Irrigation Schemes Using Solar Energy: A Case Study in Togblo, District of Athieme – Province of Mono – Benin

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DEDICATION

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ABBREVIATIONS AND ACRONYMS

ABERME	Benin Agency for Rural Electrification and Control of Energy
AET	Actual Evapotranspiration
ASECNA	Agency for Air Navigation Security in Africa and Madagascar
CARDER	Regional Action Centre for Rural Development
CeCPA	Communal Centre for Agriculture Promotion
CENATEL	National Centre of Remote Sensing and Control of forest Cover
CeRPA	Regional Centre for Agriculture Promotion
DGE	General Direction of Water
Et_{crop}	Crop Evapotranspiration
ET_m	Maximal Evapotranspiration
ENERDAS	Energy Dahito System
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organisation
GPM	Gallon Per Minute
GRVC	Revolutionary Group for Cooperative Purpose
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
INSAE	National Institute of Statistics and Economic Analysis
MAEP	Ministry of Agriculture, Livestock and Fishing
MDG	Millennium Development Goals
MMEE	Ministry of Mines, Energy and Water
NGO	Non Governmental Organisation
NPSH	Net Positive Suction Head
PADMOC	Development Program of Agriculture in Mono and Couffo provinces
PADRO	Development Program of Agriculture in the province of Oueme
PET	Potential Evapotranspiration
PPP	Public Private Partnership
PSH	Peak Sunshine Hour
PV	Photovoltaic
SELF	Solar Electric Light Fund
UAC	University of Abomey-Calavi

ABSTRACT

Due to the availability of many water courses and shallow depth of groundwater (3 to 8 m), farmers in southern Benin are increasingly interested in horticultural enterprises. However, many threats are hindering the development of their activities. Most farmers in the study areas use hand pumps, power-driving pumps or electric pumps. While the first type of pump is environment friendly and does not need any external source of energy, the two other need respectively fossil fuel and electricity. In the developing country context of Benin, the use of electric pumps is not permanently possible as there is almost no reliable supply of electricity and there are still parts of the country with no connection to mains. The current trend in fossil oil prices – continuous increase with almost no chance that this will drastically change – does not allow farmers to continue with power-driving pumps.

There is then a need for other irrigation systems that help farmers to deal with those problems in an efficient and sustainable way. This study is conducted to analyze the possibility of introducing solar pumping systems in southern Benin. The study shows that all actors in the irrigation sector are highly interested in such project. It also tries to find out problems encountered by farmers and proposes solutions to overcome them. A cost-benefit analysis has been carried out to find out cost-competitive range where solar irrigation can be afforded by farmers. Investigations have also been done to see the influence of water source (surface water or groundwater) on the overall price of the project.

The results demonstrate that solar photovoltaic pumping for irrigation purposes is economically feasible for sites with enough solar radiation, crops with low water demand and high economical value, small plots and irrigation techniques with higher efficiency.

The irrigation technique proposed in this study (drip irrigation using a reservoir for water storage) is very simple and does not need highly qualified people. However, there is still much to do, to make irrigation using solar energy a reality in Benin. The relatively high investment costs need the involvement of government, technical and above all financial institutions. Having said all this there is a promising future for solar energy in Benin as the country benefits from a relatively good sunshine throughout the year.

Keywords: Horticultural enterprise – Farmers – Solar pumping system – Drip irrigation – Southern Benin.

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1. Introduction

Like most of sub-Saharan African countries, economy in Benin largely depends on agriculture. Almost 75% of the active population work in this sector that contributes to about 40% of the GDP (INSAE, 2002). Food crops help the country to ensure a relative food self sufficiency in which urban and sub-urban agriculture plays an important role. In the major cities of Benin, horticultural enterprises are arranged in urban and suburban areas to supply cities with market gardening products. This type of agriculture is more developed in the southern part of the country (provinces of Littoral, Altantique, Oueme, Plateau, Mono and Couffo). However, food security is not yet fully guaranteed as horticultural enterprises that are an essential link in the chain of agriculture are facing many problems.
The lower part of southern Benin (provinces of Littoral, Mono and Oueme) is where irrigation for market gardening is very developed in comparison to the rest of the country. In this part of Benin many efforts have been made to reduce farmers' dependency on rainfall by introducing the use of power-driven pumps, electric pumps and hand pumps. The intensive use of manure and fertilizer also help to develop urban and sub-urban agriculture on relatively small plots. The major activities in southern Benin are rain fed agriculture, fishing, livestock, flower cultivation, processing of agricultural products, craft industry and trade. Most of the people are not getting satisfactory results from those traditional activities and are increasingly interested in horticultural enterprises. In fact, horticultural enterprises yield higher revenues and have the advantage of being practised throughout the year.

The shallow depth of the groundwater and the existence of numerous water bodies in southern Benin coupled with the relatively low costs of power-driven and electric pumps makes the practise of market gardening possible throughout the year. Another advantage is that yields from irrigated crops or vegetables are higher than from rain fed land crops. For the agricultural campaign 2003-2004, 325 ha were irrigated for the purpose of horticultural enterprises in the province of Mono. More than 500 ha were irrigated in Oueme and only about 100 ha in Littoral (MAEP, 2004). Those areas – which are relatively low compared to the available irrigation potential of Benin – will shrink if nothing is done to improve the cultural and irrigation techniques.

As land is becoming scarcer, fossil fuel more expensive, electricity supply less reliable in Benin; it is important to explore other irrigation techniques that can help farmers to by-pass current problems and continue their activities. The present study: "Irrigation scheme using solar energy: a case study in Togblo, district of Athiémé – Province of Mono – Benin" is carried out in order to contribute to the development of irrigated agriculture in general and horticultural enterprises in particular. The present study is divided in three major parts:

- the first part deals with the theoretical framework through problem statement, objectives, hypotheses, literature revue and methodology
- the second part presents the results and discussions
- the third part is concerned with verification of hypotheses and recommendations.

I- THEORETICAL FRAMEWORK

2. Problem statement, objectives and hypotheses

2.1 Problem statement

Many people do not believe in solar energy because it said to be too expensive, it needs more space, sophisticated skills, is difficult to store and so on. However there are reasons to believe that solar energy has a future. At the 2005 UN World Summit the condition of our planet was described as follow:

- half of the world's population has to survive with less than 2€ a day;
- 26,000 people are dying each day of hunger and of lack of water;
- the industrialised countries consume as much coal, gas and oil per day as nature generates within 500,000 days;
- each 32 hours the US is spending for military and wars as much money as the UN's annual budget;
- due to greenhouse effect almost a hundred species of animals and plants are becoming extinct every day
- every day humanity grows by a quarter of a million of people;
- the four richest men of the US possess more money than the poorest billion of the planet (Krauter, 2006).

This statement shows that poverty is the major problem affecting the planet. It is why the first of the eight UN Millennium Goals of Development (MDG) is to "Eradicate extreme poverty and hunger". To reach this goal sustainable development of agriculture is essential. Most of Developing Countries' populations, especially African ones are still suffering from starvation. In sub-Saharan Africa, rain fed agriculture is the major way of growing crops. Consequently, yields are heavily dependent on weather hazards as irrigation is still at its early stages. Yet, only 7 % of Africa's arable land is irrigated – down to 4 percent in Sub-Saharan Africa (FAO, 2005).

The situation of irrigation is more critical in Benin. The irrigation potential of Benin is estimated to 300,000 ha of which only 12,258 ha are irrigated, that is about 4 % (AQUASAT, 1994 & 2008). Similarly less than 1% of the 13.1 km^3 renewable surface water available is used for irrigation purpose (AQUASTAT, 2005). The rural population of Benin is estimated to 54.7 % of the total population and is relying, almost exclusively, on rain fed agriculture (IFPRI, 2007). Consequently a shortage or excess of water drastically affects the yields. To handle the problem of lack of water, some populations are developing small irrigation schemes for horticultural enterprise purpose. Most of those schemes are situated in Southern Benin, which is composed of the six provinces of Atlantique, Littoral, Mono, Couffo and Ouémé, and Plateau.

The district of Grand-Popo, situated in the province of Mono, is the most advanced one in market gardening at the national level. There is also ongoing irrigated rice cultivation project in the district of Dogbo in the province of Couffo where 315 people are organised in a cooperative and share 105 ha. In northern Benin, due to lack of water – the groundwater table is very low and there are no water bodies except in the river Niger basin - it is not easy to develop market gardening.

In the South of Benin water availability is not a big problem. The renewable water resources from the rivers Mono, Couffo and Ouémé basins are estimated to 8.76 km^3/year (Agossou & Sossou, 2005). Despite the relative abundance of water, farmers involved in irrigation are facing many problems:

- need of large manpower for those, who are still using watering cans and streams and wells as source of water;
- high cost of fuel (gasoline) for farmers, who are using fossil-fuel-power-driven pumps;
- high running costs for farmers, who are using electric pumps as electricity supply is not reliable and they are obliged to couple the electric pumps with diesel pumps;
- uncontrolled use of pesticides and fertilizers, the only goal being to achieve higher yields;
- needs for larger areas, especially in the South;
- lack of financial support and technical training;
- negative correlation between the area under irrigation, and the efficiency of the irrigation system.

Due the problems mentioned above, the profitability of irrigation schemes in Benin is subject to caution. Most farmers are complaining about the explosion in fuel prices on one hand and the unreliability of electricity on the other hand. There are also some farmers, who want to go for an automated irrigation as they are working on relatively larger areas and need increasing amount of manpower, which is also high running cost. The economic profitability of horticultural enterprises discussed here is not only in terms of revenues or benefits but also in terms of reliability of source of energy and water, environment, in other words 'sustainability'. It is well known that a controlled irrigation yields revenues that favour prosperity in countries that practise it. The highest yields that can be obtained from irrigation are more than double the highest yields that can be obtained from rainfed agriculture (FAO, 2002-a). It is therefore urgent to develop sustainable irrigation in developing countries such as Benin to ensure self-sufficiency and potentially create an export market for the excess of production. Wind energy and/or solar energy can be good alternatives to gasoline and electricity. Southern Benin does not benefit from sufficient wind speed (less than 2 m/s), but fortunately the solar radiation in Benin is significant during the dry season when crop require irrigation. The main obstacle of using solar energy is the investment cost that is really high. The drastic and continuous increase of the oil price might be another reason to look for alternative sources of energy.

Taking all those factors into account, one should not to draw any hasty conclusion in regards to solar energy but to study various cases in order to find cost-competitive ranges where solar energy can be a realistic alternative to gasoline power-driving pumps and electric-grid ones. This master thesis topic: "Irrigation schemes using solar energy: a case study in Togblo, District of Athiémé – Province of Mono – Benin" aims at studying the possibility of introducing solar pumping systems in accordance with the selection of suitable irrigation and cultivation techniques, in order to promote sustainable irrigated agriculture in Benin.

2.2 Objectives

2.2.1 General objective

The general objective is to find cost-competitive ranges where solar pumping can be a realistic alternative to the ongoing pumping systems in South Benin and indicate suitable irrigation methods, cultivation techniques and crops.

2.2.2 Specific objectives

- Identify areas where there is on-going irrigation in south Benin (Provinces of Mono, Atlantique and Oueme)
- Identify factors that hinder the development of irrigation in South Benin and get the opinion of farmers and representatives of technical and financial institutions on solar pumping
- Select a site for tomato cultivation using solar pumping systems (Case Study)

- Elaborate on the growth conditions for tomatoes (soil type, quality of water, use of fertilizer and pesticide, traditional and modern cultivation techniques.)
- Compare solar pumping and other pumping systems (gasoline, electricity) in terms of costs, impacts on the environment and reliability, especially in regard to tomato cultivation
- Formulate recommendations to improve and encourage irrigation in general and solar pumping in particular.

2.3 Hypotheses

- Solar pumping for irrigation is suitable for small schemes, for crops with relatively low water demand, for sites with sufficient solar radiation and for irrigation techniques with high efficiency.
- With the continuous increase of oil price, the awareness about environment problems and a poor electrification level in rural areas of Benin, solar pumping may be a good alternative to the traditional pumping systems currently used for irrigation purpose.

3. Literature revue

The literature revue is done through the three following sections:

- definition of concepts;
- some important factors for irrigation and solar pumping;
- presentation of the study area.

3.1 Definition of concepts

3.1.1 Irrigation

Irrigation is water artificially applied to farm, orchard, and horticultural crops (Prinz, 2007). This definition is very close to the one given by Oxford advanced learner's dictionary (7th edition) for which "to irrigate is to supply water to an area of land through pipes or channels so that crops will grow".

3.1.2 Irrigation methods

Irrigation method or technique is the way water is supplied to crops. There are five basic methods of applying water to the soil:

- surface irrigation
- sprinkler irrigation
- subsurface irrigation
- micro-irrigation
- trickle/drip irrigation (Prinz, 2007)

➢ Surface irrigation

Surface irrigation methods are based on the principle of moving a water stream over the surface of the land in other to wet it, either completely or partially.

➢ Sprinkler irrigation

It is the application and distribution of water over the field in the form of a spray, or jet, which breaks into drops or droplets created by expelling water under pressure from an orifice or nozzle.

- Subsurface irrigation

Subsurface irrigation involves the application of water to crops via underground systems. In principle, two systems can be distinguished, a buried trickle irrigation system and a ditch water infiltration system.

- Micro-irrigation

It is the slow application of water on, above or beneath the soil. It includes surface drip (SDI), subsurface drip (SSDI), micro-sprayers, or micro-sprinklers.

- Drip (trickle irrigation)

The principle of trickle irrigation is to water the plants by means of low flow pressure pipelines. Irrigation efficiency is high, since losses by evaporation are negligible and percolation losses are low.

