance for the Drinking Water treatment plant at Osman Sagar reservoir (Eq. 3.3). The raw water is drawn from the reservoir and flows by gravity through the raw water conduit for a distance of 15 kms, to reach the treatment plant. The entire distribution system of the reservoir ages more than 80 years. Since the time of its construction, the distribution system had only sporadic maintenance and monitoring for leakages. The official record of the leakages and water loss through the supply and treatment is given as 20% of the total raw water withdrawal. The Table 4.3 represents the water balance for the drinking water treatment plant for Osman Sagar reservoir.

Table 4.3: Water balance for raw water treatment plant

Year	WD	T&S Loss	Final supply
2000	40	8	32
2001	47	9	37
2002	27	5	22
2003	27	5	22
2004	25	5	20
2005	11	2	9

Note the values are in Mi m³ = Million Cubic Meters

At present only the rapid gravity filter system is in function. The two filter systems were designed to treat around 40 Mi l/day and 34 Mi l/day of water. However, at present the plants run at half of its capacity. The water balance for the treatment plant has been represented in the Figure 4.18.

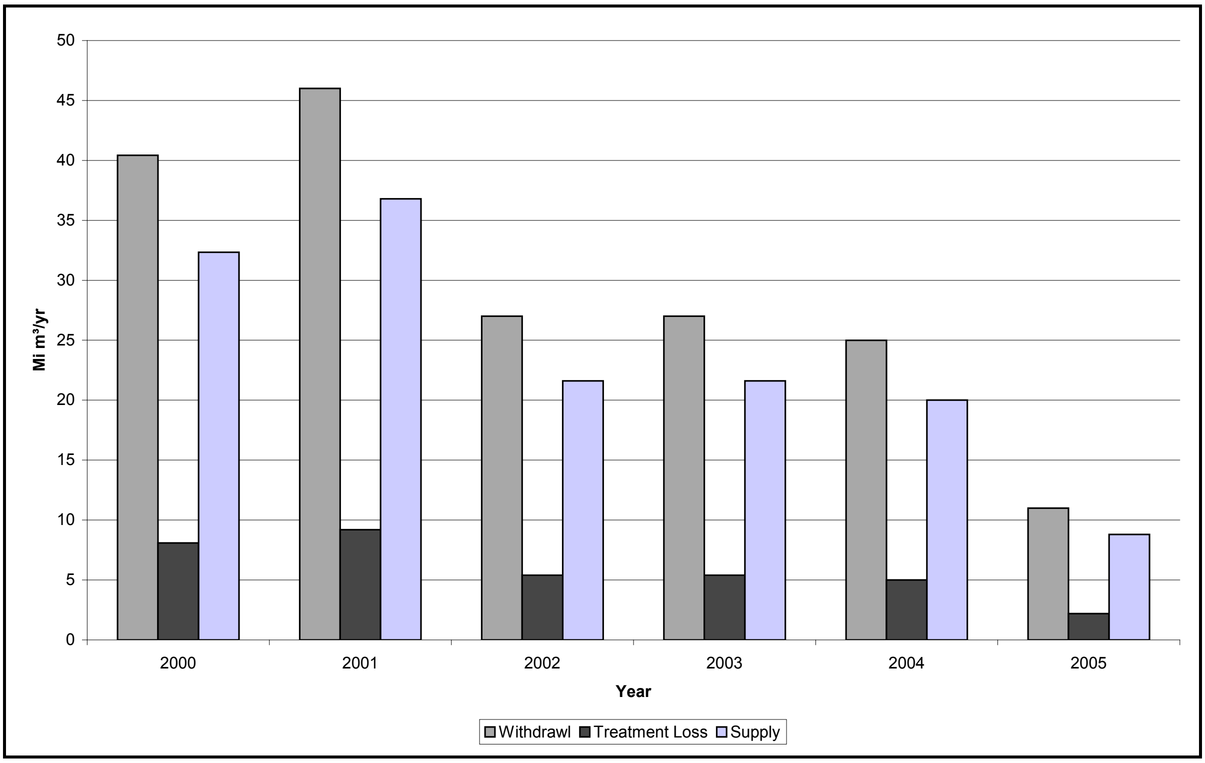

Figure 4.18: Water balance for the drinking water treatment plant: 2000 - 2005

The treatment plant underwent an evaluation check by the TATA consultancy services, in the year 1992 (TATA consulting Engineers, 1992). The observations made in the report hold good even to the present day. It has been observed that there are no flow meters at the beginning of the raw water inlet and the water measurement is done at approximation. Figure 4.19 indicates the raw water inlet to the Patterson and candy rapid gravity filter systems. Pre-chlorination system does not exist.

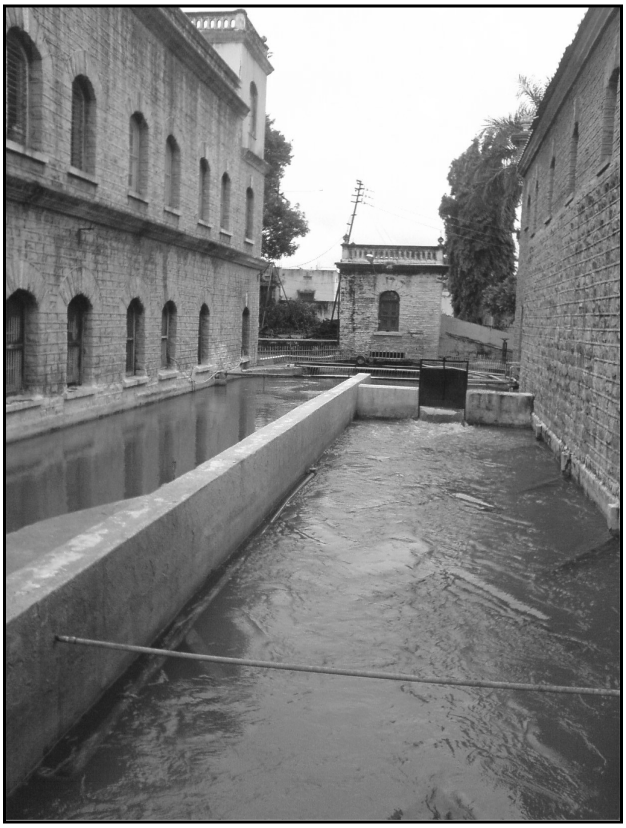

Figure 4.19: Raw water inlet in the drinking water treatment plant

The raw water after passing over the alum slabs is sent to the settling tanks. The desludging is done manually and once in 15 days According to the consultation report on field observations and consultation with the plant engineer, it has been mentioned that the desludging happens between 10 and 15 days. Due to the high fluctuation in the raw water withdrawal, the frequency of desludging varies. In the summer season, as the water is withdrawn from the lower levels of the reservoir, it has been observed that the turbidity of the water is higher. The desludging is more frequent in the summer season than the monsoon.

Figure 4.20: Manual clearing of sludge in the drinking water treatment plant

From the settling tanks, the raw water is then sent to the rapid gravity filters. The rapid gravity filters are 9 (Patterson) and 12 (Candy) in total. The backwashing of the filters are done once in a day. On discussing with the plant engineer, it was mentioned that the backwashing is stopped when the wash water in the backwash tank is completely exhausted. At this point, it is essential to monitor the backwash results based on the monitoring of the turbidity during the backwash or at frequent intervals. This would help in scientifically observe the changes in the filters and also help in minimizing the loss of water at this stage. The consultation report suggests that the amount of water used for backwashing exceeds 4% and it should be kept minimum to 2% of the total water filtered.

The filtered water is sent for post chlorination before being released to the distribution network.

4.2 Nutrient Load Analysis

If a lake has a large watershed relative to its lake volume, it will experience higher impact by inflows from the watershed. On the other hand, if a lake has a small watershed relative to lake volume, inputs from the watershed will have less impact on water quality (ILEC, 1999). Osman Sagar is spread across 22 km² and is around 3% of its total catchment area of 738.15km². The lake has a total established storage capacity of 110 Mi m³. This volume is 50% of the mean surface runoff from its catchment, of 250 Ml m³ (under normal rainfall conditions), making the lake mostly dependent on the inflows received from its catchment. And also makes the reservoir vulnerable to the agricultural runoff and nutrient inflows from the catchment.

The catchment area of Osman Sagar falls under the agro-ecological zone of hot-semi-arid region with vertisols and lateritic soils. It is predominantly agricultural in land use. Millets, oilseeds, rice, cotton and sugarcane under irrigation are some of the major crops cultivated in this region. Escalating groundwater irrigation gave way to intense agriculture in the region. It has been estimated that the agricultural production has in the last decade has increased to 60% in the region. Correspondingly, the annual fertilizer consumption has also increased. According to the FAO report (FAO, 2005) on the fertilizer use in Andhra Pradesh, India, it is observed that around 138 kg/ha is the average fertilizer consumption per annum.

Agriculture is the main non-point source for nutrient flows into the reservoir. Agricultural activities that cause non-point source pollution include confined animal facilities, grazing, ploughing, pesticide spraying, irrigation, fertilizing, planting, and harvesting. The major agricultural non-point source pollutants that result from these activities are sediment, nutrients, pathogens, pesticides, and salts (EPA, 2000). Considering agriculture as a main land use activity in the catchment, the present study elaborates on its role in the nutrient loads within the catchment and the impending threat on the fresh water status of the reservoir.

4.2.1 Fertilizer Input as a Nutrient Load Factor

In the year 2004 and 2005, in the catchment around 10440 ha and 10351 ha of area was under cultivation. The cultivation area has recorded a 19%-24% under the cereal crops, 8%-6% under pulses, 8%-9% under vegetables and 65%-60% under the crops such as rapeseed, sunflower etc (categorized as others) (Figure 2.15, Figure 2.16). According to the FAO report on the fertilizer consumption in India (FAO, 2005), the mean average per hectare consumption for different crops in Andhra Pradesh was taken into consideration for this study. The summation of the average per hectare consumption for various crops has been represented in the Figure 4.21.

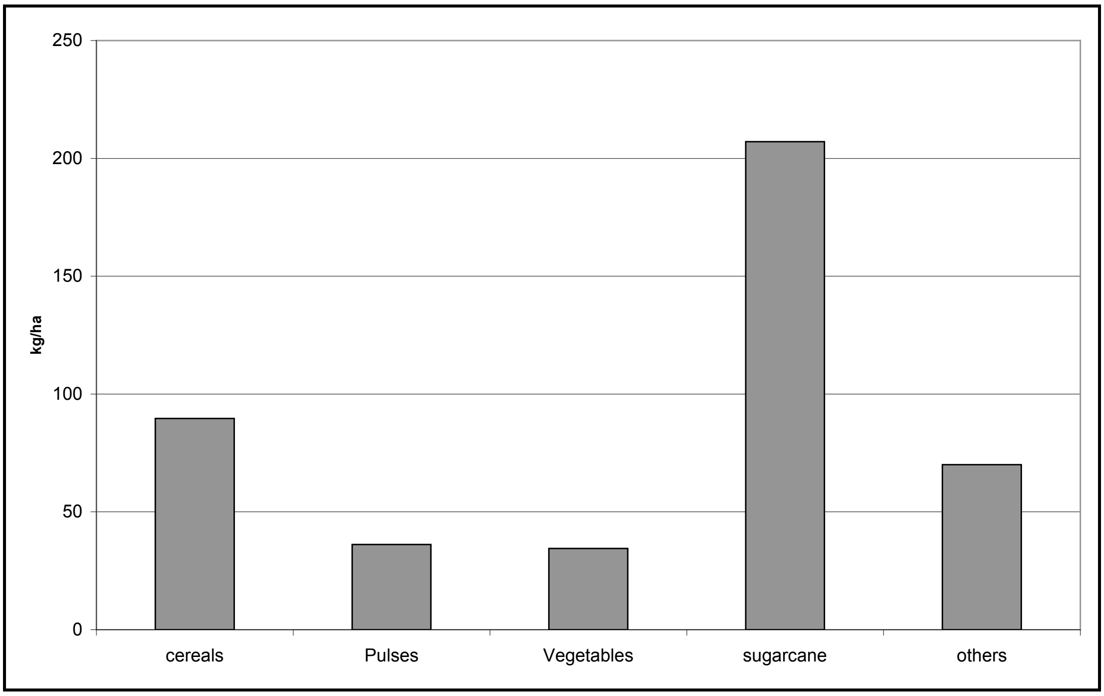

Figure 4.21: Crop-wise fertilizer consumption in the catchment (FAO, 2005)

The average per hectare consumption for cereals and pulses were recorded as 89 kg/ha and 32 kg/ha. Crops such as vegetables and sugarcane recorded an average consumption of 34 kg/ha and 207 kg/ha respectively. Other crops such as cotton, sunflower and rapeseed recorded an average consumption of 70 kg/ha.

Andhra Pradesh is the second largest fertiliser consuming state in country. The consumption of total fertilizer nutrients recorded a sharp increase of 24.1% from 1.9 Mi kg in 2004 to 2.4 Mi kg in 2005. In the same time period around 1.8 Mi kg of mineral fertilizers were used within the catchment (FAO, 2005). The Figure 4.22 shows the estimation of the annual fertilizer consumption in the catchment for the year 2004 and 2005. The amount of fertilizer used for cereal production was recorded as 460,000 kg and 571,000 kg for the years 2004 and 2005. Fertilizer consumption for the production of crops such as rapeseed, cotton and sunflower was higher than the rest of the crop groups. In the years 2004 and 2005 around 1.2 Mi kg and 1.1 Mi kg of fertilizer was used for the production of these crops. Though per hectare consumption of crops such as rapeseed, cotton and sunflower is lower than the other crop groups, as the cultivation area under these crops is higher than the rest, the annual fertilizer consumption for these crops is higher than the cereals, pulses, sugarcane and vegetables.

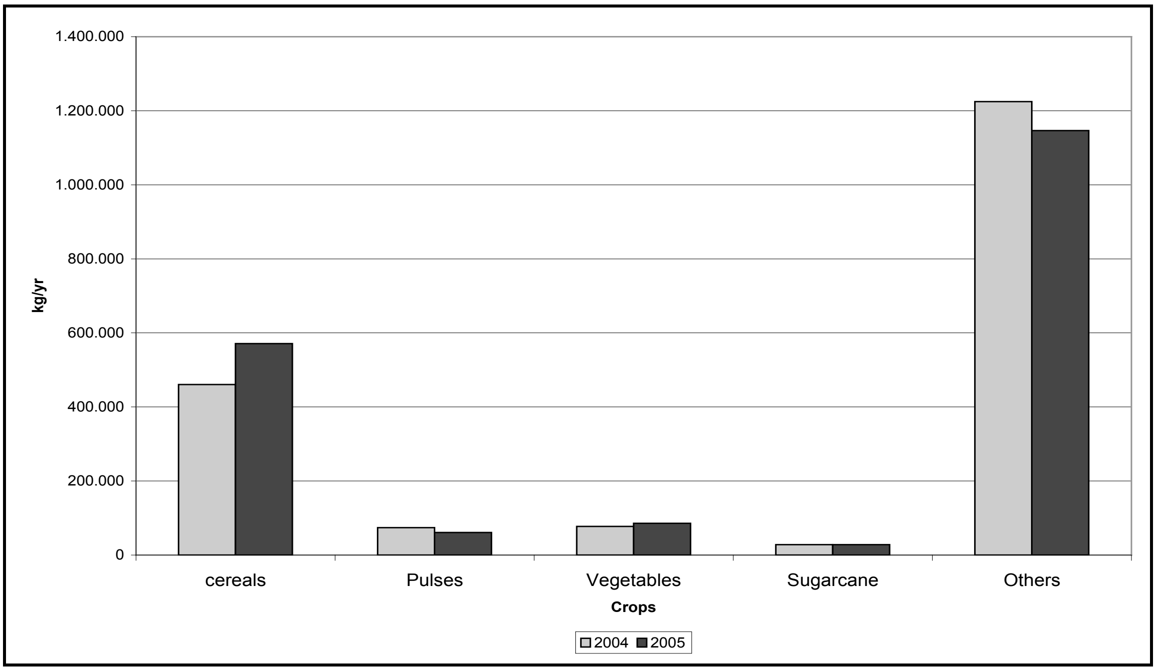

Figure 4.22: Estimated annual fertilizer consumption in the catchment

Nutrient Load

The nutrient load for the catchment was estimated according to the FAO methodology for soil assessment applied for the region of Andhra Pradesh (Eq. 3.6). The area is characterized by vertisols and lateritic soils. These soils have a natural characteristic of being phosphorous and potassium deficient. As explained in the methodology the fertilizer use efficiency factor for nitrogen, phosphorous and potassium has been considered as 0.45, 0.25 and 0.70. According to the methodology presented (Eq.3.6) the nutrient uptake from the harvest is only considered to estimate the nutrient load (Table 3.2). Considering the data available for the study area and the study period, this methodology suits the requirements.