3.1.3 Solar energy

Definitions

- Irradiance

It is solar emissive power incident on a surface per unit area. Its unit is W/m^2 (Singh, 2007)

- Irradiation

Irradiation is solar emissive energy incident on a surface. It is the integration of irradiance over a specific time. It is also known as insolation and its unit is J/m^2 (Singh, 2007)

- Solar Constant (I_{sc} or G_{sc})

It is defined as the energy per unit time (power) received on a unit area of surface perpendicular to the direction of propagation of radiation at the mean earth-sun distance (outside the atmosphere). A worldwide accepted value of solar constant is 1367 W/m^2. Due to earth's elliptical path around the sun, I_{sc} varies (± 1.7%) throughout the year.

$$I_{ext} = I_{sc} \left(1+0.033 \cos \left(\frac{2\pi n}{365}\right)\right)$$

where:

n is the day number of the year

I_{ext} is the extraterrestrial radiation incident on the plane normal to the radiation on the nth day of the year (Singh, 2007).

Solar radiation can strike a surface either directly, i.e. beam radiation or indirectly in means of diffuse radiation or albedo radiation.

- Beam radiation (direct radiation)

The solar radiation received from the sun without having being scattered by the atmosphere (Duffie and Beckman, 2006)

- Diffuse radiation (sky or solar sky radiation)

The solar radiation received from the sun after its direction has been changed by scattering by atmosphere (Duffie and Beckman, 2006)

- Total solar radiation (global radiation)

It is the sum of the beam and the diffuse solar radiation on a surface. The most common measurements of solar radiation are total radiation. However, it is also possible to measure beam radiation alone.

- Angle of incidence (θ)

It is the angle between the beam radiation on a surface and the normal to that surface. It is obtained by the following formula.

$$\text{Cos}\,\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega$$
$$\cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega \quad (1)$$

Where:

δ	Declination
ϕ	Latitude
β	Slope
γ	Surface azimuth angle
ω	Hour angle

- Instruments for measuring solar radiation

Instruments for measuring solar radiation are of two basic types:

- *Pyrheliometer :* It is an instrument using a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun (i.e. beam radiation) at normal incidence. (Duffie and Beckman, 2006)
- *Pyranometer:* It is an instrument for measuring total hemispherical solar (beam and diffuse) radiation, usually on horizontal surface. If shaded from the beam radiation by a shade ring or disc, a pyranometer measures diffuse radiation. (Duffie and Beckman, 2006)

Available solar energy

Solar radiation received on the earth's surface is subject to variations to change in the extraterrestrial radiation and also to two additional and more important phenomena: (a) atmospheric scattering by air molecules, water and dust and (b) atmospheric absorption by O_3, H_2O, and CO_2. Those factors made the estimation of solar radiation on the earth's surface difficult due to climate variation from one location to another, sometimes even inside the same climatic zone. The most useful solar radiation data is based on long-term (30 years or more) measured average values at a location (Goswami et al, 1999). The total power falling on a horizontal surface called (global irradiance) reaches a maximum of about 1000 W/m^2 at sea level. The total solar energy received in a day can vary from 0.5 k W/m^2 in a northern winter, to 6 kW/ m^2 in the tropics (Barlow et al., 1993). The global irradiance varies during the course of the day mainly because of the change in the sun angle and thus the path length of rays in the atmosphere. It also depends on altitudes and seasons. On a clear day the diffuse radiation is relatively small compared to the total radiation (about 15%) but on a cloudy day almost all radiation is diffused. Even on completely cloudy days, there may (Barlow et al., 1993) well be enough diffuse radiation to continue pumping although direct sunlight will obviously give better performance (Barlow et al., 1993). Although solar power greatly depends on climate and location in the long term the daily insolation is a well defined parameter for a given area and is less site specific than wind energy for example.

Water pumping application for solar energy

Due to the high cost involved in solar equipment, especially photovoltaic (PV) modules, solar pumping is most cost-effective for small power demand applications, say less than 1000 W. This matches very well with the type of pumping loads needed in developing countries. The two major demands for water supply in developing world are: (i) village water supply and (ii) irrigation. Some decades ago, it was very difficult to prove solar pumping cost-competitiveness in purely economic terms. Besides, most solar installation around the world for village water supply or small irrigation schemes were totally financed by international institution such as World Bank. However, as drinking water is normally a right for any human being, many solar pumping projects for village water supply in drinking water have been and are being implemented all over the world. Almost two decades ago solar PV irrigation was said to be profitable for only small schemes as stated in the following sentence. "In practise PV irrigation can usually only be competitive for micro-irrigation schemes for vegetables gardens and plots of less than about 1 ha (Barlow, 1993)". Nowadays, with the improvement of solar cell efficiency followed by a significant cut down of solar equipments prices on one hand and the continuous increase of fossil oil prices on the other hand, the boundaries of solar pumping can be extended. The great economic advantage of ecological energy generation is that sun, wind, hydro power and geothermal energy will never a bill to humans. The matter is available almost everywhere where we need it – without the necessity of complex global transport routes. What we need is the mass production new energy technologies. The prices of those have fallen by 50% since 1995 – and the costs of the old energies doubled by that time period (Krauter, 2005).

Energy requirement for water pumping

In general the daily maximum power (Hydraulic energy) required to lift water is:

$$E = QHg/\eta \quad (2)$$

Where:

Q mass of water delivered per day in ton/day or m^3 /day. As 1kg = 1liter, Q = V

H Static head in m

g acceleration due to gravity (9.81 m/s^2)

η total system efficiency at maximum flow (no dimension)

Provided those units, the result will be in KJ. To convert in MJ, we multiply by 10^{-3}. Formula (2) can be rewritten as follows:

$E = 10^{-3} x9.81\ VH$ (in KJ) (3)

Since 1 KWh = 3.6 MJ, to get the energy in kWh, we simply divide formula (3) by 3.6.

$E = 10^{-3} x9.81\ VH/3.6 = 2.725x10^{-3}\ VH$ (in kWh) (4)

We can rewrite this in the following form:

$E = VH/367$ (in kWh) (5)

The hydraulic energy needed to lift a certain amount of water is proportional to the product of the amount of water to be lifted and the height through which it is lifted, the so called Volume –Head product.

Only a small fraction of the available solar radiation is converted to hydraulic energy. Only about 10-15% of solar energy input is converted to electrical energy (Barlow et. al., 1993). Perhaps the most promising future PV cells will consist of thin films. These films are not single crystal devices, so there are limitations to carrier mobility and subsequent device performance. However, in spite of the non-single-crystal structures, laboratory conversion efficiencies exceeding 17% have been achieved (Messenger and Ventre, 1999).

Due to the relatively low efficiency of solar cells, solar pumping is recommended only under some circumstances or conditions.

Village water supply: volume-head product (Vh)< 800 m^4 and daily insolation >2.8 kWh/m^2

Irrigation: volume-head product (Vh)< 250 m^4 and daily insolation >3.0 kWh/m^2 (Barlow, 1993).

3.1.4 Pumps, diesel pumps, electrical pumps and solar pumps

A pump is a unit used for transportation of liquids, fluids and gases through pipes or similar channels (Zycon, 2008). In irrigation, pumps are used to lift water. The most used pumps in irrigation are:

- hand pumps, treadle pumps, pumps using animal traction,

- solar pumps and wind pumps, using renewable energies
- pumps using fossil fuel (diesel or gas oil)
- electric pumps using electricity.

Pumps using human or animal power or renewable energies

- ➢ Handpumps and treadle pumps

Hand pumps, although les productive than foot pumps, are the most common form of industrially manufactured, manually operated water pumps, and for that reason are very widely used. Most of these pumps were developed for use by families to provide mainly drinking water for themselves and their livestock rather than for irrigation (Fraenkel, 1997).

- ➢ Pumps using animal power

The advantages of animal power over human power are of two types. First, draught animals are five to ten times more powerful than humans, so they can pump more water from wells in a shorter time which tends to make irrigation operations more efficient and productive. Second, it frees the operator, who can often manage the water distribution system more effectively, from having to work with the water lifting device (Fraenkel, 1997).

- ➢ Wind power

The wind has been used for pumping water for many centuries; it was in fact the primary method used for dewatering large areas of Netherlands from the thirteenth century onwards. Most wind pumps need mean wind speeds of 2.5 to 3 m/s to begin to be economically attractive and wind generators need 3.5 to 5 m/s (Fraenkel, 1997).

- ➢ Solar power

Small-scale irrigation pumping is one of the more attractive applications for solar power. There are two main ways of converting solar energy into power for driving a pump. Solar thermodynamic systems depend on using the heat of the sun to power an engine, while solar photovoltaic systems convert solar radiation directly to electricity by means of photocells, and hence they can power an electric pump.

Photo 1: Solar pumping system in Kalale - northern Benin (Photo: Noumon, 2008)

Pumps using fossil fuel

- Internal combustion engine

Internal combustion (i.c.) piston engine is one of the well known and wide spread power engines, especially in areas where there is no mains electricity. Its two main forms are the petrol (gasoline) fuelled spark ignition engine (s.i.) or the diesel fuelled compression ignition engine (c.i.)

- External combustion engines

The main difference between internal and external engines is that the former burns its fuel inside the power cylinder while the latter uses its fuel to heat a gas or a vapour though the walls of an external chamber, and the heated gas or vapour is then transferred to the power cylinder.

Photo 2: Gasoline power-driving pump in southern Benin (Photo: Noumon, 2008)

Pumps using electrical power

Electrical power is the easiest and most cost-effective source of power when there is a connection to reliable mains electricity supply

3.1.5 The choice of pumping system

Before discussing the choice of pumping system it is worth to define and present some parameters related to pumps.

- Gross Working Head (Gross Pumping Head)

The gross pumping head that determines the actual power need is the sum of the friction head, the velocity head and the vertical height (static head) on both the suction side of the pump and on the delivery side.

- Friction head and velocity head (head losses)

The friction head is generated by phenomena such as resistance to flow caused by viscosity of the water and turbulence in the pump or pipes.

The velocity head is the apparent resistance to flow caused by accelerating the water from rest to a given velocity through the system. Any object or material with mass resists any attempt to change its state of motion so that a force is needed to accelerate it from rest to its travelling velocity (Fraenkel, 1997). The static head or vertical height is the difference of altitude between the suction side of the pump and the delivery side.

The main issue is to try, as much as possible, to reduce the above mentioned losses in order to increase the efficiency of the pumping system. There are graphics, designed for pumps that help to evaluate the various losses; once the discharge, the diameter and the material used to make the pipe are known. Where it is difficult to calculate the head losses, they are assumed to be 10 % of the static head (Atidegla, 2005).

- Net Positive Head Suction Head (NPSH)

This is the positive head (atmospheric head – pressure head at pump exit) above the vapour pressure (H_v) condition at given fluid temperature. This definition refers to the availability criterion; it is why NPSH is also called NPSHA. The Net Positive Suction Head Required for cavitation to begin (NPSHR) is obtained either from elaborate experimental testing or analytical equations. The criteria for identifying cavitation in experimental means are noise, bubble formation and decrease in performance. (Singh, 2007).

Manufacturers provide for each pump in function of the discharge, curves that indicate NPSH values. The theoretical maximal total suction head is 10.33 m at atmospheric pressure. As a rule, this value has to be diminished by the water vapour tension T as followed:

- 0.123 m at the temperature of 10° C
- 0.230 at the temperature of 20° C
- 0.424 at the temperature of 30° C

One must also subtract:

- head losses in the suction pipe J_{suc}, which are about 1m,
- NPSH required at the entrance of the pump that generally varies from 1 m to 5 m.

Stern (1994), states that for each pump, at a given flow, there is a maximal geometric suction head H_{gs} given by:

$$H_{gs} = 10,33 - T - J_{suc} - NPSH$$

However, it is cautious to reduce the H_{gs} value by 1 to 2 metres.

- Discharge

The discharge of a pump is the quantity of water it can provide per unit time. It can be expressed either in cubic meter per hour (m^3/h) or litre per second (l/s).

- Efficiency of pump system

The system's hydraulic efficiency can be defined as the ratio of hydraulic energy to raise the water delivered to the field through the static head, to the hydraulic energy actually needed for the amount of water drawn from the pump. It varies from 20% to 50% depending on the systems (Fraenkel, 1997).

- Pumping power or power used by the pump

It is the quantity of energy supplied in a given time (1 second or 1 hour)

- The choice of pumping system

There are three main groups of criteria: financial, economical and practical considerations.

Financial considerations: any investment has to be financed; if the investment costs are too high and/or the credit conditions too unfavourable, then a system with lower investment costs and higher running costs might be more appropriate.

Economical considerations: the ultimate criterion for choosing an irrigation pumping system is to obtain the most "cost-effective" system. This is done through: calculation of investment plus running costs and benefits and relative economics of different options.

Practical considerations: It is worth elaborating on some of the practical, in addition to economic, considerations that relate to the different types of water-lifting system. This is done by analysing the status and availability of the technology, capital costs versus recurrent costs; operational convenience; skill requirements for installation; operation and maintenance; durability, reliability and useful life and potential for local manufacture (Fraenkel, 1997).

- Installed power

Due to the difficult conditions in which the pump will work (high temperatures, continuous work), only 75% of the available power will be used. This means a reduction of the pumping power (Atidegla, 2005).

3.1.6 Pipe, join and canalisation (Definitions)

- *Pipe:* It is a tube through which liquids and gases can flow. Rebour and Deloy (1990) define a pipe as an "element of constant section used for circulation of a fluid"

- *Join:* It is a connection intended to ensure the continuity between two separated or different pipes.

- *Canalisation:* a canalisation or piping is a conduit intended to ensure the circulation of the pumped water by a pump . In our case, it is the transport of water for irrigation purpose.

3.1.7 Wells, drilling and reservoir

Chollier and Poirier (1981) define a well as a vertical hole dug in the soil equipped with masonry elements to reach the groundwater. One distinguishes traditional wells (0.9 to 1.2 m diameter) and large diameter wells (1.2 to 1.8 m diameter). Water is taken from a traditionnal well mainly by the mean of a bucket tied to a rope.

A drilling is a well realised in a modern way using a drill. The diameter of a drilling is almost identical to the one of the pipe through which water is pumped. Here, a diesel-driving pump or an electric pump is needed to draw water.

A reservoir is an infrastructure made to store water for different purposes. The standard reservoirs in Benin, are made of masonry or concrete.