The nutrient uptake for various crops has been taken from the FAO manual on fertilizer use (FAO, 2000). (Table 3.2). The nutrient balance indicates a negative balance for nitrogen and positive for potassium and phosphorous.

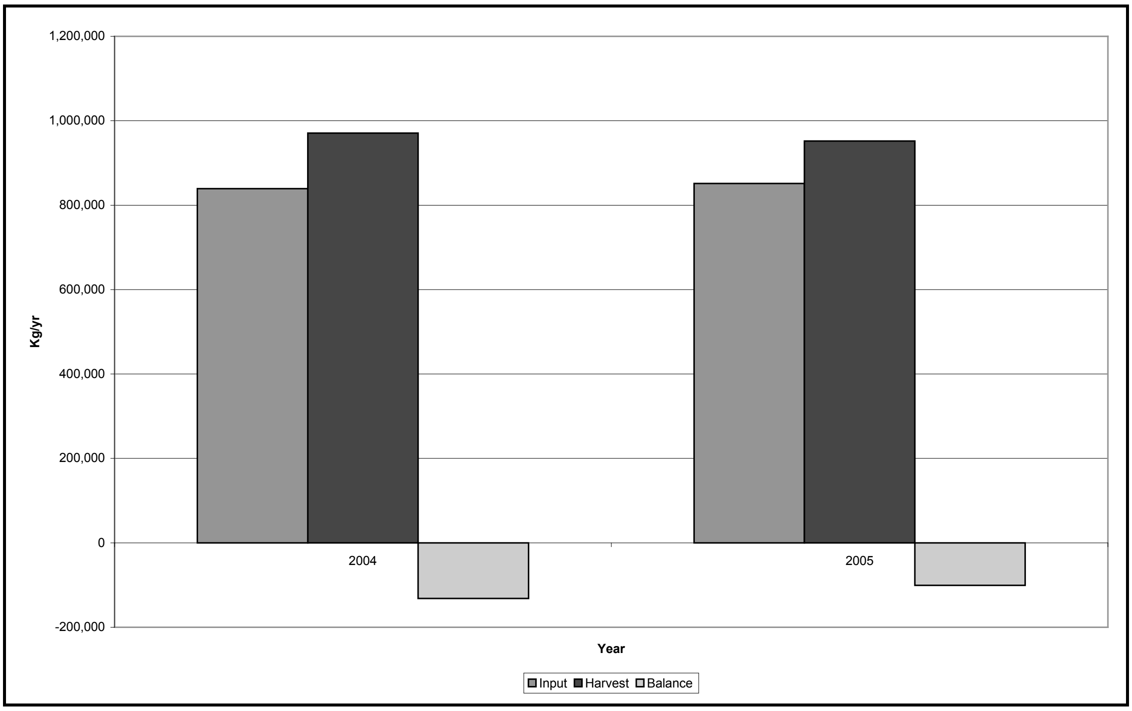

Figure 4.23: Estimated nitrogen load in the catchment

In the year 2004 and 2005 a total of 839,000 kg and 851,000 kg of nitrogen from the mineral fertilizers was estimated to be utilized by various crops within the catchment. The amount of nutrient uptake by various crops was estimated to be around 970,000 kg and 952,000 kg in the year 2004 and 2005. The negative nitrogen balance is a typical characteristic to India (FAO, 2005). The nitrogen load for the catchment was estimated considering only the role of organic fertilizers. To understand the role of the other input factors such as biological fixation and sedimentation need more detailed on field analysis.

In the year 2004 and 2005, out of the total organic fertilizers used, the phosphorous input as was estimated to be around 466,000 kg and 473,000 kg in the catchment. The annual average phosphorous output through harvest was estimated to be around 29% of the total input. This amounted to be around 138,000 kg and 140,000 kg for the years 2004 and 2005. The soil phosphorous balance exhibits a 71% excess of phosphorous. The Figure 4.24 shows the estimated phosphorous load within the catchment. Field studies conducted in the micro watershed within the catchment area suggest a more amount of P is added to the soil than the amount taken up by the crops (Wani, 2006). Considering the natural phosphate limitation in the soil, most of the phosphate is bound to the soil particles. The solubility of the various inorganic phosphorus compounds directly affects the availability of phosphorus for plant growth. Further, the solubility is influenced by the soil pH. Soil phosphorus is most available for plant use at pH values of 6 to 7. When pH is less than 6, plant available phosphorus becomes increasingly tied up in aluminium phosphates. As soils become more acidic (pH below 5), phosphorus is fixed in iron phosphates

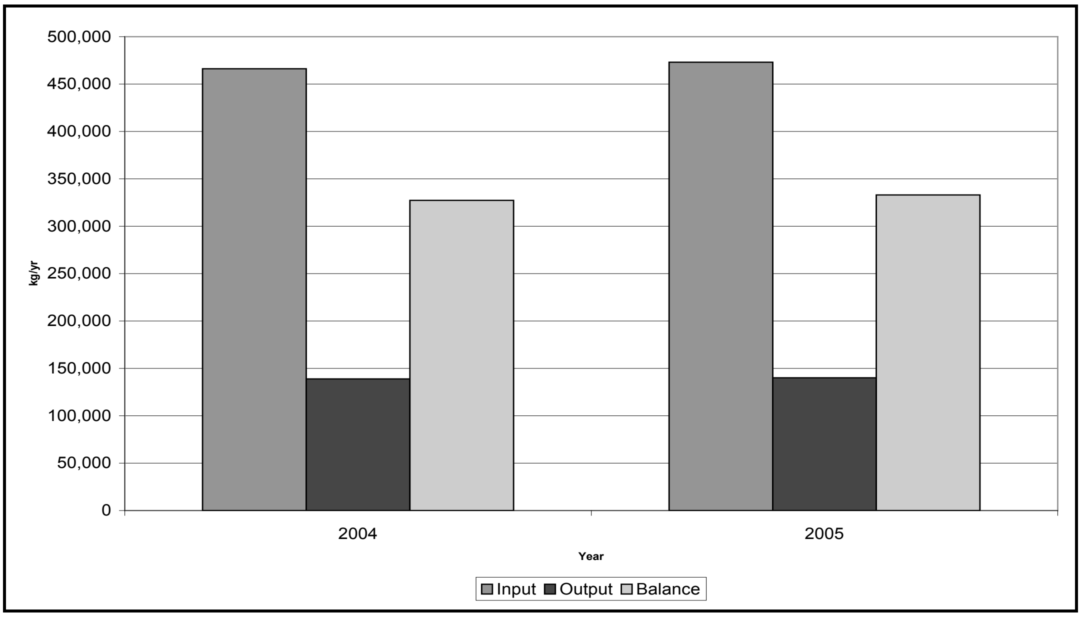

Figure 4.24: Estimated phosphrous load in the catchment

The potassium balance estimates indicate a positive balance for the catchment. An amount of 1.3 Mi kg of Potassium was estimated to be utilized from the total consumption of the organic fertilizers, in both the years of 2004 and 2005. The potassium uptake from the harvest as an output factor was estimated to be around 597,000 kg for both the years. Thereby, the balance (Figure 4.25) was estimated to be positive for the region. This is a deviation from the scientific studies conducted by ICRISAT in this region. The studies indicate depleting potassium in the soils. A detailed study at the catchment level on the soil potassium balance is necessary.

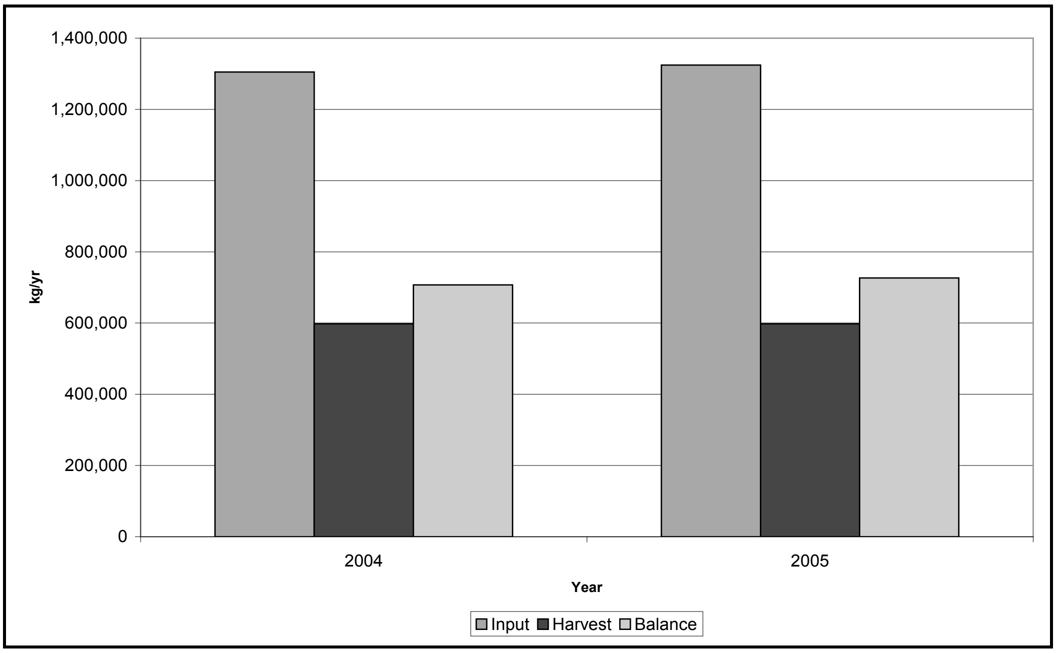

Figure 4.25: Estimated potassium load in the catchment

4.2.2 Reservoir Water Quality Status

The raw water withdrawn from the reservoir is tested for water quality twice in a month for primary water quality parameters, and the treated water for complete water quality profile, given by the WHO standards (Appendix 1) twice a year (WHO, 2006).

Inspite of intense agricultural activity within the catchment, the reservoir continues to maintain its oligitrophic status. Increasing surface retention within the catchment and the reduced inflows into the reservoir are the two factors that attribute to the quality feature of the reservoir. The water quality for the years 2004 and 2005 has been presented in theTable 4.4.

Table 4.4: Water quality Osman Sagar reservoir (HMWSSB, 2004; HMWSSB, 2005)

Parameters	**2004**	**2005**
Total Dissolved Solids (TDS)	167	120
Electrical conductivity	268	263
Nitrate (NO_3) (mg/ltr)	0. 61	0.2
DO (mg)ltr)	6. 04	4.03

The Table 4.4 signifies that the water quality of the reservoir is still unaffected neither by the agricultural intensity nor the nutrient loads upstream. The study years of 2004 and 2005, the reservoir did not receive any inflows, thereby did not receive any sediments from upstream.

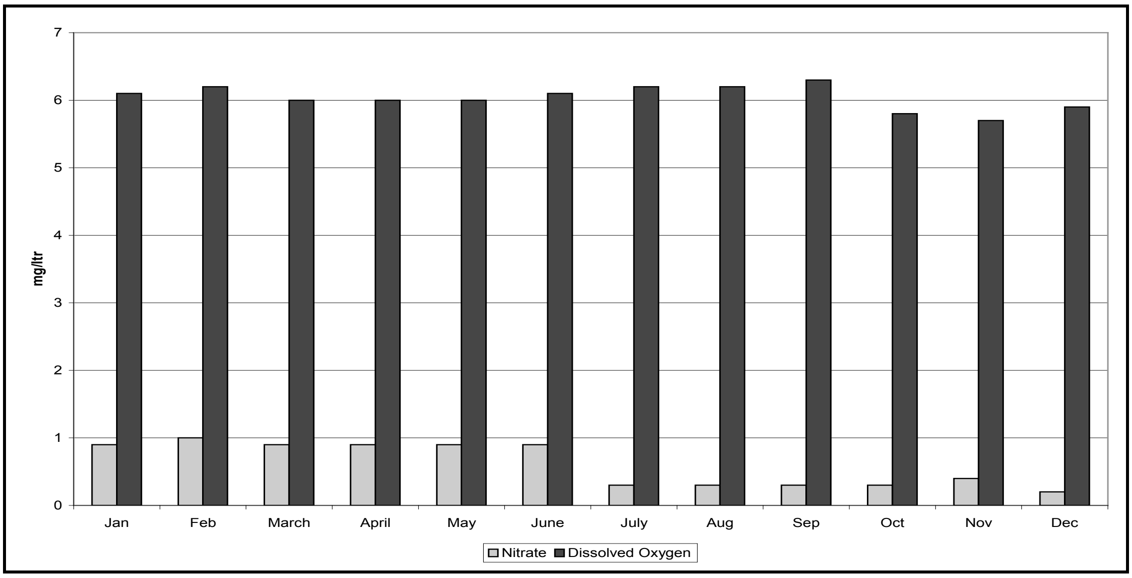

Figure 4.26: Nitrate and Dissolved Oxygen levels in 2004 (HMWWSB, 2004)

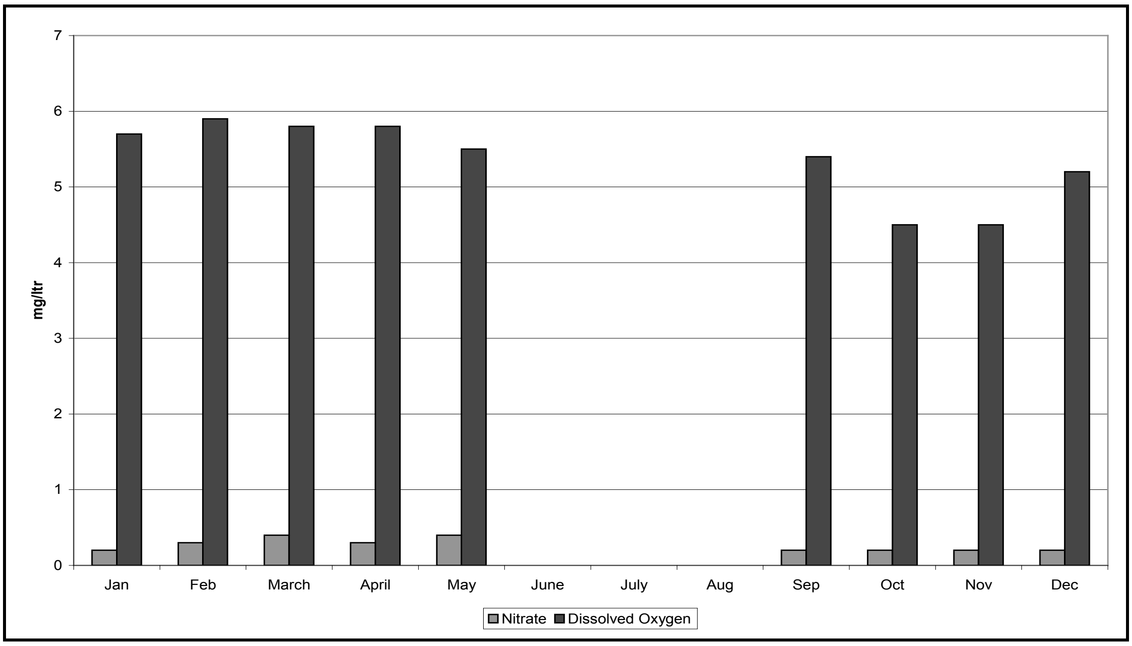

Figure 4.27: Nitrate and Dissolved Oxygen levels 2005 (HMWWSB, 2005)

The disrupted inflows from the catchment lead to physical separation of the lake from its catchment. The impact includes reduction in the dilution factor and acceleration of the nutrient cycle. Considering the approximate erosion figure of 0.5-1.5 t/ha and increasing surface retention within the catchment, it is essential to carry out a complete Nutrient Flow Analysis for the catchment and its probable impact on the reservoir.

4.2.3 Raw Water Treatment

The raw water treatment facility runs on the rapid gravity filter systems and chlorination to achieve the drinking water standards. The rapid gravity filters function by reducing the turbidity and organic compounds that affect the taste and odour of the raw water. As the raw water quality continue to fit in the primary water quality standards (Appendix 1) there hasn't been any inclusion on the biological treatment of the raw water planned.

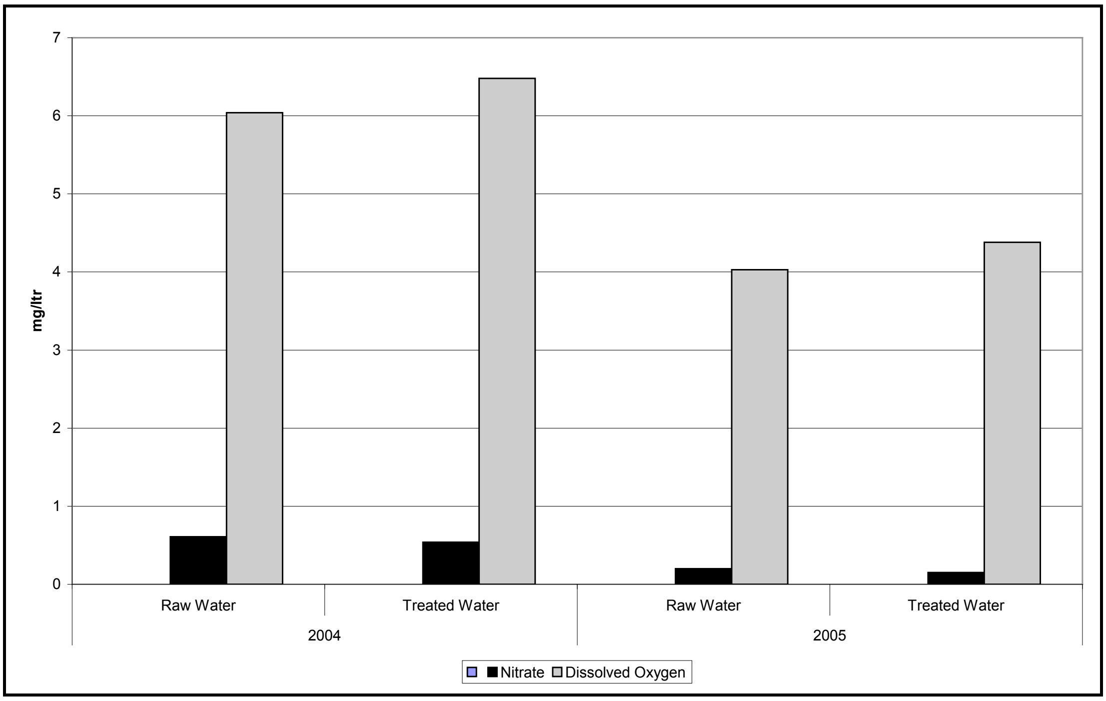

Figure 4.28: Water quality of raw and treated water

The annual summary of the water quality report (2000-2005) indicates that the nitrate concentration for the raw water range from 0, 2 mg/l to 0, 6 mg/l the dissolved oxygen ranged from 4 mg/l to 6mg/l. The nitrate concentrations for the treated water ranged from 0, 15 mg7l to 0, 5 mg/l. The Figure 4.28 represents the nitrate level and dissolved oxygen level for the year 2004 and 2005 for both raw water and treated water. The figure indicates a minor change within the concentration levels in the raw water quality.

In order to prohibit any incidents of water born diseases during the monsoon season, the treatment plant increases the residual chlorine content in the treated water. This creates displeasure amongst the citizens due to the change in the taste and smell of the drinking water. Studies conducted on the chlorine residues in the drinking water pipes indicate high chlorine content in the drinking water (Srikanth, 1997)

4.3 Scenario Development

4.3.1 Urbanization as a future threat

Assessment of the long-term hydrologic impacts of land use change is important for optimizing management practices to control runoff and non-point source pollution associated with watershed development. Land use change, dominated by an increase in urban impervious areas, can have a significant impact on water resources.

Until the recent times, the catchment area of Osman Sagar has been protected from major land use changes. However, the present urban growth and the urban expansion plans pose a threat to this drinking water source. The recent development of the city as an IT hub expanded the scope for infrastructure development in and around the core city. Projects such as Outer Ring Road and the new Rajiv Gandhi International Airport to the south are already in operation. The presence of these projects in close proximity to the Osman Sagar is assumed to instigate exploding urbanization in the catchment area. These infrastructural development in the Hyderabad city as an urban push factor has been considered to project a land use change scenario within the catchment area.

The transformation of rural to urban land use will have significant impacts on surface water quantity and quality. The impact of urbanization includes increase in peak flow, non-stationary discharge signals, decrease in travel time, and increase in total runoff, base flow changes, non-point source contamination and sewage overflows. The prime physical cause of these impacts is an increase in impervious area within the catchment.

The Figure 4.29 represents a scenario indicating the change in the surface runoff under varied land use conditions. The land use is represented by the runoff coefficient. The present runoff coefficient for the catchment is 0.4. The land use change from the present day is seen more towards the urbanization. The runoff coefficients selected for this scenario are 0.50, 0.55 and 0.6.

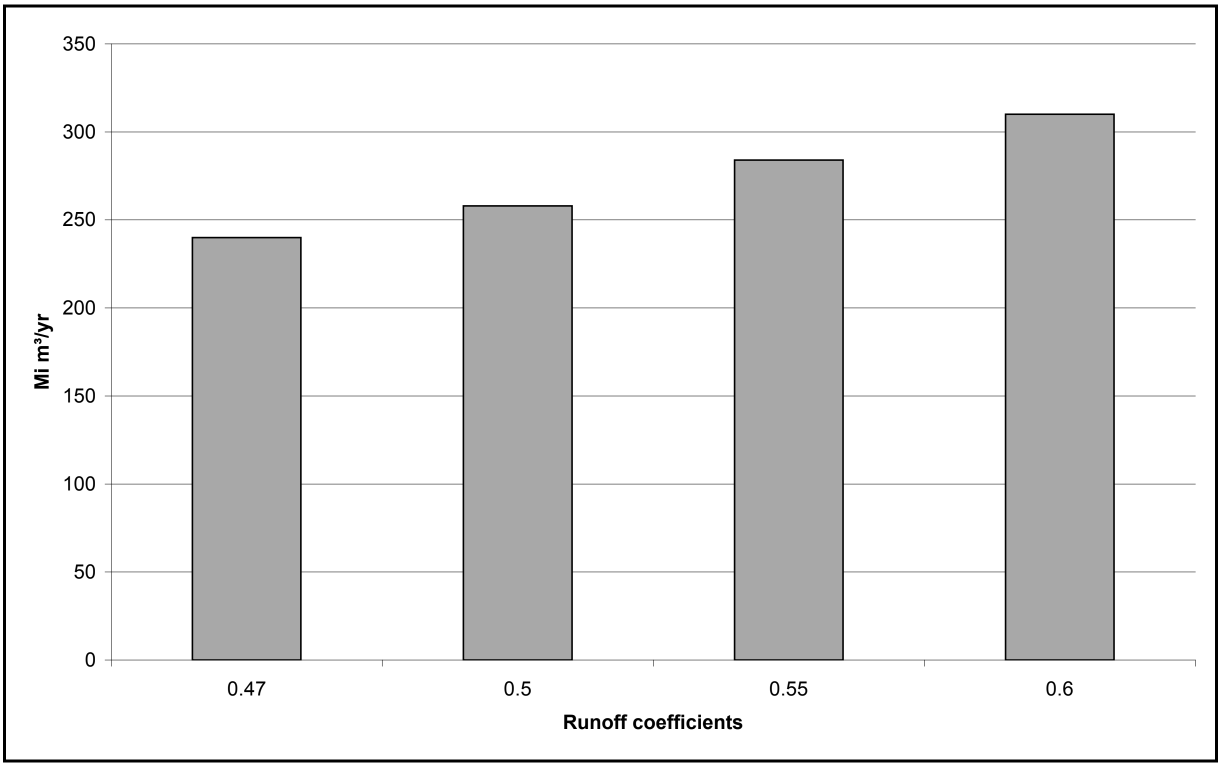

Figure 4.29: Estimation of surface runoff under different land use conditions

In accordance to the assumed runoff coefficients, the surface runoff in the catchment area would change from 47% to 60%. The scenario indicates that as the land use changes more towards the urbanization, there will be a rise of around 27% in the surface runoff. Further, urbanization also instigates increased surface runoff due to reduced open spaces for infiltration.

The population in the year 2000 as per the 2000 census was 221, 000. The present decadal growth rate for the region is given as 37%.The annual growth rate is estimated to be around 3.7% (GoAP, 2008). Considering this trend, the population growth in the catchment area is estimated to rise to around 425,000 by the year 2025. The detailed estimation of the population growth in the catchment is given in the Figure 4.30.

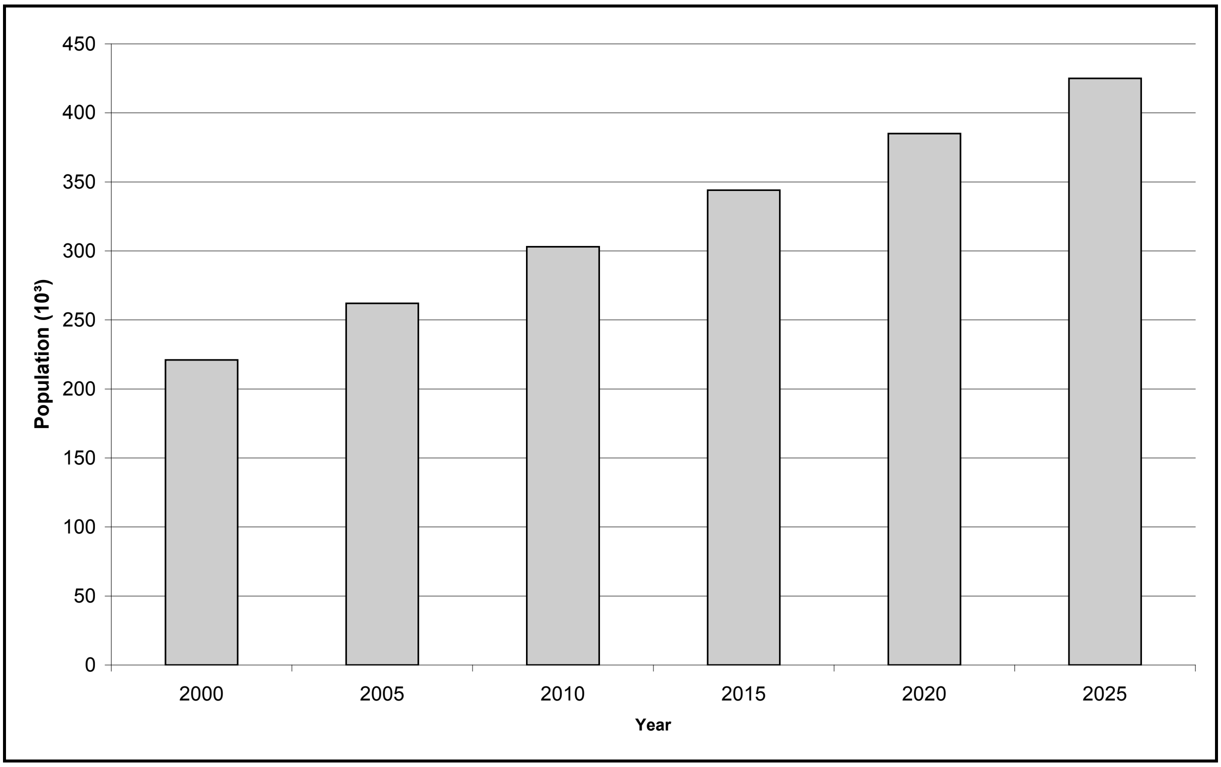

Figure 4.30: Estimated population growth in the catchment area

At present the water consumption within the region is according to the rural drinking water norms, which is 40 lpcd. The water consumption in the year 2005 was estimated to be around 15, 000 m^3/yr. Under the present consumption of 40lpcd, it is projected that the annual water consumption in the catchment would rise to 25, 000 m^3/yr by the year 2025. As the land use within the catchment move towards urbanization, the water demand and the consumption also change accordingly. In India, the present water consumption in the urban areas ranges from 80 lpcd to 120 lpcd. Following this norm, the water consumption in the catchment under 80 lpcd would range between 24,000 m^3/yr and 50,000 m^3/yr from the year 2010 to 2025. Similarly, under the consumption pattern of 120 lpcd, the annual water consumption in the catchment would range from 36, 000 m^3/yr to 75,000 m^3/yr from the year 2010 to 2025. The Figure 4.31 points out the projected water consumption within the catchment between the period of 2000-2025, under different water consumption levels.

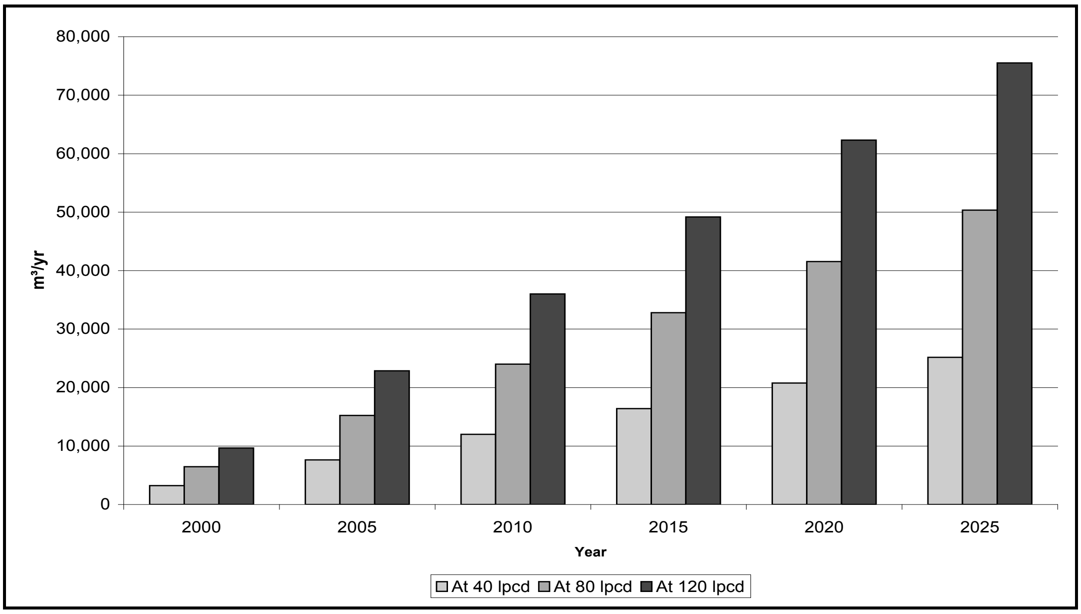

Figure 4.31: Projected water consumption in the catchment

Further with the water consumption increasing, there is also a parallel rise in the wastewater flow in the catchment. At present with 40 lpcd of drinking water consumption, around 30 lpcd of wastewater is estimated to be let out within the catchment. As most of the catchment area is under the rural administration, there is no wastewater treatment plant within the catchment. The wastewater is let out into the soak pits and the wastewater is let out into the open drains (Figure 4.32). Most of the wastewater reaches the groundwater through leaching.