3.1.8 Irrigation techniques

- Irrigation technique/method

Irrigation methods vary in different parts of the country and on different farms within a community because of various differences in soil, topography, water supply, crops and customs (Prinz, 2007). However, it is important to mention that sprinkler irrigation favours the spread of fungi diseases when used for susceptible crops like tomatoes. It is why most of farmers using sprinklers to grow tomatoes have to apply more pesticides. It is the role of the farmer, with the help of technical adviser, to choose the most convenient technique suitable for the site.

- Selection of the suitable irrigation methods

Table 1: Factors affecting the selection of the appropriate irrigation method (Prinz, 2008)

Irrigation technique	**Factors affecting the selection of the appropriate irrigation method**					
	Land	**Soil**	**Crop**	**Climate**	**Advantages**	**Disadvantages**
Surface	Land levelled or graded to control slope and surface smoothness	Suitable for medium to fine textures but not for infiltrability 15 mm/hr, 1mm/hr	For most crops, except those sensitive to standing water or poor aeration	For most climates only slightly affected by wind	Low cost, simple, low pressure required	Prone to over-irrigation and rising water table
Sprinkler	For all land	For most soils	For most crops except those sensitive to fungal disease and leaf scorch	Affected by wind (drift, evaporation, and poor distribution)	Control of rate and frequency. Allows irrigation on sloping and sandy soils	Initial costs and pressure requirements high
Drip	For all slope, regular and irregular	Fall all soils and intake rate	For row crops and orchards but not closing growing crop	Not affected by wind. Adapted to all climate	High frequency & precise irrigation. Can use slightly saline water and rough land. Reduced evaporation	High initial and annual costs. Requires expert management. Prone to clogging. Requires filtration
Micro - sprayer	For all land	For all intake rates	For row crops and orchards	May be affected by wind	High frequency and precise irrigation. Less prone to clogging	High initial and maintenance costs
Bubbler	Flat lands and gentle slopes	For all intake rates	For tree crops	Not affected by wind	High frequency irrigation. No clogging. Simple	Not a commercial product.

3.1.9 Environment

According to the Framework Law on Environment in Benin, "Environment is all of natural and man-made elements as well as economic, social and cultural factors that have influence on human beings and which can be modified by them. For example, a horticultural enterprise taken in its location (village, municipality or district) forms with the aforementioned location an environment called the ‘environment horticultural enterprise" (Atidegla, 2005).

3.1.10 Urban and sub-urban horticultural enterprise

Gardening exploitation is a piece of land used by one or many farmers to produce and sell vegetables and fruits. When the gardening exploitation is situated in or on periphery of cities, it is called urban or peri-urban horticultural enterprise.

3.2 Some determinant factors for irrigation

According to Haest (1997), factors to be taken into account while dealing with irrigation are:

- Climate,
- Soils, which serve as support for the transport and storage of water and nutrients
- Plants, that have specific water needs at each stage of its growth
- Evapotranspiration
- Human, who chooses, designs and realises the irrigation network in function of the local conditions to ensure the better use of water
- The level of technology that can be afford by local populations
- The revenues of farmers if irrigation is to be done on individual basis
- The economy of the country if irrigation programs have to be financed by the government
- Finance conditions (interests rate, investment rates, period for repayment of capital and interest)

For a better understanding of this study, concepts clarification is necessary for soil, evapotranspiration and crops water demands.

3.2.1 Soils

Soil plays a vital role in ecosystems because it transforms non-continuous rainfall or snow into a continuous supply of water for plant growth (Prinz, 2007).

In agriculture and particularly in irrigation, it is essential to know:

- The quantity of water a soil at a certain time can supply to plants. Porosity, density, infiltration rate of water in soil and the available soil moisture determine the hydraulic properties of that soil.
- The content of nutrients such as nitrogen (N), phosphorous (P) and potassium (K) influence the fertility of the soil.
- Porosity.

The water content is function of porosity, infiltrability and permeability. The maximal water volume that a soil can retain against gravity is called "field capacity", which essentially depends on the soil’s particle size. Near surface soils are saturated after a rainfall event only, normally free spaces do contain water and air; water is subject to gravity and capillary forces. Under saturated conditions, all pores are filled with water, this saturated zone forms a sheet; gravity forces are predominant (Beauchamp, 2005).

Porosity is the ratio in percentage of the volume of space in the soil (space filled by water and air) to the total volume of the soil. It varies from 30 to 40% for sandy soils and 40 to 55% for clay soils.

- Density

For soils, one distinguishes two types of density: the real density and the bulk density.

  - real density (dr): it the density of particles contained in the soils, its mean value is 2.6
  - bulk density (da): It is the ratio of the weight of dry soil of a given volume of soil in situ to the weight of an equal volume of water. Here are some values of the apparent density:

    -sandy soil: da = 1.5 to 1.8

    - silty soil: da = 1.3 to1.5

    - clayey soil: 1.1 to 1.3

- Infiltration rate of water in soil

The infiltration rate strictly depends on the volume of spaces interconnected inside the soil. Coarse soils and soils with high aggregation coefficients show generally wide spaces, consequently an infiltration and permeability higher than clay soil, which is heavy and compact. In most soils, the infiltration rate decreases with the infiltration duration. It is relatively fast at the beginning, and then decreases progressively, until it reaches a point known as "maximum rate of absorption". The infiltration rate has impacts on the duration and the flow of irrigation water. The hourly rainfall by sprinkler in mm/h should have to be equal or less than the infiltration rate. Otherwise, there is a runoff with loss of effectiveness leading to erosion of the soil surface and afterwards a destruction of the surface structure.
Table 2 gives some idea about values of infiltration rate for the main soil textures

Table 2: Infiltration rates of different soils (Atidegla, 2006)

Infiltration rate	**Mm/h**	**Types of soil**
High	30 – 80	Sand, silt, sandy-clay silt
Moderately high	15 – 30	Fine silt
Moderately low	5 – 15	Silty clay , fine silty clay
Low	2-5	Clay

It is important to remember, that the infiltration rate can considerably vary from one location to another and it is advised to do some local inspection.

- Potentially available water

The water, which is potentially available to plants during the growing season, is the water held between field capacity and permanent wilting point.

- Available soil moisture (stored water in soil)

The available soil moisture, the bulk density, the wilting point, field capacity and some other average soil physical characteristics are given in table 3:

Table 3: Average soil physical characteristics (Prinz, 2007)

Textural class	Bulk density (D_b)	Total pore space (V_p%)	Field capacity (vol%)	Wilting point (vol.%)	Available moisture by volume (AMC% = mm/dm)	Air capacity at FC (V_a%)	Average SP (%)
Sandy	1.55 – 1.80	32 – 42	10 – 20	4 - 10	6 - 10	23	23
Sandy loam	1.40 - 1.60	40 – 47	15 – 27	6 – 12	9 – 15	22	28
Loam	1.35 - 1.50	43 – 49	25 – 36	11 – 17	14 – 20	16	33
Clay loam	1.30 – 1.40	47 – 51	31 – 41	15 – 20	16 – 22	13	36
Silty clay	1.25 – 1.35	49 – 53	35 – 46	17 – 23	18 – 23	11	39
Clay	1.20 – 1.30	51 – 55	39 – 49	19 – 24	20 – 25	9	42

Tablea 4: Water available according to different soils (FAO, 1988)

Type of soil	**Moisture in % of dry weight**		**Water depth available per layer of soil, at field capacity in mm/cm**
	At field capacity	At wilting point	
Coarse sand	3 – 5	1 – 3	0.20 – 0.40
Fine sand	5 – 10	3 – 6	0.40 – 0.70
Silty sand	10 – 15	6 – 8	0.70 – 1.00
Silt	12 – 18	7 – 10	0.80 – 1.30
Silty clay	15 – 20	8 – 15	1.00 – 1.80
clay	25 – 40	12 – 20	1.60 – 3.00

The available stored water for plants also depends on the volume taken by plants' roots. The more the root system is developed, the more important is the water stored for plants.

- Roots depth

The root system of a crop determines its irrigation water demand and the soil water content as well. Young plants will just need enough water to wet the surface layers. As and when the aerial part of the plant grows, its roots also develop in depth and laterally to reach a full development when they are closer to maturity.

Table 5 gives an idea about roots depth of some vegetables that reach maturity on irrigated soils for a soil depth varying between 35 and 70 cm according to species.

Table 5: Effective roots depth of some mature gardening cultures (FAO, 1988)

Cultures	Root depth (cm)
Aubergine	75 – 90
Carrot	45 – 60
Cabbage	45 – 60
Beans	50 – 70
Lettuce	30 – 50
Onion	30 – 50
Pepper	40 – 70
Sweet pepper	40 – 70
Tomato	40 - 80

3.2.2 Potential and actual evapotranspiration

The concept of evapotranspiration refers to the total atmospheric losses of water from soil and plant surfaces. The potential evapotranspiration (PET) is a measure of the ability of the atmosphere to remove water from surfaces/plants through the processes of evaporation and transpiration assuming no limitation by water supply. The actual evapotranspition (AET) is the quantity of water that is removed due to the processes of evaporation and transpiration (Prinz, 2007)

3.2.3 Estimation of evapotranspiration

Evapotranspiration can be estimated by a lysimeter, which is a large container for measuring the different water components

Evapotranspiration is computed by subtracting losses from the total water input. The result is used to calibrate ETo computation.

3.2.4 Reference Evapotranspiration (ETo)

The reference evapotranspiration is the rate of evapotranspiration from an extended surface of 8-15 cm tall grass cover of uniform height, actively growing, completely shading the ground and not short of water or nutrients.

3.2.5 Crop stages of development and crop coefficient

There are four main stages of plant development:

- initial stage
- growth stage
- flowering and fruit stage
- maturation and senescence.

Crop water demand depends on the following parameters:

- type of crop (tomato for example has a higher evapotranspiration compared to melon)
- stage of growth period. This is why the potential evapotranspiration is corrected by the crop coefficient to adapt it to each plant at a given growth stage.

Crop coefficient (Kc) is a dimensionless number (usually between 0.1 and 1.2) that is multiplied by the reference crop evapotranspiration (ETo) to arrive at a crop evapotranspiration (Etc) estimate. Crop coefficients vary by:

- crop
- stage of growth
- by some cultural practises
- by season etc.

Appropriate crop coefficients should be used with the corresponding reference evapotranspiration that is the grass taken as reference crop or for a hypothetical crop. Tables 6 and 7 give information about crop coefficients and lengths of development stages.

Table 6: Crop coefficient according to the different growth stage (Source: Atidegla, 2006)

Crops	Stages of plant development			
	Initial	Growth s	Flowering and fruiting	Maturation and senescence
Carrot	0.45	0.75	1.05	0.90
Tomato	0.45	0.75	1.15	0.80
Onion	0.50	0.75	1.05	0.85
Pepper	0.35	0.70	1.05	0.90
French bean	0.35	0.70	1.10	0.90

Table 7: Growing periods of tomato (Source: Atidegla, 2006)

Stage	Development stage	Stage length in days
0	Establishment	20
1	Development	30
2	Mid-season	30
3	Late-season	20
4	Harvest	20

3.3 Presentation of the study area

3.3.1 Brief description of the study area

As previously mentioned above, the lower part of southern Benin is composed of three provinces: Mono, Littoral and Ouémé. It covers an area of 2965 km^2, which represents about 2.6 % of the total area of Benin. It is delineated by Atlantic ocean in the south, the Republic of Nigeria at the East, the Republic of Togo at the West and the provinces of Couffo, Atlantic and Plateau in the North (INSAE, 2003).

Those three provinces have a total population of 1,755,909 inhabitants; this represents about 26 % of the total population of Benin. The population density is 593 $inhabit/km^2$ and the population growth rate is about 2.9% (INSAE, 2003). In 2008, this population is about 2,084,464 assuming the growth rate of 2.9 %. It is essentially an agricultural population except the population of the coastline where services and commerce are more developed. Administratively, those three provinces are subdivided in districts, sub-districts and villages.

The study area covers the districts of Athiémé and Grand-Popo in Mono, the city of Cotonou in Littoral and the district of Sèmè-Kpodji in the province of Ouémé. Those areas are selected because there are already on-going irrigation there and the benefit sufficient rainfall, have shallow water table and are crossed by many important water courses. Those 4 districts count 860,154 inhabitants, which is about 13 % of the population of the region (INSAE, 2002). In 2008, the population in the 4 district is about 1,021000 inhabitants.

The region benefits a subequatorial climate characterised by low temperature variations as follows:

- a major dry season from November to April (of high interest for this study)
- a major raining season from April to July
- a small dry season from August to September
- a small raining season from September to October.

3.3.2 Location of the selected site

The selected site is the hamlet of Togblo. It is located in the district of Athieme, sub-district of Atchannou in the province of Mono. This site has been chosen for many reasons:

- The well-known know-how of its population in regard to agriculture in general and horticulture enterprise in particular (the GRVC Togblo won the Benin agricultural price in 1984, 1985 and 1989 where they participate in a regional meeting of five French West African countries in Burkina-Faso)
- Its proximity to a permanent water course (river Mono);
- Its geographical position (in Benin but very close to Togo)

On figure 1 the district of Athieme is the shaded region of the map.