Figure 4.32: Wastewater disposal in the catchment

Between the period of 2000 and 2005, around 2,000 to 5,000 m³/yr of wastewater was estimated to be disposed within the catchment. The rise in the drinking water consumption from 40 lpcd to 80 and 120 lpcd would instigate a parallel rise of the wastewater ranging from 70 lpcd to 100 lpcd. The Figure 4.33 presents a scenario of wastewater flow within the catchment.

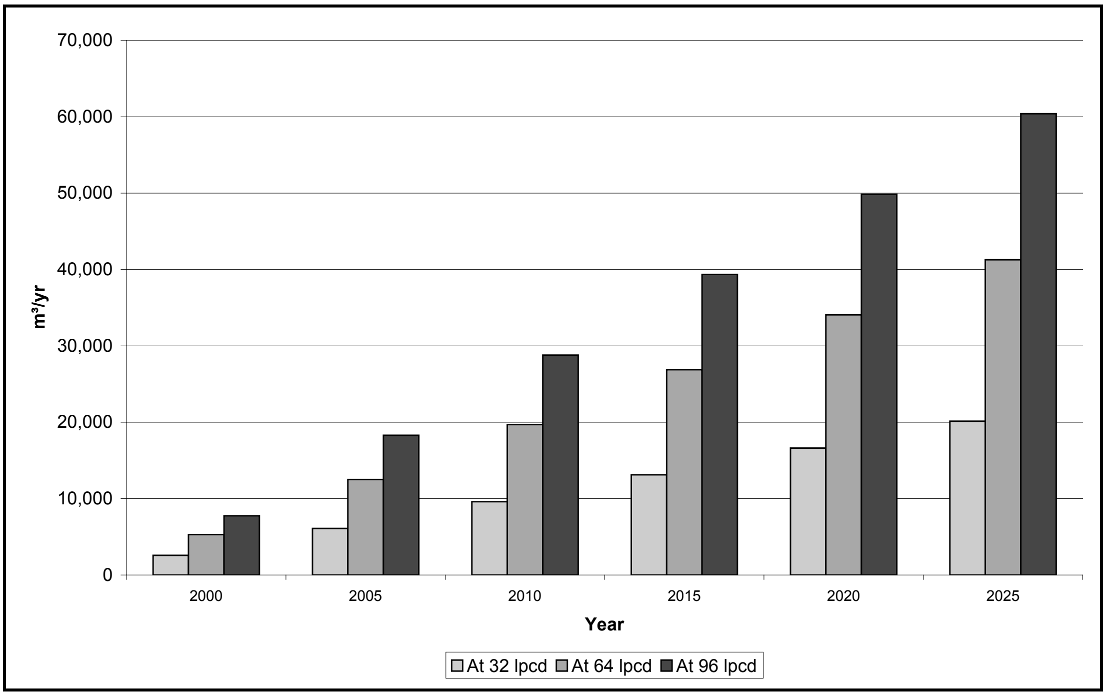

Figure 4.33: Projected wastewater flow in the catchment area

Assuming the rise in the drinking water consumption to 80 lpcd from the year 2010, the parallel disposal of wastewater in the year is projected to be around 19,000 m³/yr. If similar trend continues until the year 2025, the wastewater disposal by the year 2025 would be around 41,000 m³/yr. Under the drinking water consumption of 120lpcd, the corresponding wastewater disposal would range from 28,000 m³/yr to 60,000 m³/yr between the years 2010 and 2025.

The catchment area does not come under the Hyderabad Urban Development Authority (HUDA). However, with the area under urbanized conditions would be forced to be recognized as the peri-urban area to the Hyderabad city. These changes would draw attention to extending the drinking water supply to the catchment area by the HMWWSB and also provision of the sewerage network and also sewerage treatment plant.

At present, the catchment area does not have any sewage treatment plant. Under such conditions, the wastewater would find their way into River Musi (upstream) and finally into Osman Sagar reservoir.

Similar trend was observed with the fresh water sources of Hussain sagar (Figure 4.34Figure 4.34) and Mir Alam tank which were once the drinking water sources for the Hyderabad city today, both these fresh water sources have been reduced to mere sewerage pools. Due to the inflow of sewage and other urban runoff has led to the eutrophication of the lakes. The impact of the change from the oligotrophic state to the eutrophic is seen as loss of fresh water and drinking water status. Remediation of the lakes back to their original oligotrophic status costs huge financial and technological investments.

Figure 4.34: Dead Fish in Hussain Sagar lake, Hyderabad due to inflows of industrial and domestic effluents

4.4 *Discussions*

4.4.1 Hydrological Analysis

The year 2000 was a wet year with an annual rainfall of 698 Mi m³ (945 mm/yr) (deviation of +17% from the mean average rainfall of 780 mm/yr). The hydrological balance is a volumetric analysis of the total available water within the (supply) system. The actual evapotranspiration was estimated as 47% of the total precipitation. This amounts to around 327 Mi m³. According to the geohydrological studies conducted by IWMI in the catchment area, the natural infiltration process was indicated as 9% (Massuel et al, 2004). This amounts to 62 Mi m³.

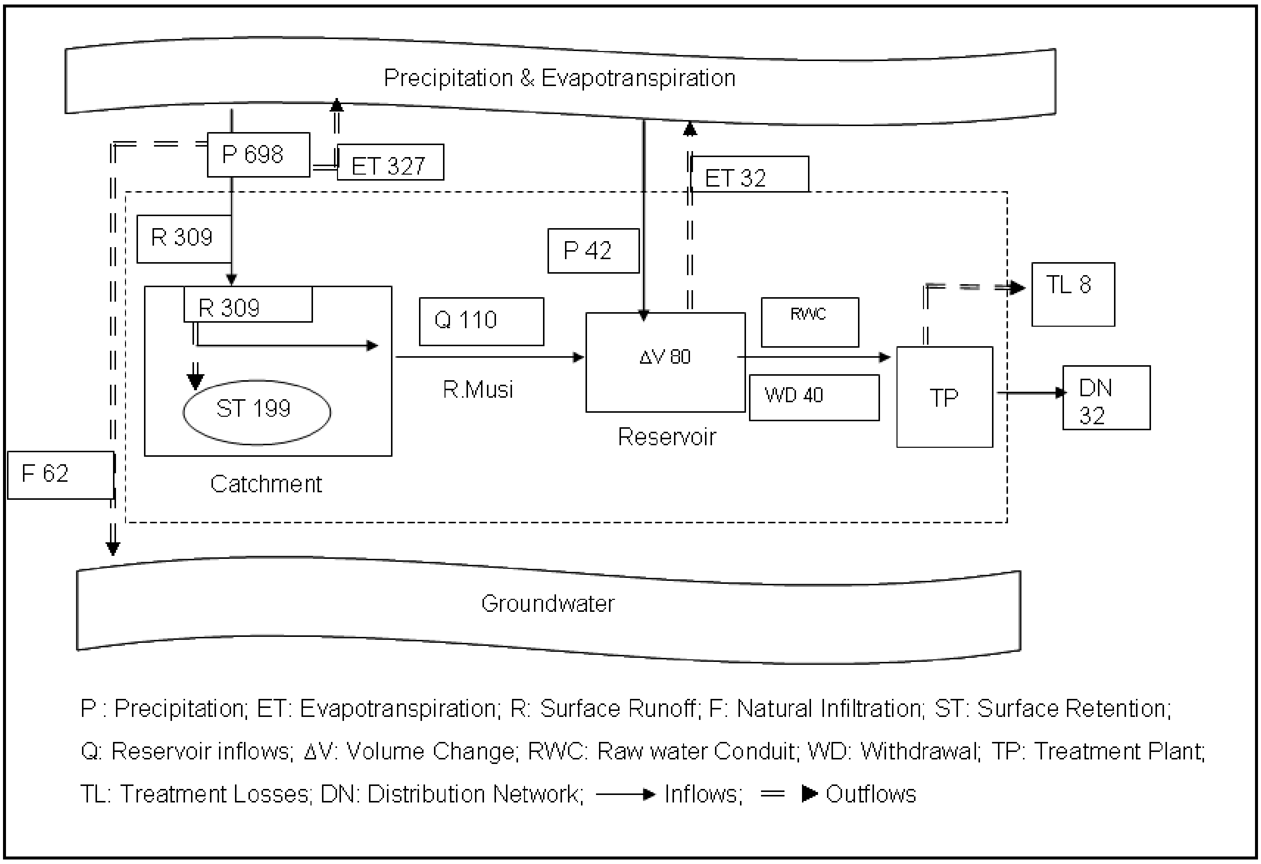

Figure 4.35: Hydrological balance within the Osman Sagar drinking water supply system: 2000 (wet year)

The surface runoff was estimated as 43% of the total precipitation. This amounts to 309 Mi m³. The reservoir inflows from the catchment were recorded as 110 Mi m³ and the balance runoff was estimated to be the surface retention within the catchment. The surface retention in the year 2000 was estimated to be 199 Mi m³. The surface retention amounts to around 64% of the total surface runoff, while the reservoir inflows were recorded as 36% of the total surface runoff.

The total input (reservoir inflows (Q) and the direct rainfall (P) into the reservoir was estimated to be around 152 Mi m³, of which the inflows from the catchment form 72% while, the direct rainfall over the reservoir form the 28%. The evapotranspiration losses form a 21% of the total input. In the year 2000, a total of 40 Mi m³ were withdrawn from the reservoir and around 32 Mi m³ of treated water was supplied to the city of Hyderabad. The treatment losses were recorded as 8 Mi m³ for the entire year.

In the year 2001, the catchment received an annual rainfall of 562 Mi m³ (787 mm/yr) of which the surface runoff amounted to 240 Mi m³ (42% of total precipitation). The reservoir inflows amounted to around 125 Mi m³ (52% of the total surface runoff) while the surface retention was estimated to be around 115 Mi m³ (48% of the total surface runoff).

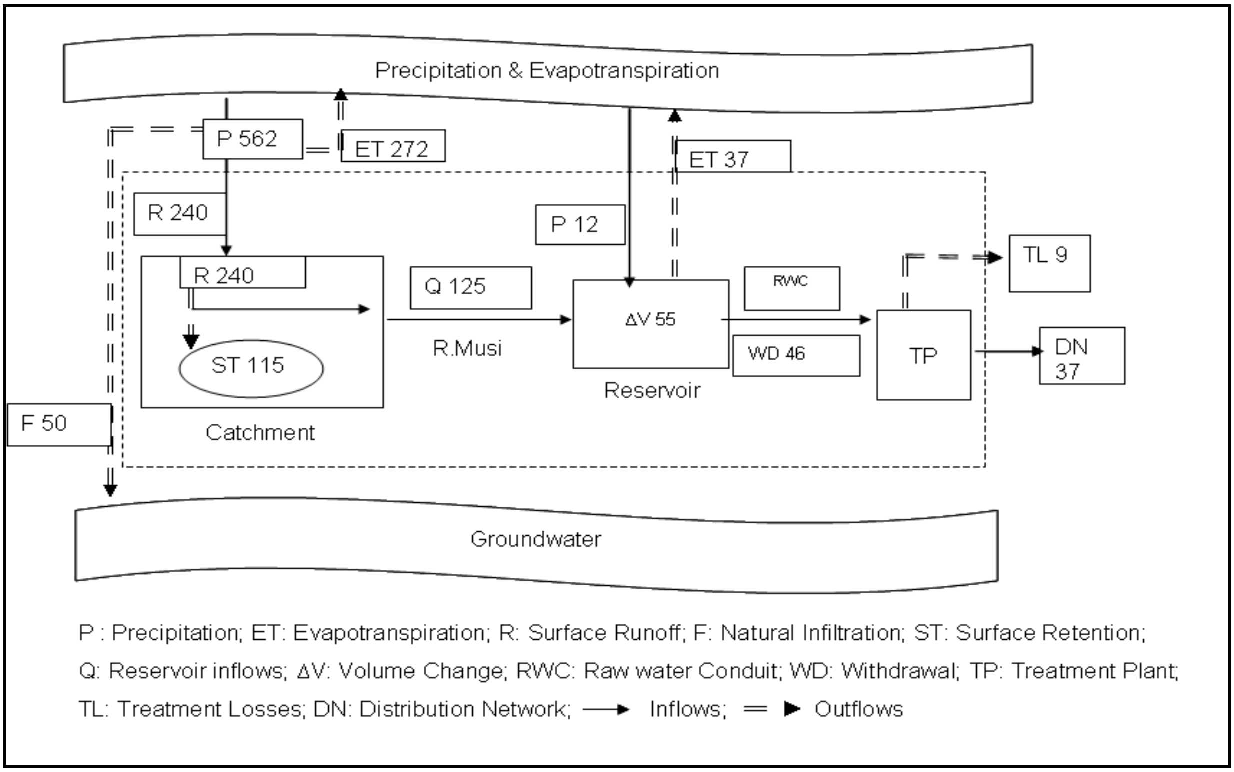

Figure 4.36: Hydrological balance within the Osman Sagar drinking water supply system: year 2001 (normal year)

The reservoir received total input (reservoir inflows + direct rainfall) as 137 Mi m³. The evapotranspiration over the reservoir was recorded as 36 Mi m³, which is around

26% of the total input. The raw water withdrawal in this year was recorded as 46 Mi m³ which is around 33% of the total input. The transmission losses from the raw water conduit and the losses within the treatment plant were assumed to be around 20% of the total raw water withdrawal. This amounts to around 9 Mi m³. The final treated drinking water supply to the city's distribution network was estimated to be around 37 Mi m³ (80% of the total raw water withdrawal).

The year 2002 recorded a deviation of -17% from the mean annual precipitation in the catchment. Therefore, the year was considered as a dry year. The available water as precipitation was estimated as 485 Mi m³ of which the evapotranspiration losses and natural infiltration process were recorded as 48% and 9%. The surface runoff was estimated to be around 206 Mi m³.

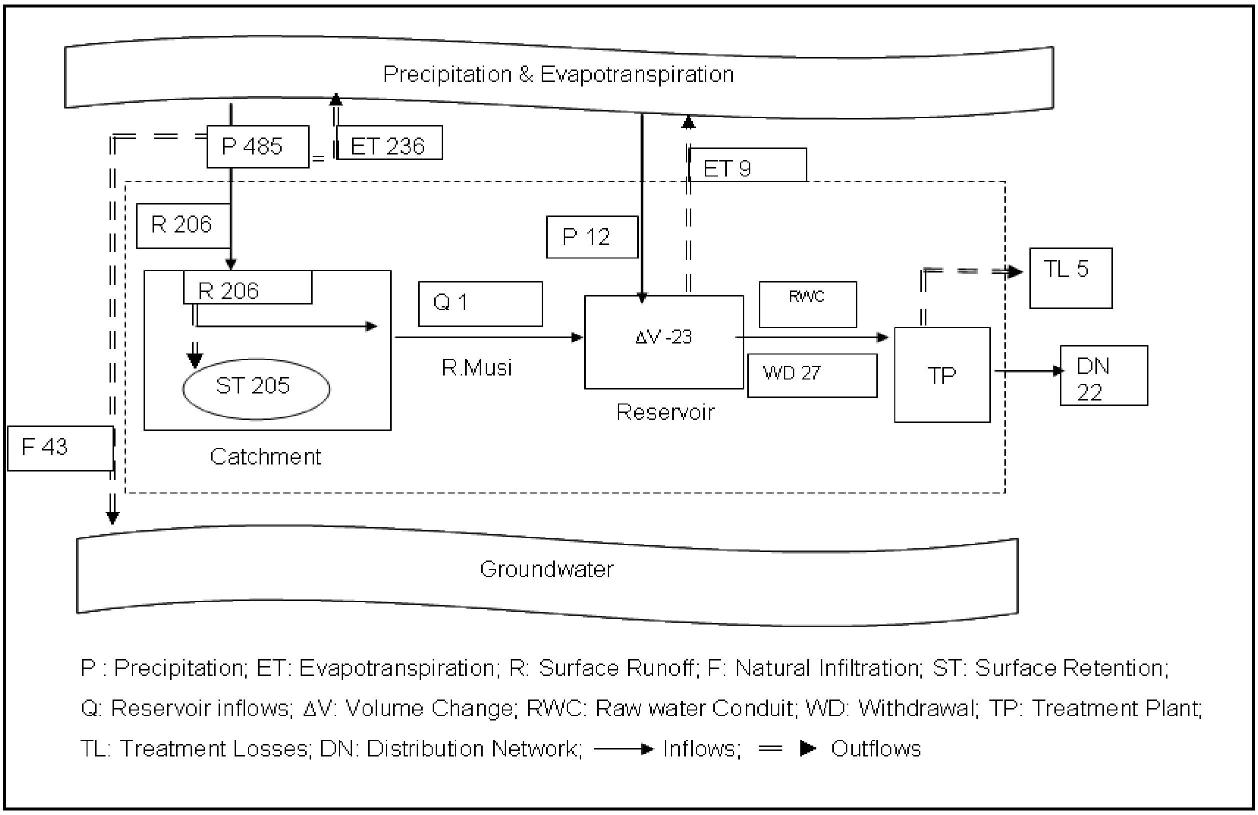

Figure 4.37: Hydrological balance within the Osman Sagar Drinking Water Supply System Year 2002 (dry year)

The year recorded around 0.4% of the surface runoff as reservoir inflows, while the balance was assumed to be retained within the catchment as surface retention.

The reservoir received a total of 13 Mi m³ of input as reservoir inflows and direct rainfall. The percentage of direct rainfall on the reservoir to the total input was recorded to be around 99% of the total input. The evapotranspiration losses were recorded as 9 Mi m³. The raw water withdrawal in the year 2002 was recorded as 27 Mi m³. The total raw water withdrawal was much higher than the total inflows received. Thus raw water was withdrawn from the available storage in the reservoir. The negative volume change in the reservoir storage indicates that the amount of water withdrawn from the available water storage in the reservoir is higher than the recharge rate of the reservoir. With 20% as the transmission and treatment losses, the total treated water supplied to the city of Hyderabad in the year 2002 was estimated to be around 22 Mi m³.

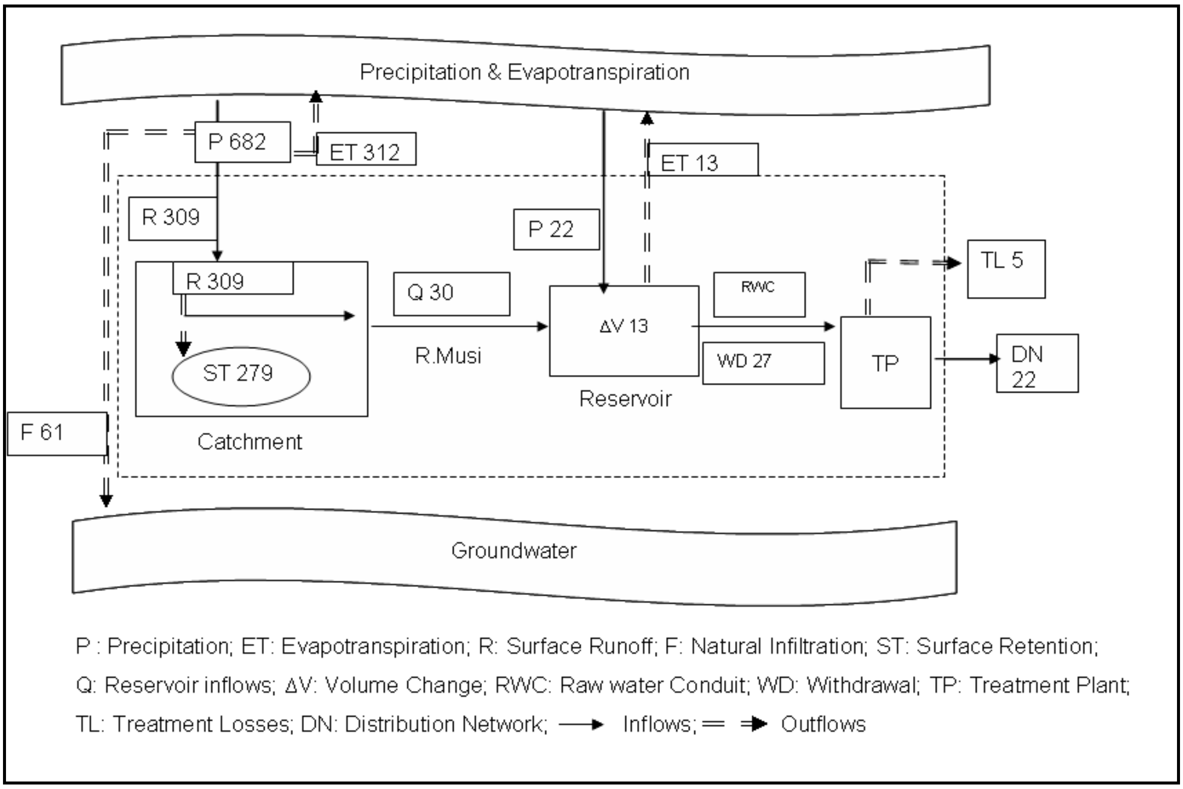

Figure 4.38: Hydrological balance within the Osman Sagar Drinking Water Supply System Year 2003 (wet year)

While the rest of the region of Andhra Pradesh experienced lean period in the year 2003, the catchment area received annual rainfall of 682 Mi m³ (1025 mm/yr). This is 31% more than the mean average rainfall of the region. The surface runoff was estimated to be around 45% of the total precipitation. This amounts to 309 Mi m³.

The reservoir inflows formed a 9% of the total surface runoff making the surface retention as 61% of the total runoff.

With the reservoir inflows being 30 Mi m³ and the direct rainfall on the reservoir being 22 Mi m³, the total input in the reservoir was 52 Mi m³ for the year 2003. The total raw water withdrawal amounted to around 27 Mi m³, leaving the volume change of the reservoir to be around +12 Mi m³ for the entire year. With 20% of the transmission and treatment losses, the amount of treated water supplied in the year 2003 amounted to around 22 Mi m³.

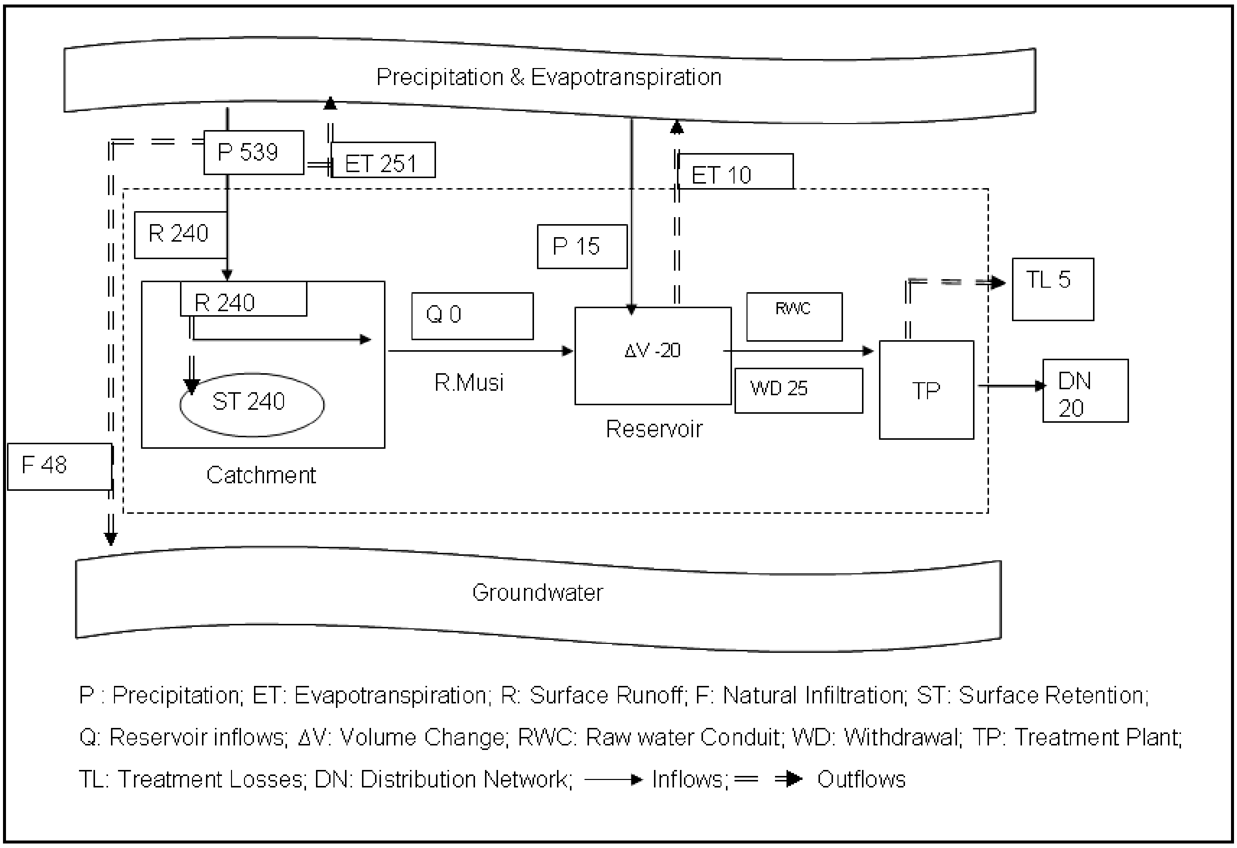

Figure 4.39: Hydrological balance within the Osman Sagar Drinking Water Supply System 2004 (dry year)

The year 2004 was a drought year with the precipitation showing a negative deviation of 20% from the mean annual precipitation for the region. Out of the 539 Mi m³ of available precipitation, 240 Mi m³ was estimated as the surface runoff for this year. No reservoir inflows were recorded from the catchment into the reservoir. Thereby, it was assumed that the entire surface runoff has been retained within the catchment.

The reservoir inflows being nil, the reservoir received the direct rainfall as 15 Mi m³ for the entire year. With the raw water withdrawal being 25 Mi m³ and evapotransipiration being 10 Mi m³ the raw water withdrawal for the drinking water continued inspite of the no reservoir inflows from the catchment. The raw water was withdrawn from the reservoir storage making the reservoir volume change -20 Mi m³ for the year. The treated drinking water for the year 2004 was estimated as 20 Mi m³.

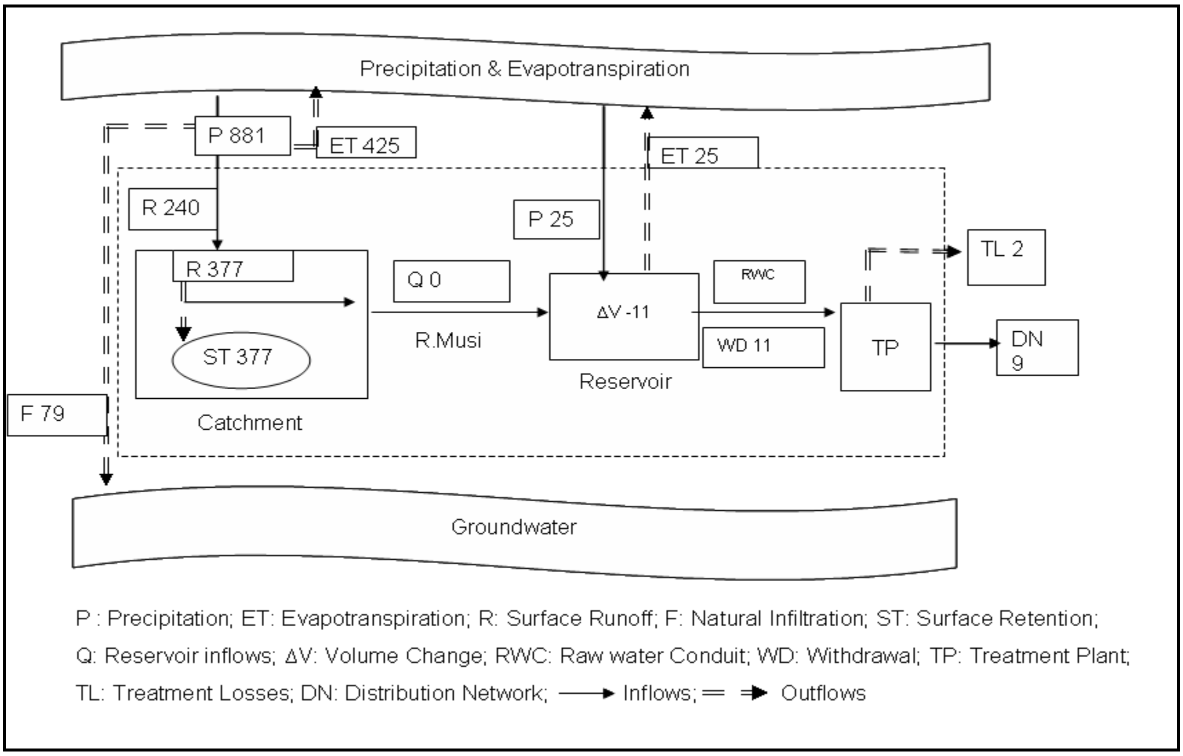

Figure 4.40: Hydrological balance within the Osman Sagar drinking water supply system 2005 (wet year)

Even though the year 2005 was a wet year with surplus rainfall of 34%, the Osman Sagar reservoir did not receive any inflows from the catchment. The surface runoff in the catchment was estimated to be around 377 Mi m^3. This entire amount was assumed to be retained within the catchment.

The reservoir was entirely dependent on the direct rainfall it received in the year. This amounts to 25 Mi m^3. The reduced inflows from the catchment had an impact on the amount of raw water withdrawn for drinking water supply. The raw water withdrawal was around 11 Mi m^3 which was withdrawn from the available storage of the reservoir. To this amount the final treated drinking water supplied to the city was around 8 Mi m^3 for the entire year of 2005.

Summation of the hydrological analysis

The study area is a semi-arid area. Frequent droughts and high intensity rainfall years are characteristic of the region (Wani et al., 2003). The study period is a representation of this climatic characteristic. The study period witnessed three wet years (2000, 2003 and 2005) and two dry years (2002 and 2004). The rainfall variation within the study period ranged from -2% (year 2001) to 34% (year 2005). The variation amongst the dry years ranges from -2% to -18% while in the wet years the rainfall variation ranges from 15% to 34%.