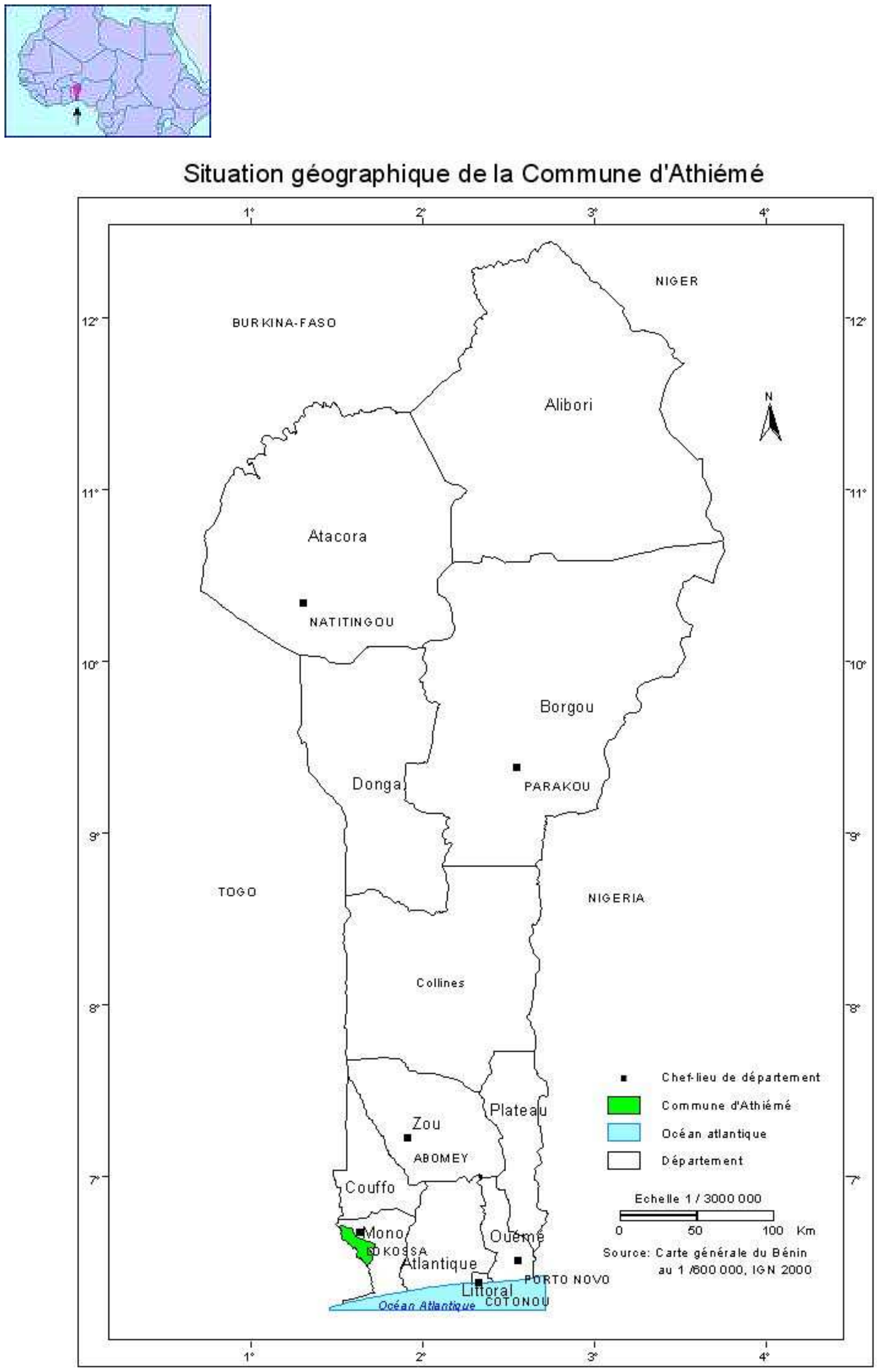

Figure 1: Location of the district of Athieme on Benin Map (Source: CENATEL, 2008)

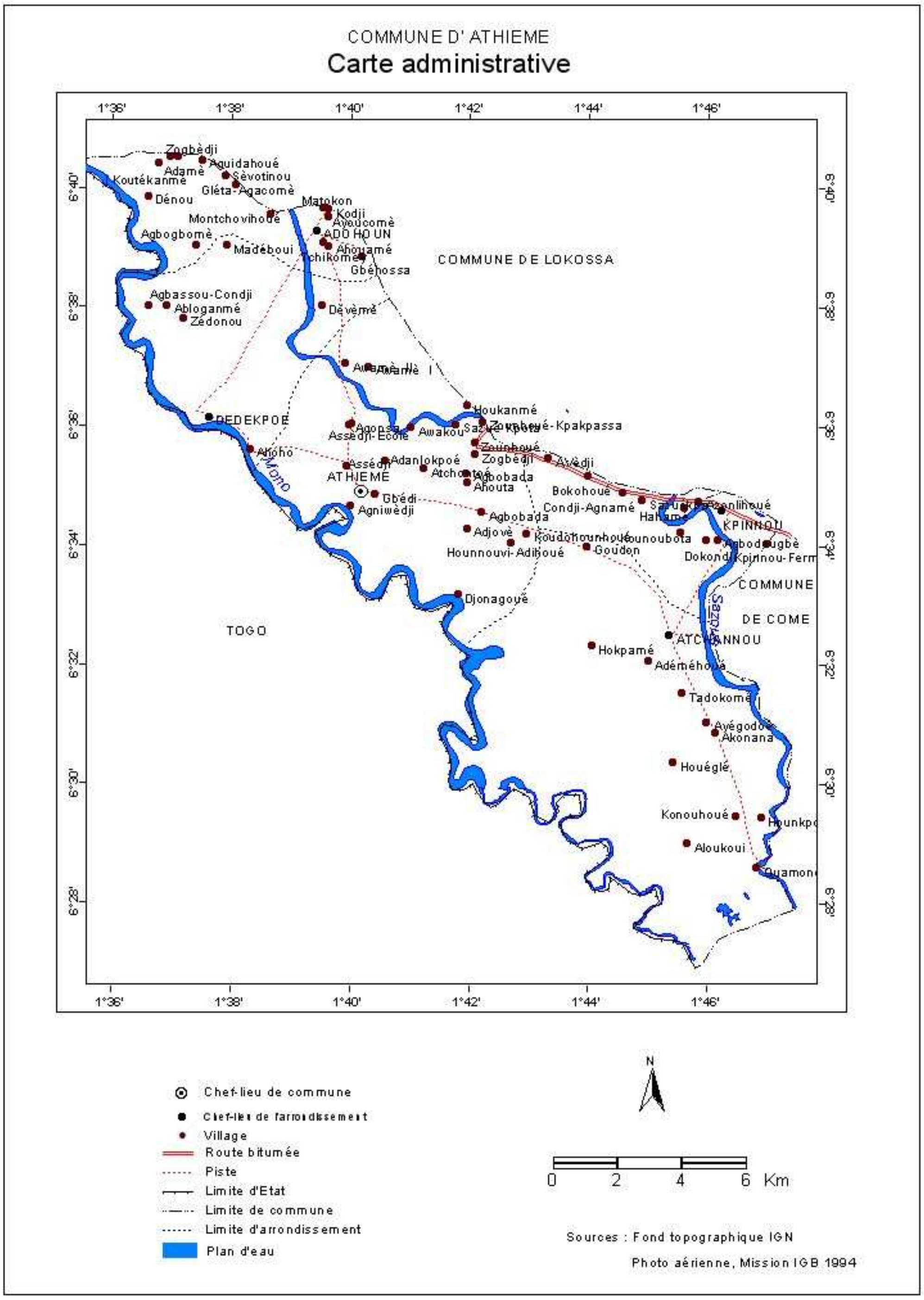

Figure 2: Administrative map of Athieme (Source: CENATEL, 2008)

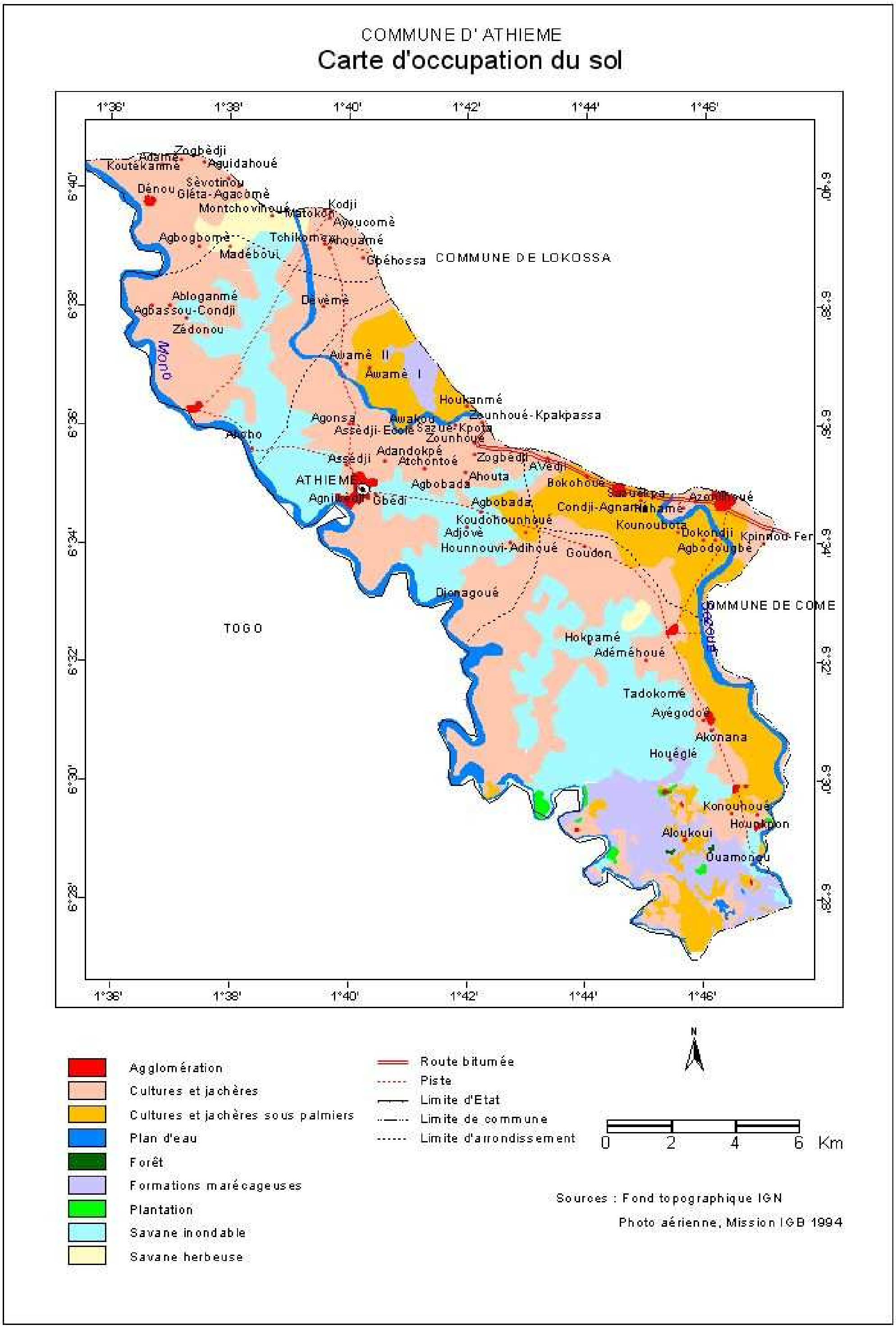

Figure 3: Land use map of Athieme (Source: CENATEL, 2008)

3.3.3 Landscape

Figure 3 illustrates the different types of land uses characterising the area in the district of Athieme. They are:

- Settlements
- Crops and fallows
- Crop and fallows under palm trees
- Water bodies
- Forests
- Marshy formations
- Plantations
- Flooding savannah
- Grass savannah

There are also some oil palms and coconut palms. Small scheme irrigation using mainly water scanning and power- driven pumps are being developed.

3.3.4 Water courses

The three above mentioned provinces are crossed by many rivers such as Mono and Ouémé, lakes such as Toho and Aheme, lagoons suach lagoon of Porto-Novo and lagoon of Cotonou. Specifically Athieme is drained by the River Mono and its diffluent Sazue, and lake Toho.

3.3.5 Hydrology: discharges and water height of river Mono

In analysing discharges and water height of river Mono, one distinguishes two periods:

- from 1944 (establishment of hydrological gauge in Athieme) to 1986 (construction of the hydroelectric dam of Nagbeto)

- from 1987 (commissioning of Nagbeto dam) to 2005.

Tables 8 and 9 show mean annual maximal and minimum discharges, water height and mean monthly discharges.

Table 8: Discharges and water height of river Mono (Modified after DGE, MMEE)

Period	Mean Qmax (m^3/s)	Mean Qmin (m^3/s)	Mean H_{max} (cm)	Mean H_{min} (cm)
1944-1986	654.7	14.83	646.26	36.07
1987-2005	516	34.58	683.94	192.24
Mean annual discharge		101		

Before the construction of Nagbeto dam, peak discharges and water height were very important. On the other hand it happens that the river bed is totally dry. Since the construction of the dam, water heights and discharges are regulated by the operation of the dam. Consequently the peak discharges are lower while the minimal discharges have higher values. Both maximal and minimal water height are higher than before the construction of the dam. The annual mean flow is 101 m^3/s and the annual quantity of water at Athieme station is about 3.2 km^3.

Table 9: Mean monthly discharges in m^3/s (Modified after DGE, MMEE)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
44-86	3.26	1.63	2.77	5.10	8.54	58.87	167.64	303.59	416.23	275.62	73.47	12.21
87-05	81.35	85.50	63.11	58.99	65.63	64.81	167.02	245.66	364.26	315.53	130.31	119.74

The peak discharge occurs in September irrespective of the period (before or after Nagbeto dam). However the magnitude of peak discharge is more important before the Nagbeto dam than after its commissioning. With the commissioning of the dam, river Mono discharges are distributed over the year; there is always water in the river bed.

3.3.6 Soils in the study area

Southern Benin (Provinces of Littoral, Mono and Oueme) shows rather different soils.

In Littoral soils are white and ferruginous soils. Due to the proximity of sea, there are also some salty soils.

The types of soils in Mono are colluvial and alluvial soils of rivers and lakes basins. Most of soils are hydromorph, very rich soils in organic matter, and fertile but subject to inundation due to seasonal rise of river Mono water level. There are also sandy soils, less fertile suitable for coconuts trees. There are many unexploited swampy areas.

Ferralitic, clayey and sandy soils are the characteristic soils of the Oueme province. They have low field capacity with deep water table. There are also alluvial, colluvial and hydromorphic soils, which are fertile; and sand and less fertile soils essentially suitable to coconuts trees.

Located between two water courses (the River Mono and its tributary Sazue), the district of Athieme is mainly made of hydromorphic and rich soils, subject to frequent inundations.