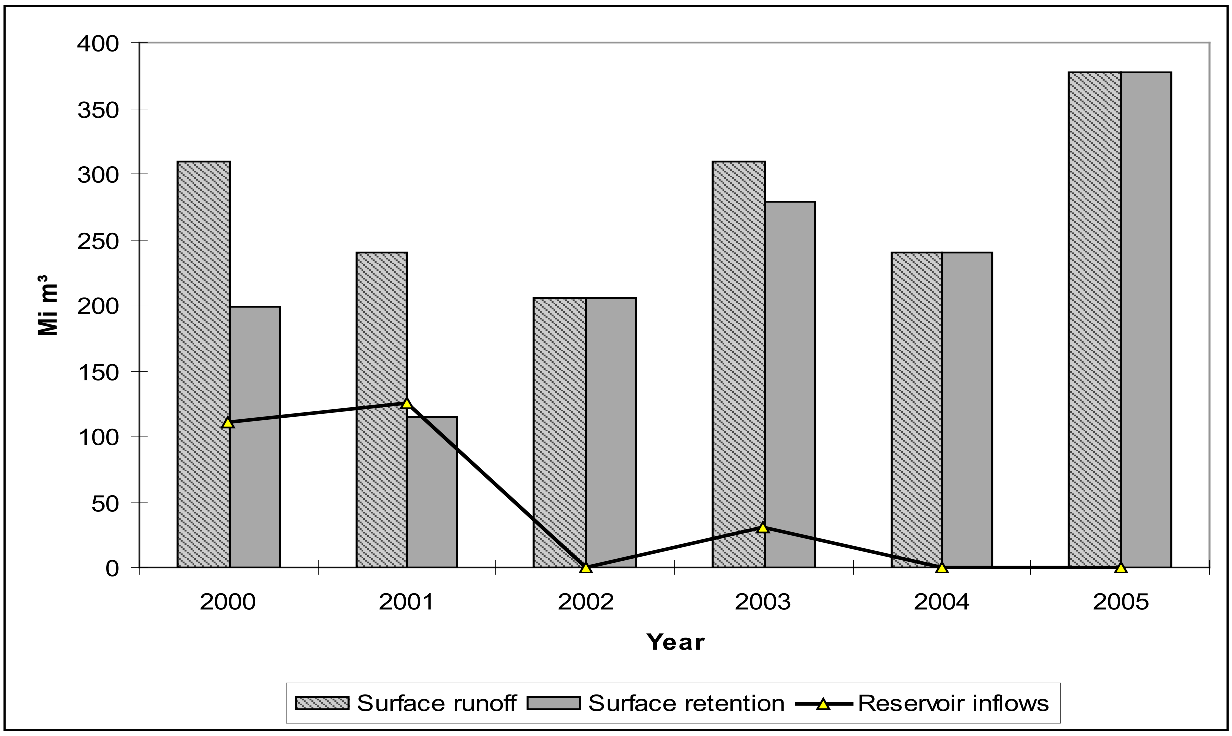

Figure 4.41: Surface water regime in the catchment from 2000-2005

Amongst the natural losses within the catchment, there is 47% evapotranspiration and up to 9% of natural groundwater infiltration. The remaining is the surface runoff which amounts to around 43% of the available rainfall. An average surface retention around 83% has been calculated from the water balance. The surface retention within the catchment ranges from 47% in the year 2001 to 100% in the years 2004 and 2005. The average amount of reservoir inflows was calculated to be around 15% of the total surface runoff. The annual fluctuations for the reservoir inflows range from 0 to 50%, indicating wide variation within the years. The reservoir inflows were 50% of the total surface runoff in the year 2000 (which was a wet year). At the end of the study period, in the year 2005 (wet year) the reservoir inflows were reduced to 0% of the total runoff.

Throughout the study period, the average dependency of the Osman Sagar reservoir on the reservoir inflows was analysed to be 37%. The dependency ranged from 1% to 91%, While the dependency on the direct rainfall ranged from 8% in the years 2001 and 2002 to 100% in the years 2004 and 2005.

The Osman Sagar reservoir could supply around 88% of the total input (reservoir inflows and the direct rainfall) within the study period. This amounts to around 29.5 Mi m³ of raw water in the period from 2000-2005. The raw water was withdrawn from the available storage for two consecutive years of 2004 and 2005. Though in the year

2004 the withdrawal was around 20 Mi m³, the withdrawal reduced to 50% in the year 2005 and only 11 Mi m³ of raw water was withdrawn from the reservoir. The cumulative impact of the reservoir volume change has been represented in the Figure 4.17.

The official number for distribution and treatment losses within the raw water supply and treatment system is given as 20% (Reddy, 2007). This amounts to an average loss of 6 Mi m³. The average treated water supply from the Osman Sagar drinking water supply system within the study period has been analysed to be around 23 Mi m³. This amounts to around 52% of the total reservoir inflows received within the study period and 8% of the average surface runoff within the catchment.

Osman Sagar drinking water supply system was designed to supply around 98.5 Mi m³ per annum to the city of Hyderabad (HMWWS, 2007). Within the period 2000-2005, the system on an average could supply around 23 Mi m³ per annum, making that as 0.06 Mi m³ per day. This indicates a 77% reduction in the performance of the supply system with reference to its established capacity.

In many river basins, upstream development and annual variations in rainfall can cause both episodic and chronic shortages in water supplies downstream (Gaur et al, 2008). In the Osman Sagar catchment, the surface retention in the upstream is an indication of extensive surface water development activities to support groundwater development. Scientific field studies conducted by ICRISAT, IWMI and CGWB authenticate this observation (Massuel et al., 2004, Wani et al., 2005, CGWB, 2007)

Further, the hydrological drought presented in the study period highlights the challenges to allocate water equitably among different irrigation zones and water use sectors (domestic, in particularly to the Hyderabad city). Due to continuing upstream development, the frequency of such events will increase in the future

Development of numerous surface water reservoirs as a basis for securing future water supply is a regular practice in semi-arid regions. The total impact is often considerably greater than the volumes extracted for water use, due to the large amount of losses by evaporation. The latter is the price to be paid by fulfilling water demand from surface-water storage facilities (Gunther et al, 2005). The potential evapotranspiration in the catchment ranges from 1600 to 1700 mm/yr. The increasing surface retention in the form of surface storage structures would imply increasing scope for higher evapotranspiration. And on a systems level, there is more water lost than being utilized within the system (potential reservoir inflows or groundwater infiltration).

In specific to the Osman Sagar drinking water supply system, the need is to view, understand and integrate the hydrological process upstream to the existing river network in the region (River Musi – upstream). The common goal towards such a process is to improve the water management within the system considering the common need for water resources amongst the different uses and users (irrigation in the upstream and drinking water for Hyderabad city in the downstream).

While integration of the hydrological regime within the entire Osman Sagar (supply) system would aim for improved reservoir inflows, it would also imply increasing nutrient load along with the inflows (considering the agricultural activity in the catchment). The water management at the river basin level need to go hand in hand with the quality aspects of the water regime.

4.4.2 Nutrient Load Threat to the Reservoir

In the semi-arid region the seasonal variation in the hydrological regime plays a vital role in the water quality aspects. By the very nature of the ephemeral behaviour of the River Musi, the Osman Sagar is a stagnant lake most part of the year, except for the monsoon season when it receives inflows from its catchment. The analysis from the years 2004 and 2005 indicates that the Osman Sagar reservoir has not received any inflows from the catchment and has solely been dependent on the direct rainfall over it. If this state continues, the stagnation of the reservoir would pave way to accelerated nutrient cycle within the reservoir. This would lead to eutrophication of the reservoir.

According to the water quality data (Figure 4.26, Figure 4.27) the dissolved oxygen level, nitrate levels are in the permissible limits of the primary water quality standards. The continuous withdrawal from the reservoir maintains the water resident time of the lake constant. However, this process has a drastic impact on the water level of the reservoir, which has been drastically reducing over the last few years (Figure 4.17).

As the level of the lake continues to lower due to high volume usage and reduced inflow, the elevation of the thermocline, a zone that separates a layer of cool water from a layer of warm water, also is lowered. As a result, the raw water withdrawal points, which are located at fixed elevations, may be exposed to a layer of warmer lake water, which is associated with poorer quality water. This may require increased efforts to treat the drinking water, which may lead to higher treatment costs (ILEC, 1991). To ensure continual drinking water supply, in the year 2008, raw water was being pumped out from the reservoir (Figure 4.42). This practice is carried out only at the extreme conditions when the water storage level in the reservoir reaches below the spillway point. Pumping out the raw water adds onto the energy costs.

Figure 4.42: Raw water being pumped from the reservoir

4.4.2.1 Agriculture as a Non-Point Source for Nutrients

The Osman Sagar catchment areas has around 136 kg/ha of fertilizer consumption in the year 2004 and 2005, while in the average per hectare fertilizer consumption in the rest of the India was 89.8kg per year. The consumption rate in the catchment area is recorded to be the highest in India. In terms of nitrogen, phosphorous and potassium, the consumption was 84.1, 35 and 17.7 kg/ hectare respectively (FAO, 2005)

The nutrient balance studies conducted by the ICRISAT at a micro-watershed in the catchment region showed they are low in available P (1.4 to 2.2 mg kg-1 soil), available N (11 mg kg-1 soil), in addition to low in organic carbon. The balances also showed that all systems were depleting N and K from soils, and that more P is applied than removed by crops. The trend is similar to that analysed in the present study, where the nutrient balance is negative for nitrogen and positive for

Phosphorous (Figure 4.23, Figure 4.24). However differs with Potassium (Figure 4.25).

The concern of the present case study is the probable threat of the nutrient input into the surface waters. At present, the watershed development activity and the soil conservation strategies could halt the water and sediment inflow into the reservoir. The soil erosion in the catchment has been recorded to be around 0.5 – 1 t/yr (Wani et al., 2003).

Considering the absence of reservoir inflow for the year 2004 and 2005, it is assumed that the nutrient runoff from the agricultural field would be distributed in various surface storage structures across the catchment. This situation enables the reservoir to still remain in oligotrophic status. However, the area is known to witness high intensity rainfall events. At time of such events, there is a threat of nutrient runoff from the agricultural area along with the surface flow into the reservoir.

The nutrient load analysis carried out in the present study is based on simple mass balance analysis. The attempt is to indicate the extent of nutrient consumption in the catchment, which is a potential threat to the oligotrophic status of the reservoir. In order to bring out the impact of the nutrient load on the reservoir, a much detailed nutrient flow analysis needs to be carried out. Such a detailed analysis must consider the seasonal, annual hydrological fluctuations (characteristic of the monsoon type of climate) and the resident time of the water in the reservoir. An (2000), indicate that under the monsoon type of climate annual water resident time may not be appropriate because of the dramatic monsoon fluctuations: annually and also seasonally (variation within the monsoon period). In respect to the nutrient loading, the author suggests that water resident time is one of the important parameters in diagnosing reservoir trophic state and suggest inverse relations of resident time to Nutrient Loads (OECD, 1982) studies of lakes and reservoirs (Vollenweider 1968) demonstrated that such models can be applied in the steady state of hydrology in lake-reservoir system.

At present, considering the oligotrophic status of the reservoir, severe protection against any kind of load is necessary, the emphasis lying on preventive measures. The GO 111 which is the conservation law for the Osman Sagar catchment restricts the establishment of any industries, hotels, residential colonies and other establishments that generate pollution within the 10 km radius of the reservoir (GoAP, 1996). But the GO does not refer to any guideline towards the restrictive usage of fertilizer within the catchment. This measure would be important to minimize the threat of excessive nutrient load into the reservoir. The catchment management strategies and practices in Germany stand out as possible guideline to adopt in the Osman Sagar scenario.

Earlier to the Water Framework Directive, the standard on ‘Protection of Drinking Water Obtainment’ (GDR standard, TGL 24.348) in Germany specifies the relevant provisions. The agricultural enterprises situated in the catchment areas of protected lakes and reservoirs may essentially reduce nutrient losses from their fields by specialization, for example to the soil exploitation type ‘grain-cultivation of forage plants.’ In the protected area the standard prohibits grazing tillage, application of organic fertilizers and their spreading as well as those of pesticides by plane. Territorial development schemes for catchment areas should always include statements on a proper water management and water quality development. At all places where drinking water supply with regional importance is given priority, the total development of this region shall be subordinated to this main utilization (Klapper, 1980).

The Federal Water Act (WHG) (BMU, 2002) also contains various approaches affecting agricultural activities. The discharge of substances into groundwater and the storage and deposition of substances which could contaminate the groundwater are prohibited. In addition to discharges other uses of water pursuant are likewise subject to licensing. The latter refers to measures deemed likely to cause permanent and significant harmful changes to water. The licence obligation therefore applies to agricultural measures which may pose a significant threat to water. However, good agricultural practice is not subject to a licensing under current water legislation (BMU, 2002). In case of Indian conditions, promoting organic agriculture needs to be given a higher priority

During the designation of drinking water protection areas, restrictions may be formulated for agriculture. The affected farmers may have an entitlement to financial compensation for the losses suffered as a result of the change in management. In conjunction with agriculture, the Flood Protection Act of 2005 mandates the Federal Länder to adopt provisions to avoid erosion and the discharge of pollutants (Marcel et al., 2002).

The Use of Fertilisers Ordinance, which implements the EC Nitrate Directive in German law, requires the preparation of fertiliser balances and stipulates that fertiliser quantities must be geared to plant requirements. For organic fertilisers of animal origin, the upper limits have been set at 170 kg N per hectare, per annum.

The Crop Protection Act contains principles for the authorisation and application of pesticides in accordance with ‘’good agricultural practice“. For instance, pesticides may not be used if their application is likely to have harmful effects on human or animal health or on the groundwater or the natural balance. When licensing a pesticide, the Federal Environmental Agency will investigate, whether any of its active ingredients or principal metabolites is likely to seep into the ground on a relevant scale. In order to keep the risk of damage to an ecologically justifiable level, where necessary, application provisions will be specified at the time of licensing. In order to protect against unjustifiable/undesirable discharges into the groundwater and surface water as a result of surface run-off, the use of selected pesticides is only permissible subject to the presence of a marginal strip of a defined minimum width sealed by plant growth, or application using a mulching technique. (Marcel et al., 2002)

In Germany, the standards given by different regulations are in accordance to the regional geological, ecological and the on-going agricultural practices. Similar scientific studies have to be carried out to set a safe limit for the usage of fertilizers in different river basins of India. Further, the strategies and directives in Germany display a strong integration amongst various sectors, agriculture, land use planning and water resource management. Adaptation of such framework in Indian scenario would require the same. The water resources management in the agricultural sector and the water resources monitoring and management are separated by administrative jurisdictions. Integration of these two sectors requires identifying the common needs and goals.

5 Conclusions

Instituting drinking water protection with a source water protection program involves balancing competing interests and conflicting demands within the watershed (EPA, 2000). To begin with it is essential to consider the watershed or the catchment as an integral part of the entire drinking water system. The integrated view presented in the present study) encompasses the catchment, reservoir and the treatment plant as a single system. This approach is an attempt to identify and understand various interactions (amongst climatological, geomorphological and anthropogenic factors) that affect the water dynamics within the Osman Sagar drinking water supply system.

The hydrological balance presented in the present study could identify and highlight the strong influence of the water dynamics of each of the subsystems on the overall functional behaviour of the entire Osman Sagar drinking water system. It was observed that within the period 2000-2005, Osman Sagar reservoir could supply around 23 Mi m^3 per annum to the city of Hyderabad. This indicates a 77% reduction in the performance of the supply system with reference to its established capacity (98.5 Mi m^3 per year). The present study could highlight three main issues that influence the water regime within the Osman Sagar drinking water system:

- natural climatic conditions
- influence of upstream agricultural activities on the reservoir inflows
- loopholes in the present conservation and management practices

The study highlights the strong influence of the natural ephemeral behaviour of the River Musi on the reservoir making it stay stagnant during most part of the year, except during the monsoon season. This is a typical situation to most of the river in the semi-arid region of India. Further, the annual fluctuations in the precipitation levels also exhibit a strong influence on the reservoir inflows. On an average within the study period of 2000-2005 the reservoir could receive around 44 Mi m^3 per year of inflows While the inflows are seasonal, the withdrawal is continuous making the withdrawal completely dependent on the available storage levels in the reservoir. Between 2000 and 2005 the storage capacity in the reservoir ranged from 80 Mi m^3 to -11 Mi m^3 per year. The study highlights the gradual increase of the reservoir dependency (from 30% to 100%) on the direct rainfall. In the year 2004 and 2005 the reservoir was completely dependent on the direct rainfall it received. Even though the year 2005 was recorded as wet year with surplus rainfall of +34%, the reservoir did not receive any inflows from its catchment.

The water regime assessment was carried out with two basic assumptions

- the surface runoff is the potential reservoir inflows
- the surface retention is the percentage of the runoff that is being retained within the catchment.

The surface retention was considered as an indicator for the surface and groundwater development activities that aid the irrigation needs within the catchment. Surface retention ranges from 47% to 100% within the study period. However, considering the high groundwater dependency within the catchment, it is essential to study and understand the surface water and groundwater interactions in detail.

At management level, the study could highlight the loopholes in the conservation practices of the reservoir. In particular to the exclusive rights on the surface water given to the reservoir clearly failed in sustaining the reservoir inflows. the conservation practices clearly ignored the influences of upstream surface and groundwater dynamics to the overall reservoir inflows within the system.