3.3.7 Socio-economic activities

The major economic activities vary from one province to another. In Littoral province, the major activities are manufactory industries (17%), fishing, livestock, market gardening and above all trading (42%) . Fishing, agriculture and livestock (50%) are the major occupations of Mono's populations. These activities are followed by the transformation (processing) of agricultural products, artisans and trading (22%). Trading (45%), agriculture (15%) and other sevices (13%) are the major activities practised in Oueme province (INSAE, 2004).

The district of Athieme being located in Mono, its population practise the same activities as the one described above. But in addition to rainfed agriculture, people living near the river Mono practice agriculture on the bank or recessing farming in the "Togome gble" (literally "fields near the water"). This involves growing vegetables for commercial sale (Trebaol & Chabal, 2003)

3.4 Opportunities for irrigation in the study area

3.4.1 Climatic factors

Climatic factors determine the suitability to undertake irrigation activities. Those climatic factors are mainly rainfall, temperature, evapotranspiration, solar radiation and sunny days, and relative moisture content of the air.

- Length of records required

The length of record necessary to obtain an adequate description of a meteorological element and to cover its variations in time, depends upon the same factors as network density, with some differences in emphasis. Table 10 shows the required number of years.

Table 10: Number of years of records required for meteorological elements (WIESNER, 1970)

Climatic element	Extra tropical regions				Tropical regions			
	Islands	Coast	Plains	Mountains	Islands	Coast	Plains	Mountains
Temperature	10	15	15	25	5	8	10	15
Humidity	3	6	5	10	1	2	3	6
Precipitation	25	30	40	50	30	40	40	50
Sunshine or cloudiness	4	4	8	12	2	3	4	6

- Rainfall

Only recent rainfall data (1999-2007) are available for Athieme and the number of years of this period does not fulfil the requirements suggested in table 10 by Wiesner (1970). However, Athieme is located in the same climatic zone as Bohicon where rainfall data have been collected since 1965. The mean monthly rainfall data at Bohicon's station are given in the following table for the last 41 years (1965-2005).

Table 11: Rainfall in Bohicon from 1965 to 2005 (Source: ASECNA – 2008)

Rainfall	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	4.9	29.7	69.6	131.2	137.5	163.9	149.9	117.1	142.3	115.2	23.18	14.04
Wet days	0.9	2.1	6.7	10.5	12.5	15.1	13.4	12.4	13.4	12.0	3.1	1.1

Over the period 1965-2005, the annual mean rainfall is 1098.5 mm with monthly variation from 4.9 mm to 163.9 mm and the total number of wet days is 103.2. It is important to mention that seasons are, nowadays, subject to many modifications. In analysing rainfall data one has to distinguish two periods: the wet (humid) sequence (before 1972) and the dry sequence (after 1972) when the recorded rainfall has started decreasing significantly in the River Mono basin (Amoussou et al, 2007). The major raining season that generally starts in mid-march is starting these days in May. This means that the major raining season is getting shorter and the dry one longer. There is then a real need to grow crops in dry season if populations in southern Benin in general and those from Athieme in particular want to reach self-sufficiency. Those changes in rainfall distribution throughout the year also create another problem. There are excess of water in June that causes inundation of farms and destruction of cereals such as maize and roots crops.

- Temperature

Due to its geographical situation (near to Equator), the study area in general and Athieme in particular receive a lot of sunshine. This situation varies slightly from one season to another. The largest number of sunshine hours is noticed from October to May (ASECNA, 2008). In the tropics, temperatures often depend on solar radiation; this is why the recorded temperature are relatively high. Figure 4 shows the range of temperatures in Bohicon from 1959 to 1989.

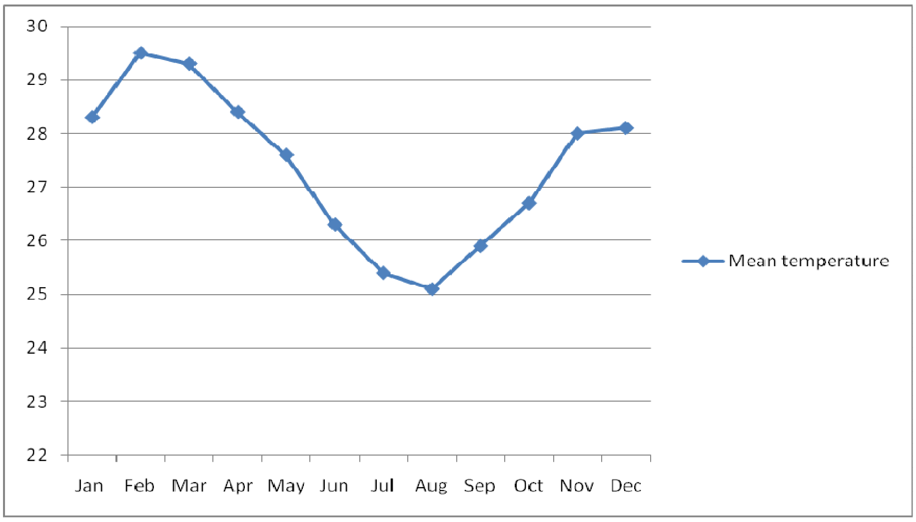

Figure 4: Mean temperature in Bohicon from 1959 to 1989 (Source : ASECNA, 2008)

➢ Evapotranspiration

The annual mean potential evapotranspiration (PET) over the period 1965 to 2005 at Bohicon's meteorological station was 1498.12 mm. Table 12 indicates monthly value of evapotranspiration at Bohicon's station from 1965 to 2005.

Table 12: Evapotranspiration at Bohicon station from 1965 to 2005 (Source: ASECNA, 2008)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PET (mm)	128.2	135.4	149.1	141.8	136.6	116.6	110.6	109.3	112.7	125.9	128.2	123.8

➢ Relative air humidity

The figure 5 shows the relative air moisture from 1959 to 1989 at Bohicon's station. The relative air humidity is high throughout the year. Its lowest value (63.5%) is recorded in January and its highest values are recorded from June to October with a peak in August (80.8%) in August

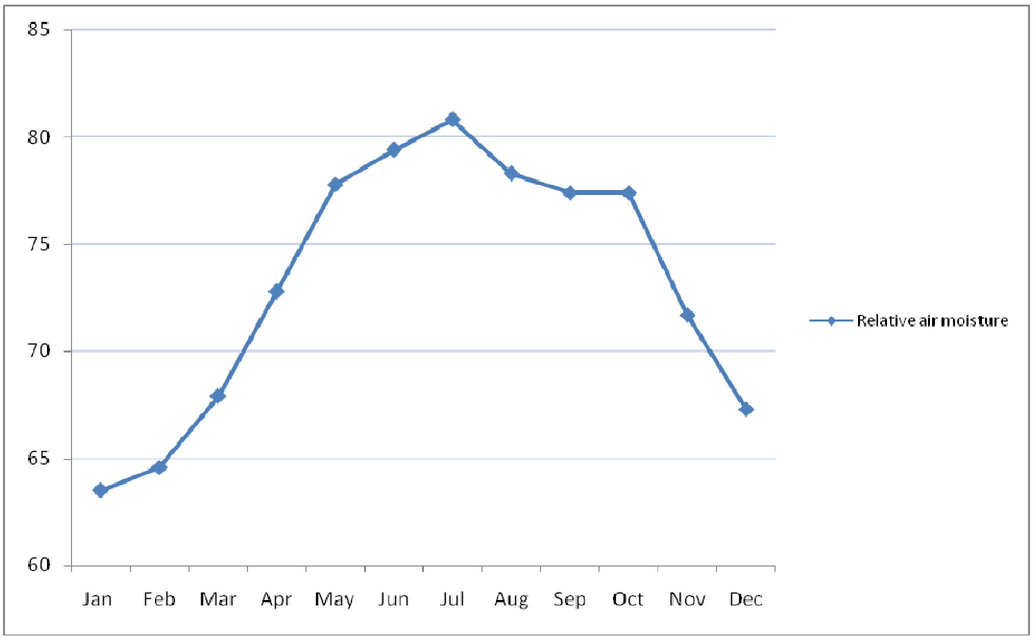

Figure 5: Mean relative air moisture at Bohicon from 1959 to1989 (Source: ASECNA, 2008)

- Sunshine hours

The mean sunshine hours from 1994 to 2004 at Bohicon station are shown in Table 13.

Table 13: Sunshine hours at Bohicon station (Source: ASECNA – 2008)

Sunshine hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Monthly average	196	197	190	201	211	170	116	96	125	204	233	219.63
Daily average	6.32	6.98	6.13	6.68	6.82	5.68	3.75	3.08	4.16	6.57	7.78	7.08
Sunshine/sunset hours	11.6	11.7	11.9	12.1	12.3	12.4	12.4	12.2	12	11.8	11.6	11.6

Solar radiation or specifically sunshine hours play an important role in the process of plants development. In fact, solar radiation facilitates photosynthesis for heliophile plants as the ones grown in horticultural enterprise. It appears from Table13 that the suitable period where one has higher sunshine hours runs from October to May which fortunately includes the major dry season in the southern Benin in general and in the district of Athieme in particular. From June to September the sunshine hours decrease because of clouds formation (full raining season).

3.4.2 Identification of irrigation periods

The influence of rainfall and temperature (evapotranspiration) on the determination of irrigation period is shown on the figure 6.

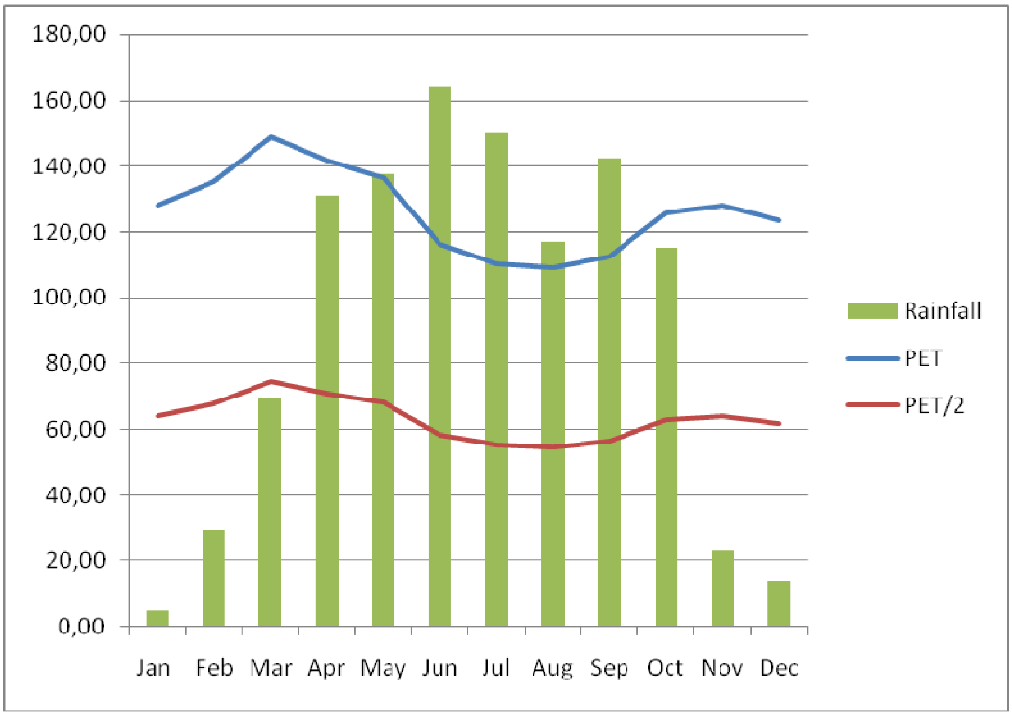

Figure 6: Determination of irrigation periods (Source: ASECNA, 2008)

The irrigation periods correspond to the periods during which the rainfall is less than half of Potential evapotranspiration (PET/2). From April to September the rainfall is higher than PET/2. Thus farmers (market gardening farmers) don't systematically irrigate vegetables but the decision to irrigate depends on the growth stage of the crops.

Analysing figure 6 one can conclude that the systematic irrigation period in the study area is November to March (5 months). With the recent changes in rainfall distribution, the month of April nowadays requires irrigation, this extends the duration of the main dry season from 5 to 6 months.

It is important to mention that in June the rainfall is so high that no irrigation is needed in the study area in general and Athieme in particular.

4 Methodology

The adopted methodology is composed of three main parts namely: data collection, data processing and analysis and finally the case study.
The data collection phase dealt with primary and secondary data, and literature revue as well.

4.1 Documentation and data collection

Data were collected from different offices such as ASECNA- Benin (Security and Air Navigation Agency in Africa and Madagascar - Benin) and DGE (General Direction of Water):

- ➢ Statistical data: they concern documents with quantifiable data. They are related to:
- climate of the study area: rainfall, temperature, humidity, evapotranspiration, solar radiation, sunshine/sunset hours (length of day), and sun peak hours.
- hydrology: discharges (maximal and minimal), hydrostatic head (maximal and minimal), monthly discharges
- dynamics of population in the study area (Demography)

- ➢ Literature: they consist of public and private records dealing mainly with the state of horticultural enterprise in the study area. The main sources of information are:
  - Ministry of Agriculture, Fishing and Livestock (MAEP)
  - International Institute of Tropical Agriculture (IITA)
  - University of Abomey-Calavi (UAC)
  - Agency for Security of Air Navigation in Africa and Madagascar (ASECNA)
  - National Centre of Remote Sensing and Control of forest Cover (CENATEL)
  - Communal Centre for Agriculture Promotion Athieme (CeCPA - Athieme)
  - Regional Centre for Agriculture Promotion Mono (CeRPA - Mono)
  - General Direction of Water (DGE)
  - Non Governmental Organisation such as "Protos"

- Benin Agency for Rural Electrification and Control of Energy (AMERME)
- Solar company such as Energy Dahito System (ENERDAS)
- Program for Agriculture Development in the provinces of Mono and Couffo (PADMOC)
- Program for Agriculture Development in the province of Oueme (PADRO)

In addition to the data collected with different offices, socio-economic surveys have been conducted with farmers in the study area to get useful information. Key persons have also been interviewed.