Even to this day, the management of freshwater sources in India has been very re-active. Preventive measures to halt the degradation of the fresh water sources have been given less emphasis and curative measures (remediation techniques) which are costly and technologically intensive gain more attention and popularity. As a pro-active measure, the catchment management act for Osman Sagar to an extent could halt the degradation of the reservoir. However, a mere restriction of certain land use activities such as establishment of hotels and industries around the reservoir and within the catchment could not halt the reservoir from depletion.

The case study of Osman Sagar (supply) system could once again highlight the sectoral conflicts (i.e agriculture versus urban water needs) and indicates the need for a review of the water allocation rights taking into consideration the water needs and demands of both upstream and downstream activities. This only draws our attention to the need for larger perspective of catchment management based on the integration of scientific assessment and appropriate management strategies. Recognizing the scarcity of water resources and an increasing water demand by changing climatic, environmental and socioeconomic conditions, adoption of integrated measures of water management is required to secure water availability in the future.

6 Outlook

The basis of any theoretical and practical consideration pertinent to lake management is the establishment of a sound mass balance. This applies to both water as a solvent and the solutes themselves. As far as possible these evaluations should be based on measurements in areas, the catchment and the lake (ILEC, 1990).

The present study is an overview of the hydrological regime across the drinking water supply system. The study brought out the importance of the changes at the source level (catchment) that could create a trivial to drastic impact on the freshwater resources. The water balance approach used in the study was an attempt to highlight the water dynamics as a systems perspective.

The monitoring system for River Musi is distinguished by its dual behaviour as a freshwater source (upstream) and wastewater carrier in the downstream. The monitoring stations for the river are present only in the downstream of the river. Thereby any data from these stations could not be considered for the present study. There are no monitoring stations in the upstream of the river, especially in the catchment area. In this regards, the data had to be compiled from different government, scientific and non-governmental sources. Considering the restriction in the time and other resources, field measurements could not be carried out and so validation of the acquired data had to be based on certain scientific assumptions. For instance, the surface retention factor in the present study was considered as a cumulative impact of the surface and groundwater development activities within the catchment. To validate this assumption, field observations and interactions with the scientific and research experts both in Germany and India could help in establishing the analytical framework of the study. However, a detailed scientific analysis is essential to further establish the identified interactions such as:

- influence of groundwater regime to the surface water flows in the catchment,
- impact of watershed development activities on the surface flow process,
- Specific land use changes within the catchment that hinder the surface flow process,
- morphometric dynamics and seasonal fluctuations of the upstream River Musi are necessary.

Further, it is essential to monitor these dynamics continuously and include it in the larger picture of basin level water management.

The spatial scale and the areal extension of the Osman Sagar supply system, makes it conducive to study and apply the principles and strategies of Integrated Water Resources Management. Effective IWRM models must address the two distinct systems that shape the water management landscape:

- Factors related to the bio-physical system, namely climate, topography, land cover, surface water hydrology, groundwater hydrology, soils, water quality, and ecosystems shape the availability of water and its movement through a watershed.
- Factors related to the socio-economic management system, driven largely by human demand for water, shape how available water is stored, allocated, and delivered within or across watershed boundaries. Increasingly operational objectives for the installed hydraulic infrastructure constructed as part of the management system seek to balance water for human use and water for environmental needs.

Adopting these principles the water management plan for the Osman Sagar drinking water supply system, on a long term perspective needs to consider and integrate the following aspects:

- **Semi-arid climatic feature of the region:** The high evapotranspiration would be an essential parameter to consider. Especially in the lieu of the surface storage structures within the catchment, there would be more water loss due to potential evapotranspiration than the water withdrawn from the structures.
- **Ephemeral behaviour of the River Musi:** The monsoon climatic feature of the region enables the water availability only during certain period of the year, making the rest of the year dry. The seasonal hydrological regime of the region influences not only the water availability but also the water quality aspect of the system.
- **Frequent droughts and high intensity rainfall:** Addressing water stress due to frequent droughts draws attention towards the water management both at supply end and also at consumption end. In the case of Osman Sagar (supply) system, it would be groundwater consumption for irrigation and domestic water in the catchment and also the water demand downstream in the Hyderabad city.
- **Land use changes within the catchment:** Although changes in the land uses are generally expected to change the water quality of receiving streams, the effects of land use changes on water quality can be difficult to evaluate

and are not likely to be similarl across land use types. In addition, different combinations of land use elements can create a spectrum of water quality effects. In reference to the present land use type (agriculture) and the projected urban push factor from the Hyderabad city, it would be essential to monitor the land use changes within the entire Osman Sagar system in order to prevent drastic water quality changes.

7 Recommendations

7.1 Immediate Measures

7.1.1 The Amendment of GO 111

Foremost, to ensure the drinking water status of the reservoir, it is essential to conserve the fresh water status of the Osman Sagar reservoir. The immediate threat to the reservoir is the urbanization from the Hyderabad city. The need for more space for the growing city is pushing the city limits more into the catchment area of the reservoir. The conservation measures issued by the GO 111 regarding prohibition of the establishment of hotels and industries within the 10 km radius of the reservoir should continue to be implemented.

The execution of Environment Impact Assessment studies (EIA) should be included in the GO and mandatory for any land use development activities within the catchment. Developments involving the constructions of farm houses, recreational resorts and residential areas need to go through EIA studies to understand the impact on the water regime within the catchment.

Secondly, the exclusive water rights on the surface Water for drinking water needs of Hyderabad city needs to be amended immediately. The exclusivity of the water rights restricts the integration of the water management for the entire catchment. For allocation of the water rights, a more detailed study reviewing the water needs, requirements of both upstream and downstream activities needs to be carried out.

7.1.2 Impact Assessment of Agricultural Activities

Watershed Activities

The hydrological balance presented in the present case study could highlight the impact of the surface retention on the overall water regime of the system. It is essential to further study and analyzes the specific impact of the watershed development activities in terms of the surface storage structures, artificial groundwater recharge mechanisms on the overall surface and groundwater regime within the system.

In terms of the surface storage structures, it needs to be understood that these storage structures (farm ponds, check dams etc) are interconnected all along the hydrological network of the catchment, mutually influencing their inflow and outflow volumes. Any further development of the lakes must therefore be to ensure the provision of a well-balanced relationship between utilization requirements (both upstream and downstream) and primarily aim towards bringing back the inflows into the River Musi.

Fertilizer Usage Impact
Considering the intensity of the agricultural practice within the catchment, it is essential to study and analyse the impact of the fertilizer usage on the water regime of the region. At present, the Osman Sagar reservoir is still at an oligotrophic status. Incase of oligotrophic lakes and reservoirs, severe protection against any kind of load is necessary, the emphasis lying on preventive measures (Klapper, 1980). System level assessment studies such as Material flow analysis' can be considered for needed study. Impact assessment of the Fertilizers on the overall water regime of the system would help in preparing timely preventive measures that would halt the process of nutrient loads into the reservoir.

7.1.3 Establishment of Monitoring System

Establishment of Water monitoring system across the catchment is essential to further understand the dynamic changes within the system; it is recommended to carry out regular monitoring of these hydrological interactions, through appropriate scientific intervention within the system. The interactions at each of the subsystem level have been pointed below:

Further, the monitoring system should comprise of:

- the groundwater consumption dynamics for irrigation,
- surface water harvesting schemes and activities,
- regular monitoring of the nutrient loads across the catchment and the surface runoff from the agricultural area into the surface waters.

Catchment

- the groundwater abstraction for irrigation and domestic usage,
- change in the natural infiltration process
- the impact of the watershed activities towards augmenting the artificial infiltration process within the catchment.
- contribution of the River Musi to the groundwater regime of the catchment.

Reservoir

- contribution of the reservoir to the groundwater.

- evapotranspiration losses.

Treatment Plant

- reasons for Transmission losses
- losses within the treatment facility

A schematic representation of the plausible integration points is presented in the Figure 7.1.

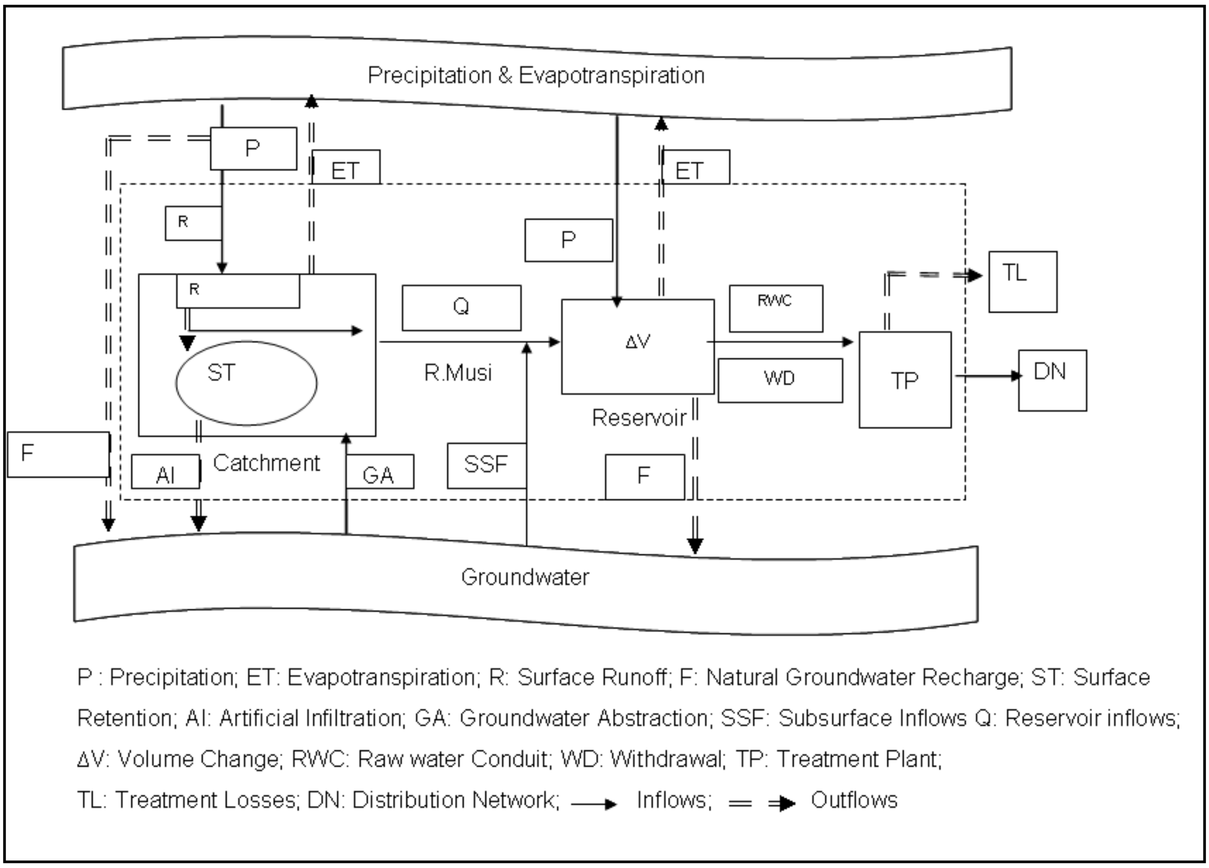

Figure 7.1: Integrated water management within Osman Sagar supply system

Note the dotted lines represent the loss within the system and the straight lines represent the inflows through the system.

Amongst the various interactions, the groundwater and the surface water interaction is vital. The groundwater abstraction (GA) in the form of irrigation and domestic consumption has to be monitored on regular basis. A sound monitoring system with the help of involvement of different stakeholders across the system would ensure a better understanding of the behaviour of the water regime. The data gathered from the monitoring system can be used for creating necessary water conservation and management strategies in tune with the necessary scientific and technical intervention

7.1.4 Controlling the Transmission and Treatment Losses

It is essential to monitor the transmission losses within the with drawl and the distribution network. At present the losses make upto 20% of the total raw water with drawl, which is a considerable amount.

7.2 Long Term Measures

7.2.1 Revising the Primary Water Quality Standards

The present 'Primary Water Quality Standards' referred by the Ministry of Water Resources need to be revised according to the nature of the water body and also the utility factor. Revision of the kind of parameters for assessment is essential. Towards this consultation with different Hydrological Research Institutes to establish the revision of the quality standards need to be considered. The quality standards should also consider the regional climatic, geomorphological and land use conditions.

7.2.2 Maintenance of the Reservoir and the Transmission System

Regular desilting of the reservoir would improve the storage capacity. This would enable the storage of the surplus flows that occur in the wet years when the rainfall exceeds the mean average rainfall.

The transmission losses during the supply of the raw water to the treatment plant needs to be checked regularly for leakages and illegal with drawl from the main pipe line. Further, considering the age of the transmission system, the impact of the water quality within the transmission line and the distribution system should also be checked time and again.

In many cases, the water loss indicators shown in these figures reflect the inefficiency of the management of the water supply system. Any reduction in water losses requires coherent action to address not only technical and operational issues but also institutional, planning, financial and administrative issues (WHO, 2000).

7.2.3 Water Conservation and Management at the Consumer Level

While the water management at the source and the supply level would aim to ensure regular supply of drinking water, conservation strategies that enable water saving practices at the consumer level (households, residential colonies or apartments) should be emphasized. Proper maintenance of the water meters at household level and promotion of rainwater harvesting practices should be emphasized. Controlling the storage limit of the public water supply could ensure equitable distribution of the water for the city. Towards this consumer level water consumption survey has to be conducted to arrive at per household actual water consumption number.

7.2.4 Upgradation of the Treament Plant

With respect to the changing land use, the quantity and quality of the raw water is also bound to change. Regular monitoring of the raw water quality within the reservoir is necessary. At the same time, upgradation of the treatment facility to meet the treatment requirements of the changing raw water quality and quantity is also essential.

7.2.4.1 Institutional Framework for Integrated Water Resource Management

In recent times, the increasing role and relevance of institutional structure to manage water resources at river basin level is gaining prominence. This is due to failure of large scale centralised interventions in the river basins and with growing concern for community-based approach. The failures are due to a misunderstanding that the river systems and communities as stable systems and can be controlled for development purely through techno-centric approach. However, the question is the overriding institutional issue on how to encourage an economically efficient and equitable allocation of water resources in view of the conflicting demands from various sectors, (agricultural, industrial and municipal water supply). This is complicated by the invariable presence of externalities and valid to the present case study where for example upstream and downstream interests lie in different geographical or legal jurisdictions (The World Bank, 2006).

The catchment of Osman Sagar is under the rural administration while the management of the reservoir is under the HMWWSB, Hyderabad city administration. There is a clear difference in geographical jurisdiction. However thinking across the geographical boundaries it would be essential to think on the lines of river basin in order to attain the common goal of fresh water resource protection. By managing water resources according to the territorial unit of an ecosystem rather than political-administrative boundaries, River basin management is designed to address the interdependencies between, in particular, upstream and downstream effects, water quality and water quantity, and water and adjacent land-use resources (OECD, 1989; Quarrie, 1992; The World Bank, 1993; UN-ECE, 1995).

The EU-WFD institutionalises river basin management across the European Union, requiring water management plans, programmes of measures and environmental quality objectives to be pursued on the scale of entire river basins. Within the broad range of policy objectives and instruments stipulated by the WFD, several have an explicit or implicit bearing on forms of land use relevant to maintaining and improving the quality of rivers, lakes and groundwater resources. By orienting water management around river basins the EU hopes to encourage a more holistic and territorially integrated approach to solving water-related problems. The new environmental quality objectives target not only point sources of pollution but also diffuse sources and a major innovation for EU water policy—the geomorphological and biological status of Rivers and lakes.

Mainly through the development and implementation of River Basin Management Plans, the WFDs overall environmental objective is the achievement of ‘good status’ for all of Europe’s surface- and ground-waters. The WFD establishes a framework providing a common approach, objectives, principles, definitions, and basic measures for water resource management in European countries. Covering both water quantity and quality, it stipulates that “for water quantity, overall principles should be laid down for control on abstraction and impoundment in order to ensure the environmental sustainability of the affected water systems ” and that “control of quantity is an ancillary element in securing good water quality and therefore measures on quantity, serving the objective of ensuring good quality, should also be established” (The World Bank, 2006).