4.2 Execution of the field survey

The field surveys were conducted from April 12th 2008 to 20th May 2008 and consisted of two main steps: collection of data and data processing. Interviews were conducted with 40 farmers among which there were 8 women. Each farmer has been interviewed on his/her farm. The list of the interviewed farmers is given in annex 3 (see table 4.2 in annex 1)

4.3 Collection of field data

4.3.1 Selection of the survey areas

The interviews have been conducted in areas where there are on-going irrigation schemes. Most of them are urban and peri-urban areas. Those areas are distributed over three provinces. In each province, districts where irrigation is developed or has a high potential were selected. The city of Cotonou was selected in the province of Littoral; the district of Seme-Kpodji in Oueme and districts of Athieme and Grand-Popo in Mono. Only active farmers were interviewed.

4.3.2 Samples for the field survey

The statistic unit is the farmer on his or her farm. As it was difficult to get a list of all farmers operating in the concerned districts, the most productive farmers per district were selected. The selection criteria are:

- Size of the farm (at least 0.5 ha)
- Having grown crops for at least two growing seasons
- Having been identified as farmer by CeCPA or CeRPA

4.3.3 Data collection techniques

The following means were used for data collection: individual interviews, formal interviews, measures, test, and calculations.

Direct interviews

The main way of collecting information and data was the direct interview on the farm. The interviewer asks question and reports answers on the questionnaire sheets designed for the purpose. Data collection dealt mainly with irrigation techniques, source of energy, source of water, number of irrigation campaigns per year, production, yields, harvest and commercialisation of agricultural products. Moreover, environmental problems, difficulties met by farmers in their activities were included in the questionnaires. The interviewed person was the owner of the farm.

Informal and free interviews

These were free interviews conducted with or without pre-established questionnaires. Even when a questionnaire is used the scope of questions and answers are wider than what is proposed in the questionnaire. Mainly key persons were interviewed. Some of the key persons interviewed are:

- Responsible of CeCPA Athieme and Grand-Popo in Mono, Cotonou in Atlantic and Seme in Oueme
- Responsible of PADMOC
- The Manager of ENERDAS
- The responsible for hydro-agricultural arrangements of the NGO "Protos"

Those discussions helped to get other useful information and understand other aspects of the practise of irrigation in the study area.

Source of energy for pumping system

Most of the farmers in the study areas use fossil fuel-driven pumps. Some farmers have both electric and power-driven pumps. Electric pumps have higher productivity (less running costs than power-driving pumps) but the reliability of electricity in the study area is subject to caution. There are few farmers using exclusively watering cans. In fact, due to the large amount of manpower needed and the relatively low productivity, almost all farmers are trying to buy one or more power-driving pumps. Those pumps have the advantage of being cheaper. Outside the study area, in northern Benin, precisely in the district of Kalale, two villages (Dunkasa and Bessassi) have benefited from solar gardening projects. Since October 2007 those two villages are practising drip irrigation with solar pumping system.

Source of water

Boreholes are the most used sources of water for irrigation purpose. However there are few farmers using surface water such as river Mono and its effluents as water sources.

Questionnaires

Questionnaires are the main instrument used during surveys. Before retaining the final structure of the questionnaire, a pre-test was made on the questionnaire by interviewing two farmers. Based on answers given by those farmers, required adjustments and corrections have been made that helped to design the final structure of the questionnaire. The questionnaire was composed of nine (9) main parts:

A- Identification of the farmer
B- Characteristics of the farm
C- Other activities developed by the farmer
D- Agricultural techniques, planning and technical training
E- Pre-requisites for irrigation (valid only for farmer that are practising yet irrigation)
F- Factors that can have influence on the introduction of irrigation
G- Description of existing irrigation systems
H- Cost, profitability and diagnosis of problems encountered by farmers
I- Evaluation of the chance of solar pumping system

4.4 Data analysis

The collected data have been analysed and processed using excel 2007. This software has been used to draw the different graphs presented in this study. The questionnaire used for this study is made using the software "Le Sphinx". "Le Sphinx" is software designed specifically for questionnaire elaboration and data analysis.

II- RESULTS AND DISCUSSIONS

5 Irrigation in the study area

5.1 Results of field surveys

5.1.1 Interviewed farmers

As previously stated 40 farmers have been interviewed in 4 districts distributed as followed:

- 2 districts (Athieme and Grand- Popo) in the province of Mono;

1 district in the province of Oueme and;

1 district in the province of Littoral.

Annex 3 gives the list of interviewed farmers, their location (village), the source of water and water lifting devices they use.

5.1.2 Areas under irrigation

Figure 7 shows that most of farmers involved in market gardening (irrigation) have small schemes. Out of the 40 farmers that were interviewed, 75% have farms that are not larger than 1ha; 22.5% of farms have a size ranging from 1 to 2 ha and only 2.5% (1 farmer is) exploiting 25 ha. The field survey shows that, to meet farmers expectations, this study should focus on small schemes of irrigation.

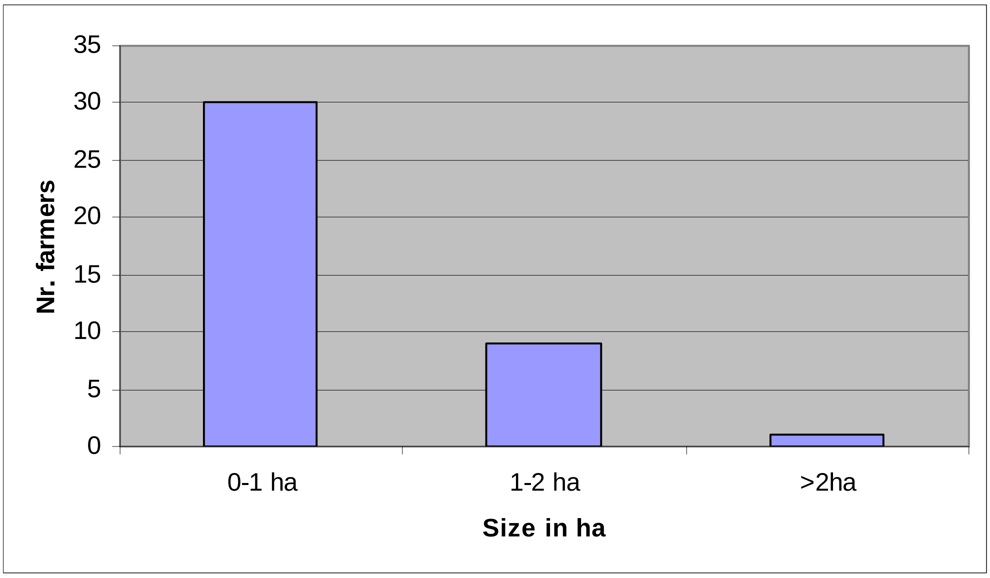

Figure 7: Size of irrigated farms in the study area

5.1.3 Vegetables in the study area

A variety of vegetables is grown in the study area. The most grown vegetables are: Amaranth, Bitter leaves (Vernonia amygdalina), onion, tomato, chilli (hot pepper), sweet pepper, carrot, lettuce and some local vegetables. Table 14 gives price information for some vegetables.

Table 14: Prices of some vegetables (Modified after Amoussou, 2006)

Vegetables	**Unit of measure**	**Price in abundance (Euro)**	**Price in shortage (Euro)**	**Difference (Euro)**	**Increase (%)**
Carrot	Plot of 8mx3m	22.87.	68.60	45.73	200
Onion	Plot of 8mx3m	22.87	76.22	53.36	233
Tomato	Basket of about 40 kg	4.57	36.59	32.01	700
Hot pepper	Basket of about 10kg	3.81	15.24	11.43	300
Solanum microcarpum	Plot of 8mx3m	3.05	12.20	9.15	300

From table 14 it can be seen that tomato benefits from the highest increase from abundance period to shortage period. This is due to the fact that it is very difficult to grow tomato in dry season due to lack of water and higher night temperatures that hinder its development. However, there are cultivars that tolerate higher temperatures. If suitable cultivars are found, the main problem remaining is then water and suitable soil.

5.1.4 Revenues of farmers in the study area

Revenues of farmers are low even though farmers involved in horticultural enterprise have higher revenues than those dealing exclusively with rain fed agriculture. Figure 8 indicates that 50% of farmers have revenues below 762 euros; 30% of farmers have revenues between 762 and 1524 euros; 17.5% are getting benefits ranging from 1524 to 2287 euros and only 2.5% have revenues above 2287 per hectare and per year.

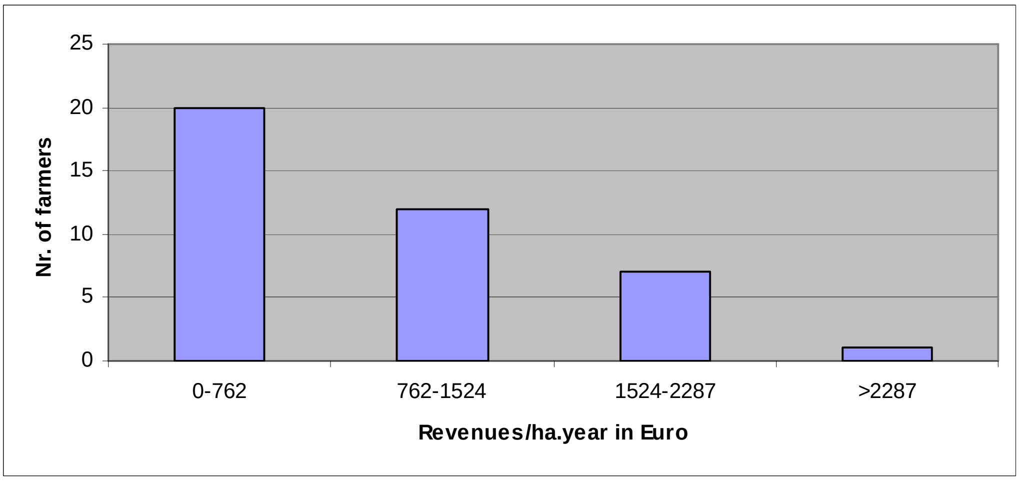

Figure 8: Revenues of farmers in the study area

5.1.5 Other activities

Most of the interviewed farmer farmers (2/3), especially those growing on small plots, are involved in other activities in addition to market gardening farms. This can be explained by the fact that revenues from irrigation is not enough for them to reach self-sufficiency either because those additional activities are not too demanding and don't need permanent presence of the farmers. Figure 11 below gives an idea of percentage of farmers involved in other activities and also the revenues they get from it.

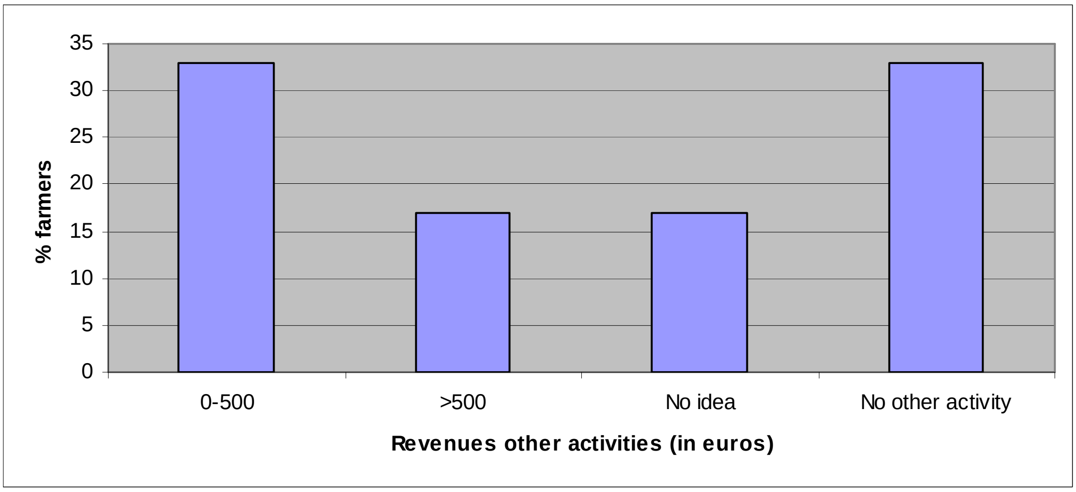

Figure 9: Farmers involved in other activity and their revenues

5.1.6 Problem encountered by farmers

General problems

Farmers involved in irrigation in southern Benin are encountering many problems ranging from lack of water and land, to lack of infrastructure and soils impoverishment. In fact the population density in the study area is very high (224 IH/km^2 in Mono, 570 in Oueme and 8414 in Littoral Province). Thus there is a real pressure on land. Littoral Province is a 'city-province', dominated by Cotonou, the economic capital city of Benin. Here there is a real lack of land for agriculture. Despite intensive use of fertilizer, most soils are becoming barren due to overexploitation and it is difficult to expand agriculture. There is also a problem of land tenure. Individuals claim to be the land owners while legally land is property of the state of Benin.

In Oueme, especially in the district of Seme-kpodji where there is the largest irrigation farm, the main problem is the soil. It is a sandy and barren soil with low water holding capacity. Farmers working there had moved from another place because there was lack of land. At the opposite of Littoral province, the problem is not quantity of available land but its quality.

In the department of Mono, soils are rather fertile and rich in organic matter. However, there are some variations. The whole district of Athieme is located in the river Mono basin. Consequently populations are subject to frequent flooding. Agriculture (rainfall or irrigated one) is not possible in flood period (generally from August to October). In Grand-popo there are sandy soils with average fertility. More specifically the collected problems are the following:

- lack of water in the dry season
- low yields despite intensive use of fertilizer and pesticide
- access (lack of good roads)
- low level of financial support from authorities and NGO
- dependence on weather hazards (unexpected higher temperature that damages plants: climate change)
- lack of space for extension
- high price of fuel (gasoline and lubricants)
- inexistence or inefficient supply of electricity (to ease the use of electric pumps)
- barren soils
- difficulties to sell horticultural enterprise products in abundance period
- land tenure.

Environmental problems

Many environmental problems are associated with the practise of horticultural enterprise in southern Benin. Permanent cultivation with almost no appropriate crop rotation, generates environmental problems occur. To face those problems farmers adopt techniques that in the long term will harm the environment. To deal with low yields farmers apply enormous quantities of NPK fertilizer up to 1 ton/ha for crops such as tomato and onion. Those quantities are high compared to the requirements given by FAO (2002). Details about FAO requirements are given in section 5.8.8. To deal with pest and diseases farmers also apply chemical pesticides even though those pesticides are known to harm the environment. Moreover, almost all farmers practise sprinkler irrigation either using pipes or sprinkling devices. This irrigation technique has medium efficiency and induces fungal diseases for sensitive crops such as tomato. In more concise terms, here are some environmental problems induced by the practise of market gardening:

- intensive application of fertilizer and pesticides leading depletion of micro nutrients in the soils and pollution of surface and groundwater
- overexploitation of land
- overexploitation of water resources (mainly groundwater as surface water is not yet very much used)
- atmospheric pollution due the use of power-driven pumps (gasoline, gas oil and lubricants)
- Probable loss of soil micro-nutrients as only high amount of macro-nutrients are applied (NPK).

5.1.7 Opinions of farmers and key persons about solar pumping

Apart from the three women cooperatives of Kalale (northern Benin), most of interviewed farmers had no idea about solar pumping. After giving information about solar pumping, all of the interviewed farmers expressed a high interest even though they were aware that it is a very expensive system.

Non-Government Organisations (NGO) such as "Protos"; financial institutions such as PADMOC and PADRO; technical institutions such as CeRPA and CeCPA; private companies such as ENERDAS and governmental energy institution such as ABERME show high interest and think that solar pumping can be a suitable alternative to traditional pumping systems and supply of electricity.

5.1.8 On-going solar projects in Benin

There are many on-going solar projects in Benin. The first solar-village was established by the government in 1993 in a village called Sedje-Denou. In total there are 24 solar villages in Benin. Each solar-village is equipped with a reservoir (drinking water supply), medical centre (maternity hospital, nursery etc.), streetlight etc. All those infrastructures are realised and maintained by ABERME. There are some private houses equipped with solar panel for their energy needs.

In addition to the above mentioned projects, there are three solar-gardening projects in the district of Kalale in northern Benin. Those projects have been realised by the American NGO SELF (Solar Electric Light Fund). The project has been funded by World Bank and private donors.

5.2 Water lifting devices

The main water lifting devices used by farmers in the study area are:

- Power-driving pumps using gasoline (majority of farmers)
- Electric pumps (used by farmers that have access to electricity mains)
- Hand pumps (few farmers)
- Watering can scanning (very few farmers)

5.3 Assets and weaknesses of motorised and manual irrigation

The main advantage of manual irrigation (watering cans or hand pumps) is that running costs are very low. It needs only manpower and access to reliable source of water. The disadvantage is that it is very difficult to irrigate larger areas. Moreover the irrigation efficiency is subject to caution. It is suitable for farmers irrigating small plots.

The motorised irrigation (power-driven pumps or electric pumps) has the advantage of irrigating larger areas. With motorised irrigation and adequate irrigation systems, a farmer in the district of Grand-Popo has been able to irrigate 25 ha. However, he does not have yet an automated irrigation system; he is still in need of important manpower. Here the efficiency of the irrigation system is better than for manual irrigation. Here the main disadvantages are running costs and maintenance costs. In addition to the investment (purchase of pump), the farmer needs to provide fuel and lubricant daily. Even those who have electric pumps are obliged to have access to power driven pumps as the supply of electricity is not reliable. With the continuous increase of oil's price the profitability of such pumps is getting smaller and smaller.

5.4 Preliminary work on the selected site

In order to get some characteristics of the selected site (slope, distance from farm to the river, location of reservoir and panel), a topographic survey was conducted. This surveying resulted, among others, in the establishment of grid levelling and contour lines. Details are shown in annex.

5.5 Justification of the project

The major raining season in Benin theoretically runs from mid-March till end of July and major dry season from November to Mid-March. During the raining season crops are most of the time damaged either by excess of water or lack of rainfall – farmer sow crops after the first rains and plants die due to lack of water as the rains appear again only in June with an intensity that inundate farms. On the other hand the district of Athieme (Togblo) is fully in the River Mono Basin and thus subject to frequent flooding especially after the construction of the hydroelectric dam of Nagbeto in Togo. These floods occur generally in the small raining season, from September and October. Even though they last only few days, they cause damage to crops as most of them cannot withstand stagnant water. So it urges, for the survival of Athieme's populations to adapt to those weather hazards and flood risks.

The idea is to develop rice cultivation in raining season – from May to July when there is enough water and almost no need to irrigate – and grow vegetables and low water demanding crops in dry season when there still enough water in the River Mono and also the water table is shallow. Due to the fact that the dry season is getting longer and longer (almost 6 months as it starts really raining nowadays in May instead of mid-March), it is worth to investigate adaptation measures to make a better use of the dry season. Gasoline and diesel prices are continuously increasing and the district of Athieme does not have access to reliable electricity mains. These are the reasons why this project proposes to study the growth of tomato in dry season using solar energy.

Tomato (Lycopersicon esculentum) is the second most important vegetable crop next to potato (Solanum tuberosum). Present world production is about 100 million tons fresh fruit from 3.7 million ha. (FAO, 2002-b). It is a crop that is used for cooking purpose in Benin and which cost varies a lot from raining season to dry season when it is very expensive and has a high economic value. Tomato water requirement is about 400mm to 600 mm for a growth period of 90 to 120 days (FAO, 2002-b). Even in dry season when this project is going to be implemented, this amount of water can be supplied by the river Mono or groundwater. There is a market for tomato commercialisation in Benin and in the neighbouring countries such as Nigeria and Togo. If the project is well managed, it will surely yield benefits in the short and medium term.

5.6 Irrigation system and water demand

5.6.1 Crop selection

The main crop that is going to be grown is tomato. This crop will be rotated with carrot or other appropriate vegetables in raining season. The choice of tomato is based on the fact that the costs involved in irrigation system installations are important and need to be recovered. It is why this project is going to focus mainly on the growth of tomato during the main dry season. On the other hand tomato is a rapidly growing crop with modest water requirements.

Soils in the river Mono valley (Athieme) are hydromorph (fertile and rich in organic matter) and are adequate for vegetable growth. Optimum mean daily temperatures for growth are 18 to 25ºC with night temperatures between 10 and 20ºC (FAO, 2002-b). The temperatures on site in dry season are slightly higher than those limits but fortunately there are varieties of tomato that can withstand higher temperatures. Some of those varieties are developed by ICRISAT (International Crops Research Institute for Semi-Arid Tropics) in Niger and "Le centre Songhai" in Benin. All together, the growth of tomato is really possible on the site.

5.6.2 Irrigation method

Tomato is very sensitive to fungi diseases. It is why any irrigation techniques that spray or sprinkle water would not be adapted. It is projected to use drip irrigation. This technique has the advantage to irrigate only the plant at its roots and not the whole plot. Consequently the efficiency of the system is very high, up to 90% (Prinz, 2007).

5.6.3 Size of the site and size of the area under irrigation

The site of Togblo has an area of several hundreds of hectares. Though it is located in the River Mono basin, it is not completely flooded when flooding occurs. The plots will be positioned in such a way that they are accessible and protected at any time. One of the objectives of this study is to investigate how the plot size influences the overall price of solar irrigation for fixed given conditions. It is projected to study the growth of tomato on a farm of ten (10) hectares divided in plots of 0.5, 1, 2, 5 and 10 ha. However, only small plots will be studied in details in this work. This means that the farm of 10 ha will be divided into plots according to the size adopted. For each plot, the irrigation water demand will be calculated; PV panel will be sized; a reservoir will be design and solar pumps will be selected. The plot's size is determined by the maximum volume of water that can be lifted through a given head according to the available solar radiation and the water demand of tomato per hectare.

5.6.4 Water requirement of tomato (FAO, 2002-b)

Total water requirements (ET_m), after transplanting, of a tomato crop grown in the field for 90 to 120 days are 400 to 600 mm depending on the climate. Water requirements related to reference evapotranspiration (ET_o) in mm/period are given by the crop factor (K_c) for different crop development stages. Crop coefficient ($K_{c)}$ values and corresponding development stages are summarised in the following table.

Table 15: K_c values and development stages of Tomato (Source: Modified after FAO, 2002-b)

Nr.	**Stages**	**Days**	**Kc values**
1	Initial	20	0.45
2	Development	30	0.75
3	Mid-Season	30	1.15
4	Late-Season	20	0.8
5	Harvest	20	0.6

Irrigation water requirement = Crop's evapotranspiration – Effective rainfall

In practice if one add the nursery period that is about 20 days the water requirement can be slightly higher. In this work the growth period is assumed to be 120 days. Moreover by adding the nursery period, the irrigation water demand can exceed the values given above as the irrigation water demand will also depend on the local climate (evapotranspiration and temperature) and the variety of tomato.

5.7 Water demand for a growth period of 120 days

5.7.1 Cropping techniques

To reduce the daily irrigation water demand and to ensure a continuous supply on markets, the whole area (for example 10 ha) will not be planted in one time but in five different schedules (times). The first plot will be planted in October in order to benefit the rainfall of the end of the small raining season and supply the market with tomato in December and January (Christmas and New Year feast). This first planting will benefit from pesticides application to decrease the risk of fungi diseases. The second plot will be planted in February after harvesting the first plot and will supply the market in May when tomato has its highest price. From June to October, maize and/or other appropriate vegetables will be grown to ensure effective crop rotation. FAO, 2006 suggested that tomato should be grown in a rotation with crops such as maize, cabbage, cowpea, to reduce pests and disease infestations.

5.7.2 Average daily water demand, ET_{crop} and irrigation water requirement.

Effective rainfall

The effective rainfall is the amount of water from rainfall actually available in the root zone to be taken up by crops. The proportion of rainfall taken as effective rainfall differs from a season to another and from month to month. In different months different percentages are considered to be effective out of the total rainfall received. In this study, the effective rainfall is assumed to be 80% of the total rainfall received each month.

Table 16 gives ideas about effective rainfall as a percentage of total rainfall received in Vietnam for rice cultivation.

Table 16: Percentages of received rainfall taken as effective rainfall (FAO, 1974)

Period	% taken as effective	Remarks
April-September	75	Wet season
October	65	High rainfall intensity
November	80	Dry season
December-March	90	Dry and cool season

Gross average irrigation water demand

After carrying out calculations for each month, it appears that the plot planted at the beginning of December shows the highest daily water demand (59.65 m^3/ha.day) in the mid-season stage. The daily irrigation water requirement of tomato is assumed to be 60 m^3/ha.day in this study even though there are stages that show lower values.

Table 17: Irrigation water demand of tomato over a growth period of 120 days

Period	Growing Stage	K_c	PET (mm)	ETcrop (mm)	R (mm)	ER (mm)	NIWR (mm)	GIWR (mm)	GIWR (m3/day.ha)
01/12-20/12	Nursery	0,45	80,75	36,34	9,06	7,25	29,09	32,32	16,15
21/12-20/01	Active	0,75	43,02	32,26	4,98	3,99	28,28	31,42	28,56
	Develop	0,75	80,27	60,20	3,19	2,55	57,65	64,06	32,03
21/01-19/02	Mid	1,15	47,90	55,09	1,75	1,40	53,69	59,65	**59,65**
	Season	1,15	94,05	108,15	20,15	16,12	92,03	102,26	51,13
20/02-11/03	Late	0,80	41,33	33,06	9,55	7,64	25,43	28,25	25,68
	Season	0,80	46,74	37,40	24,68	19,74	17,65	19,61	21,79
12/03-31/03	Harvest	0,65	102,31	66,50	44,87	35,90	30,61	34,01	17,00
Total 1ha								**339.26**	

K_c = Crop coefficient ; PET = Potential evapotranspiration ; ET_{crop} = Crop evapotranspiration R = Rainfall ; ER = Effective Rainfall

NIWR = Net Irrigation Water Requirement GIWR = Gross Irrigation Water Requirement

NIWR = ETcrop – ER and GIWR = NIWR/ network efficiency (8)

5.8 Required conditions for tomato cultivation

Tomatoes are planted throughout the year: the rain fed crop is very susceptible to diseases and the late planted dry season crop can be adversely affected by high day and night temperatures (Philipps, 1977)

5.8.1 Suitable soils for tomato

Tomato can be grown on all types of soils ranging from sandy loams to heavy clay soils. In any case it is essential that the crop benefits from enough nutrients and water.

Well-drained, fertile soils with a good moisture retaining capacity and a relatively high level of organic matter are best although many cultivars tolerate a range of soil conditions. Slightly acidic soils with a pH of 5 – 6.5 are suitable (Rice et al., 1991). FAO (2002-b) stated that tomato can be grown on a wide range of soils but a well-drained, light loam soil with pH of 5 to 7 is preferred. Soils on the selected site are clay soils. They are fertile and rich in organic matter.

5.8.2 Temperatures

Low soil temperatures retard the growth of seedlings and absorption of minerals. High air temperatures above 27 ºC can cause pollen sterility and high night temperatures adversely affect flower initiation. Night temperatures lower than day temperatures are recommended. FAO (2002-b) recommends the following range of temperature in degree Celsius: 20 (night) < air temperature < 27 (day). However there are cultivar that can withstand higher air and night temperatures. Some of those cultivars are developed by ICRISAT in Niamey and "Le Centre Songhai"[1]. A diurnal variation of at least 5 - 6ºC is considered ideal for most cultivars. High temperatures, combined with low relative humidity, can seriously affect fruit setting. Both high and low temperatures can affect fruit quality, particularly the column of the fruit. It is essential to have naturally occuring optimum temperatures conditions or to create those conditions to obtain satisfactory yields.