WFD implementation involves a vast range of stakeholders, ranging from individual consumers, major water-using sectors such as agriculture and industry, and secondary uses like water-based recreation, to water supply/treatment companies, scientists, nature conservationists and the authorities involved in planning land and water use at local, regional, national and international levels.

The Figure 7.2 represents organizational structure of the Wesser River Basin commission in Germany. It has integrated the Water Framework Directives as part of their River basin management strategies. Consortium of the management organizations of the seven German regional states through which the Weser River flows. The consortium comprises the following regional states of Bavaria, Bremen, Hesse, Lower Saxony, North Rhine-Westphalia, Saxony-Anhalt and Thuringia (RBC, 2008)

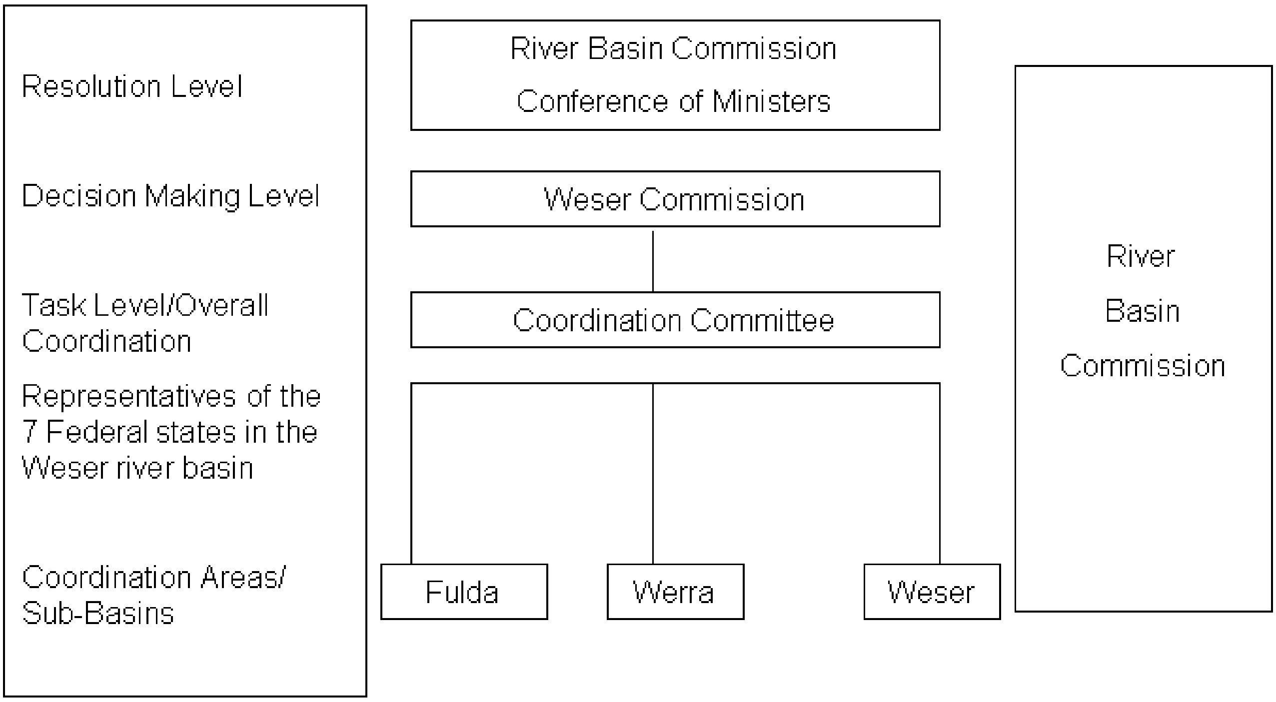

Figure 7.2: Implementation structure for the Water Framework Directive in the Weser river basin district (RBC, Weser, 2008)

The broad objectives of the Weser River Basin commission are enumerated as follows:

- Realize and coordinate water management activities throughout the Weser River basin. the main focus is anti-pollution measures,
- Coordinate large scale water management programs and measures, as well as decisions relating to water legislation, with a view to keeping the Weser clean,
- Gather data on and assess the water quality of the Weser and its headwaters, and publish the results of investigations (RBC, 2008).

Adaptation of the integrated water resource management for the Osman Sagar supply system should include the following aspects as essential preliminary activity:

- **Review of the Monitoring System** The water resources management plan has to be based on scientific understanding and regular monitoring of the surface and the groundwater dynamics (both quantitative and qualitative) within the system. At present, the monitoring system is held at two levels.

a. Surface water quality at the Reservoir level (monitored by the HMWWSB)
b. Groundwater quality at the different stations in the catchment (monitored by the CGWB).

It is essential to extend the monitoring system of the surface water to the entire catchment. The surface water quality parameters for the reservoir need to be reviewed on two important aspects

a) In view with the nature of the water body which is a reservoir.
b) The intensity of fertilizer consumption in the agricultural sector in the catchment.

At this point, it is essential to highlight the need to include phosphorous as an essential parameter in the monitoring system as phosphorous is the deciding factor in the nutrient cycle of a lake/reservoir.

This task would require the intervention by the Central Water Commission and the Union Ministry of Water Resources of India to review the national primary water quality standards in India (Appendix 1).

- **Water rights** institutionalizing the integrated water resource management of the Osman Sagar catchment would be to recognize the water resource (both surface water and groundwater) as a common resource for all the stakeholders within the system.The stakeholders include the agricultural sector upstream and the water consumers in the Hyderabad city. Even to this day, the agricultural sector in the catchment area is prohibited from using the surface water for irrigation. The exclusive rights of the surface water from the upstream of River Musi are with the consumers of the waters from Osman Sagar reservoir. By recognizing water resource as a common resource for both the stakeholder groups would mean extension of the water rights to the agricultural sector in the catchment too. This step calls for an amendment of the conservation laws for the Osman Sagar reservoir (GO 111, 1996).

- **Identification of stakeholder groups** Identification and inclusion of the stakeholder groups as part of the framework should be based on the user group (as agriculture, domestic water use, drinking water use-Hyderabad city etc) rather than the political regions. The region already includes groups such as water users association, watershed development agencies which are active within the rural development sector of the catchment area. Integrating these groups to the larger catchment management committee is essential to understand the agricultural and irrigation needs and perspectives.

With these background activities in place, the framework for the integrated water resource management for the Osman Sagar catchment is represented in the Figure 7.3

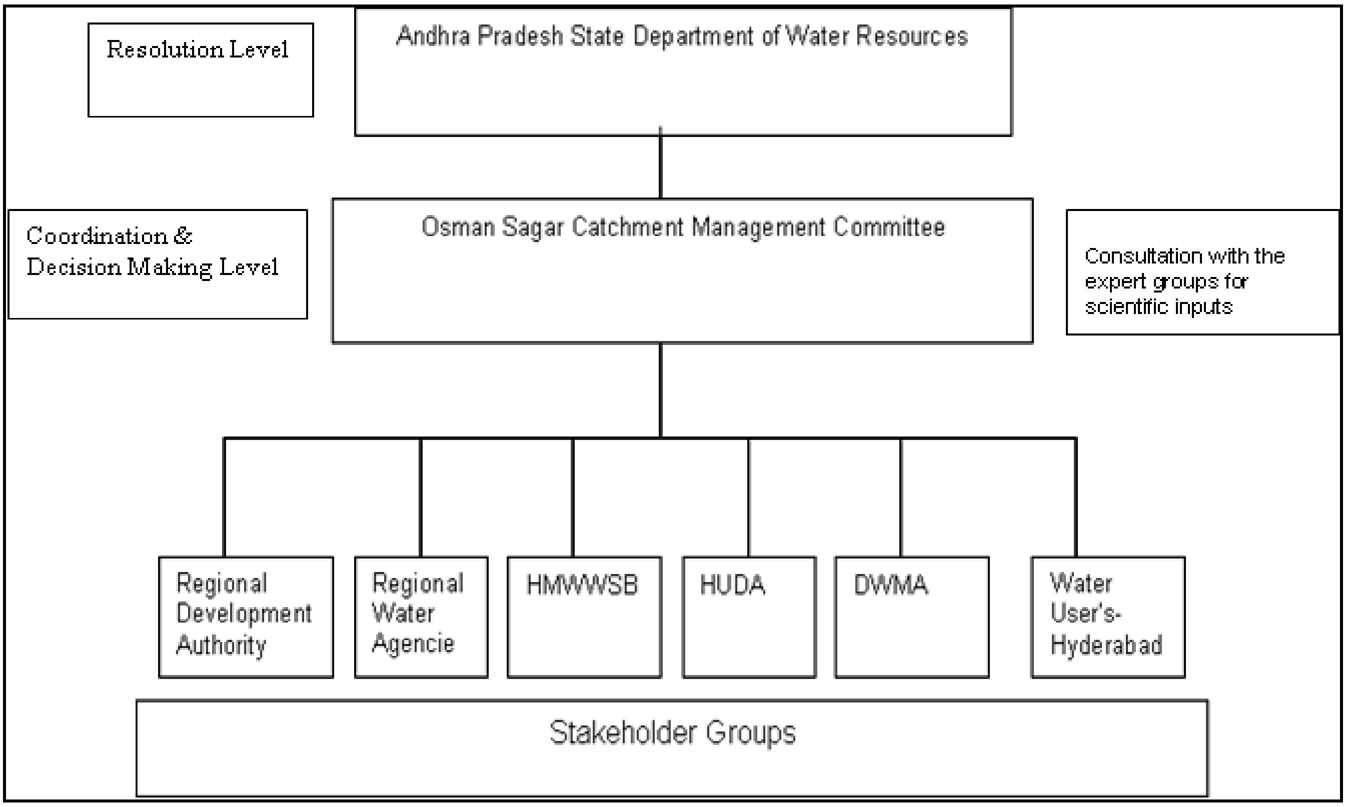

Figure 7.3: Proposed organisation structure for Osman Sagar catchment management

The proposed organisational structure is a three tier framework involving the stakeholder groups, the catchment management committee and the Andhra Pradesh State Department of Water Resources.

The stakeholder groups

- **Regional Development Authority:**
  The Mandal Revenue Office (MRO) is the highest administrative authority at the mandal level in India. It plays an important role as the regional development authority. The catchment area comprises of six mandals and the involvement of all MROs is important. Their role is mostly towards regulating the land use changes and the local development plans.

- **Regional Water Supply and Sewerage Boards:** this group of stakeholder includes the water supply and sewerage boards in all the six mandals present within the catchment. Their role would be primarily to monitor the drinking water consumption and wastewater production status within the catchment.

- **District Water Management Agencies (DWMA):** They are primarily responsible for water management at the agricultural sector. Inclusion of DWMA is essential to understand the dynamics of watershed and groundwater development activities within the respective micro watershed of the catchment. In regards to the water quality monitoring at respective micro watersheds, the groups can be equipped with basic water monitoring devices to carry out the activity.

- **HMWWSB:** It is the primary organisation responsible for the management of the Osman Sagar reservoir. The board is also responsible to monitor the water quality of the reservoir, the treatment and the supply of the drinking water to the respective consumers in the city of Hyderabad.

- **HUDA:** Hyderabad Urban Development Authority (HUDA) as the primary organization in the regional development of the Hyderabad city. Its role within the Osman Sagar Catchment Management committee is vital in view of integrating the Hyderabad urban development plans and activities with the development and conservation activities of the catchment.

- **Water users group of Osman Sagar reservoir:** This group includes the consumer section of the drinking water from the Osman Sagar within the city of Hyderabad. The presence of this group is also an essential feature to connect the consumer to its source. Further, it is essential to understand the water demand and consumption dynamics at the consumer end, in order to maintain the efficiency of the entire supply system.

Decision Making Level

- **Osman Sagar Catchment Management Committee:** this committee is the central coordinating and decision making committee. The committee should include a representative from each of the stakeholder groups to mitigate the information across the stakeholder groups and also to the resolution committee at the Andhra Pradesh state department of the water resources.

The role of the management committee should be:

a) Compile the data and information on the water dynamics (both quantitative and qualitative) across the different stakeholder groups.
b) Monitor the water management practices across the stakeholder groups and take appropriate decision. For instance, the committee can decide on the number of groundwater wells or surface storage structures within the catchment in the greater interest of the water management at the catchment level.
c) Regularly mitigate information to the State Department of Water Resources.

The committee should take opinions and intervention of the scientific groups to review the strategies and practices with institutions such as EPTRI, CGWB and NGRI could be in regular consultation.

Resolution Level

The Andhra Pradesh State Department of Water Resources in coordination with the Ministry of Water Resources have the highest authority to resolve the decision taken by the Catchment Management Committee. The Ministry as part of the regulatory affairs can continue its role as a facilitator in the activities concerning the water resources management. The specific role in regards to the catchment management would include reviewing conservation laws and acts, amendment of the acts and Government orders if required and facilitate financial and other resources towards smooth operation of the water resource management activities.

The proposed management plan is a plausible adaptation of the integrated River basin management practices in Germany. Modification and concrete establishment of the plan has to be based on an in-depth scientific analysis of the hydrological interactions which are more specific to the Indian conditions and more specifically to the catchment of Osman Sagar.

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Appendix

Appendix 1 Tolerance limits of relating to selected pollution parameters for Inland surface water required for different uses (Bureau of Indian Standards)

S.NO	Characteristics	Unit	A	B	C	D	E
1	pH		6.5-8.5	6.5- 8.5	6.5-8.5	6.5-8.5	6.0-8.5
2	Electrical conductivity a 25C	Micromho/cm/ max	-	-	-	1000	2250
3	Calcium	mg/l (max)	80	-	-	-	-
4	Magnesium	mg/l (max)	24	-	-	-	-
5	Iron	mg/l (max)	0.30	-	50.00	-	-
6	Free ammonia	mg/l (max)	-	-	-	1.20	-
7	Chloride	mg/l (max)	250.00	-	600.00	-	600.00
8	Fluoride	mg/l (max)	1.50	1.50	1.50	-	-
9	Sulphate	mg/l (max)	400.00	-	400.00	-	1000.00
10	Nitrate	mg/l (max)	20.00	-	50.00		
11	Dissolved Oxygen	mg/l (max)	6.00	5.00	4.00	4.00	-
12	Biochemical Oxygen demand	mg/l (max)	2.00	3.00	3.00	-	-
13	Total coliform	Most probable number (MPN)/100ml	50.00	500.00	5000.00	-	-
14	Arsenic	mg/l (max)	0.05	0.20	0.20	-	-
15	Boron	mg/l (max)	-	-	-	-	2.00
16	Cadmium	mg/l (max)	0.01				
17	Chromium	mg/l (max)	0.05	0.05	0.05	-	-
18	Copper	mg/l (max)	1.50		1.50		
19	Cyanide	mg/l (max)	0.05	0.05	0.05	-	-
20	Lead	mg/l (max)	0.10		0.10		
21	Manganese	mg/l (max)	0.50				
22	Mercury	mg/l (max)	0.001				
23	Zinc	mg/l (max)	15.00		15.00		
24	Phenolic Compunds	mg/l (max)	0.002	0.005	0.005		
25	Total Hardness	mg/l (max)	300				
26	Sodium percentage	(max)					60.00
27	Sodium Absorption Ratio	(max)					26.00

The elaboration for the classification of the classes as A, B, C, D and E as:

A	Drinking water source without conventional treatment but after disinfection.
B	Outdoor bathing (organized)
C	Drinking Water source after conventional treatment and Disinfection
D	Propogation of wildlife and fisheries
E	Irrigation, industrial cooling, controlled waste disposal.

Nutrient removal by different crops

Crop groups	**Crops (kg/ha)**	**Fertilizer use (kg/ha)**	**Average fertilizer use (kg/ha)**
Cereals	Rice		89.65
	Wheat		
	Maize		
Pulses	Soghum		36.2
	Pigeon pea		
	legumes		
Sugarcane		207.1	207.1
Vegetable s	Potatoes		34.5
	Tomatoes		
Others	Oil seeds		70