5.8.3 Requirement of irrigation water quality

Due to the adopted irrigation techniques (drip irrigation), water used for irrigation must be as clean as possible. High content of salt, especially calcium may lead to frequent clogging. In case where surface water sources such as river is used, it is essential to equip pumps with

[1] "Le Centre Songhai" is an agricultural research and training centre founded by Mr. Godfrey Nzamudjo in 1985 in Porto-Novo. "Le Centre Songhai" is present in the old six provinces of Benin.

filter devices or design a retention basin. In any case, regular maintenance is necessary to ensure, that the system works perfectly. To avoid water stress, the crop (tomato) will be irrigated daily. Table 18 shows the characteristics of River Mono's water on the site. These results are obtained from tests conducted by the laboratory of IWG- Universitaet Karlsruhe (TH).

Table 18: Characteristics of River Mono water at Togblo (district of Athieme in Benin)

Sample	**pH**	**Hard Ca**	**Ca**	**Mg**	**Zn**	**Cu**	**Cr**	**B**	**Na**
		mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L	mg/L
5 p.m.	6.23	0.10	0.82	2.98	120	0	0.0	0.042	9.58
12p.m.	6.25	0.11	1.56	3.68	120	9.4	0.0	0.063	10.4
8 a.m.	6.52	0.08	0	0.96	220	1.6	2.2	0.143	10.5
Mean	**6.33**	**0.096**	**0.79**	**2.54**	**153**	**3.67**	**0.73**	**0.083**	**10.16**

This table shows that the pH of the sample (River Mono) is slightly acidic but very close to neutral. Calcium (Ca), copper (Cu), chrome (Cr) and magnesium (Mg) contents are low; sodium content is average while zinc (Zn) content seems high. The sample seems to be soft water. The very low content of boron (B) is good as high concentration of Boron has toxic effect on plants.

5.8.4 Cultivars of tomato

In wetter areas south of the Guinea zone (including southern Benin), local selection , often with corrugated fruit are better suited. They also appear to be less susceptible to virus diseases. In the Guinea and Sudan zones, the cultivars Alicante, Enterprise, Ife Nr.1, Harvester, la Bonita , Marzanino, Roma VF and Romita are very successful (Philips, 1977). San "Marzano and Roma"cultivars are oval shaped fruit. They are canning tomatoes and are allowed to grow in a bushy manner without stakes (Rehm & Espig, 1991). In southern Benin the imported cultivars that can be grown or planted throughout the year are Caraibe, Monga, Red Master and Roma. They can withstand higher diurnal and night temperatures.

5.8.5 Seed rate

There are about 350 seeds /g and with good nursery management 140 g of seed should provide sufficient seedlings to transplant a hectare on industrial tomato schemes. Per hectare, 280 to 420 grams seem to be needed.

5.8.6 Transplanting

Tomato seedlings are ready for transplanting when they have developed 3-4 true leaves or attained a height of 12-15 cm. Before transplanting a base dressing of 250 to 500 kg/ha of compound fertilizer should be incorporated. Transplanting should be done in early morning or late afternoon.

5.8.7 Spacing

In drier areas north of latitude 10º (in Nigeria), a plant population of about 55 000 per hectare (60x30 cm^2 per plant) is common. In wetter southern areas a population of about 27 000 (60x60 cm^2 per plant) is used. Staking reduces fruit rot and so gives higher yields in the wetter southern areas. In Benin each plant of tomato occupies about 50x60 cm^2.

5.8.8 Mineral fertilizer and pesticides

Liquid fertilizer can be applied at planting and repeated after about 40 days. Soils low in potassium should be dressed with potash at intervals of about 21 days until flowering begins. Excessive nitrogen may, however, promote leaf growth instead of flower initiation and nitrogen should therefore be applied sparingly after the second flower cluster has set. NPK at 20: 10:10 or 21:14:14, 12:24:12 and 15:15:15 all give satisfactory results for a base dressing before transplanting (Philips, 1977). Fertilizer requirements for high producing varieties range from 100 to 150 kg/ha N, 65 to 110 kg P and 160 to 240 kg/ha K (FAO, 2002)

Pesticides are also applied to crops (from nursery till full development) to fight diseases and pests. The farmer put a device on his/her back and with a sprayer in form of a stick, he/she sprays the pesticide on the plants. Photo 3 shows application of pesticide to nursery.

Photo 3: Preparation and application of pesticides in Kalale (Photo: Noumon, 2008)

5.8.9 Mulching and Manure

Mulching is advantageous in both dry and wet season. It is a good complement or alternative to excessive mineral fertilizer application.

Most of farmer in the study apply animal manure to improve the soil quality. A mixture of crops rests and animal excrements are used to make such manure. Photo 4 shows manure storage and manure application.

Photo 4: Manure storage and application in Cotonou – Benin (Photo Noumon, 2008)

5.8.10 Harvest, yields, diseases and price

Harvest and yield

Fruits can normally be harvested from intermediate tall growing cultivars 70-100 days from transplanting. Determinate cultivars begin fruiting after about 60 days (Rice et al., 1987). The harvest period can extend from 30 to 60 days depending on the cultivars and temperatures.

The tomato crop responds to good management. In the Guinea and Sudan zones, wet season yields of 25 -30 tons per hectare are possible; where fungicides are applied with the early established irrigated crops, yield of 35-50 tons per hectare are common. In the southern areas, there is a greater incidence of diseases and root-knot nematodes; wet season yield of 12-20 tons per hectares are considered good. Farmers, who do not fertilise, stake or spray get only about 5 tons per hectare (Philips, 1972).

Pests and diseases

Tomato is very sensitive to pests and diseases. The crop may be affected by the following pests and diseases: yellow patch virus disease; leaf curl; foliage diseases; bacteria wilt; root-knot; bloosom-end rot; fruit worm.

Prices of tomato in Benin

In raining season tomato does not cost anything. Most of the time farmers use the fruit to produce seeds and store them for the dry season when the seeds and tomato fruits are very expensive. In raining season, the price of tomato hardly exceeds € 15 cents per kg. In dry season the same kg costs between 1 and 1.5 €. It is worth to grow such crop, especially for expensive irrigation systems such as drip irrigation using solar pumping system.

Dry season tomato farms in the study area

Photo 5 shows two different farms of tomato grown in dry season in Athieme. The farm on left lacked of water at the initial stage while the farm of the right benefits from sufficient water.

Photo 5: Tomato farms lacking of water and with sufficient water (Photo Noumon, 2008)

5.9 *Characteristics of existing solar gardening in Kalale (northern Benin)*

The solar gardening project in northern Benin consists of 3 farms of 0.5 ha each (1 in Dunkassa village and 2 in Bessassi village). Both projects (Dunkassa and Bessassi) have been partially financed the World Bank and private donors and realised by the NGO SELF (Solar Electricity Light Fund). The projects have started in October 2007. Bessassi and Dunkassa have been selected because in those two villages, there exist a tradition of horticultural enterprise since 1992 (in Bessassi) and 1991 (in Dunkassa). The two villages are distant 45 km apart. These are pilot projects that will be extended to 42 other villages in the district of Kalale. Annex 3 shows photos of both cooperatives.

5.9.1 Bessassi solar gardening farms

The two farms are located on the same site, only a track separates them. The water source is a permanent flowing water body. The pump house and PV generator are closed to the water body. The two farms are owned by two women cooperatives. Each cooperative is composed of 33 women and one man. To be accepted as a member of the project, one has to pay about 14 euros (9 euros as membership fees and 5 euros as social capital). In addition the member of the cooperative has to pay 0.15 euro per week. Any member that does not pay his weekly contribution on time is charged a penalty of 0.08 euro per week. In addition to the stated conditions, the member has to follow the regulation of the cooperative. Each cooperative has a responsible, a secretary and a treasurer, who are responsible for the project.

Each farmer is given a plot of 60 m x 1 m on which she is allowed to grow different vegetables. The most grown vegetables are: aubergine, onion, tomato hot pepper (chilli), potato and other local vegetables. The vegetables are sold locally but also sent to Nigeria as Kalale is a border district between Benin and Nigeria.

The pumping system is composed, for each farm, of: PV generator, a pump, a reservoir in reinforced concrete (usable capacity: 21 m3) and the water distribution network. The total cost of the project is 20, 000 US$ (about 13,333 euros) for 0.5 ha.

5.9.2 Dunkassa solar gardening farm

Only one farm of 0.5 ha is arranged in Dunkassa. The main reason is the water source. Unlike Bessassi, Dunkassa does not have a permanent flowing water body. The groundwater table is rather deep (20-25 metres). The Pump and PV generator are situated far from the farm (about 800 metres). The cooperative of Dunkassa is composed 38 women and 2 men. The structure of the leading team, the crops grown and market conditions are the same as for Bessassi.

The pumping system is almost the same as in Bessassi. The only difference is the fact that there is a solar controller to help the pump work any time at the maximum power point either by controlling the current or the voltage in other to ensure the required power for pumping water. The Dunkassa project is more expensive than the Bessassi's ones. It costs 25,000 US$ (16,667 US$), drilling cost not included.

5.9.3 Technical training

After the commissioning, SELF has entrusted a technical team with the running of the project. The team is composed of two technicians (1 in civil engineering and the other in agricultural engineering). They are paid by SELF and give regular reports to SELF. The technician in civil engineering is responsible for the whole pumping system and its maintenance while the agricultural technician gives advice to farmers on how to grow crops (from nursery to harvesting) and the maintenance of the drip lines.

5.9.4 Maintenance and supervision

On each site there is a person in charge of checking the system on a daily base to ensure that everything works perfectly. Another person is charge of switching the generator on every day at 7 am and off at 7 pm.

Once a week, the solar panels are cleaned with water and an appropriate duster. The cleaning can be more frequent in dry season when there is more dust. Children are kept far from the panel and they are aware of not throwing stones on the panels.

The reservoirs are covered with traditional mat to avoid development of algae. The reservoirs are cleaned regularly.

Drip pipes and drip lines are also cleaned regularly. To fight clogging (happening more frequently with surface water than groundwater), drip lines are immerged in 6% acidic solution for 2 days. After this they are washed with water before they are used again for irrigation.

5.9.5 Opinion of the beneficiaries

Though it is too early to draw a consistent conclusion from the running of those projects, it is important to mention the opinion of farmers. They are really satisfied with the project and think that it yields more benefits and requires less effort than the rain fed agriculture. Most of farmers (men but also women) used to grow cotton as source of private income. However, with the increase of fertilizer and pesticide costs coupled with a poor management from the government side, most of farmers are abandoning cotton cultivation and are in search of other sources of revenues. It also important to mention that men, who farm only in raining season (rain fed agriculture), are very proud of their wives as they contribute to ensure self-sufficiency of the family all year round.

6 Assessment of the available solar radiation

6.1 *Solar and other energies in irrigation*

6.1.1 Prerequisites for using solar energy

According to Roy et al., 1993 solar energy is suitable for irrigation if the daily solar radiation is greater than 4 kW/m^2 and the volume-head product is less or equal to 250 m^4. The volume head product is obtained by multiplying the daily water needed by the head through which water is lifted.

This condition implies that the selected crop should not have high water demand and the head should be as small as possible if one wants to irrigate relatively large areas. If the daily volume-head product needed exceeds the above threshold value, it is better to use diesel or wind rather than solar power. However, due to new results in solar field leading to cutting of prices and the continuous increase of fossil oil price, the above mentioned threshold may not be the same 15 years later (in 2008).

6.1.2 Wind energy

Wind energy is suitable for irrigation of areas with relatively high wind speed. Wind energy will be preferred to solar if the mean wind speed is larger than 4 m/s. (Roy et al., 1993). The threshold value of the volume head product is the same as for solar pumping system.

6.1.3 Diesel or gasoline

For short term cost-benefits analysis and without taking environment's protection into account, using diesel for irrigation is more "cost-effective" than using solar and wind energies. In addition, diesel pumps can irrigate larger areas with higher volume-head product. However with the continuous increase of oil price added to damages caused by fossil oil's combustion, the "cost-effectiveness" of diesel engines is increasingly subject to caution.

6.2 *Assessment of solar radiation in Togblo, district of Athieme in Benin*

The assessment of solar radiation is done step by step through the use of many formulas.

6.2.1 Calculation of declinations

Declination is time dependent. The following formula is used for declinations calculation.

$$\delta = 23.45 \sin(360 \frac{284 + n}{365}) \quad (9)$$

Where:

δ the declination in radian

n the number of day in the year (for January 1st, n = 1)

Table 6.2.1 in annex 5 shows the values of declinations for the recommended average days for the different months.

6.2.2 Calculation of Zenith angle at solar noon on a horizontal plane

At solar noon ω = 0, in addition β = 0 (horizontal plane); so formula (2) can be rewritten as follows

$\cos\theta_z = \sin\delta \sin\phi + \cos\delta \cos\phi = \cos(\phi - \delta)$. This leads to:

$$\theta_z = \phi - \delta \text{ in the northern hemisphere} \quad (9a)$$

or

$$\theta_z = -\phi + \delta \text{ in the southern hemisphere.} \quad (9b)$$

Table 6.2.2 in annex 5 shows the values of θz in for the locality of Togblo.

6.2.3 Sunset/sunset angle ω_s and daily sunshine hours (T)

The sunset/sunshine angle helps to calculate the daily sunshine hours. The following formulas (10) and (11) are used to calculate the sunset/sunshine angle:

$\omega_s = \cos^{-1}(\tan\phi.\tan\delta)$ (10)

and

$T = 2\omega_s /15$ (11)

Table 6.2.3 in annex 5 gives the different values of ω_s and T for the locality of Togblo.

6.2.4 Overall solar energy on a horizontal plane

The overall sun energy on horizontal plane is computed using the formula (12).

$H_0 = [24x3600x1367/ \pi].(1+0.033\cos (360.n/365)x(\cos\phi x\cos\delta x\sin\omega_s$

$+2\pi x\omega_s x\sin\phi x\sin\omega_s /360)$ (12)

With H_0 in $J/m^2.day$. Table 19 gives the values of H_0 for the selected site throughout the year.

Table 19: Overall sun energy on horizontal plane

Average monthly day	**n**	**H_0**	**K_T**	**$H = H_0xK_T$**
				($kJ/m^2/day$)
17th Jan	17	33,38	0,46	15,36
16th Feb	48	35,66	0,47	16,76
16th Mar	75	37,33	0,46	17,17
15th Apr	105	37,70	0,46	17,34
15thMay	135	36,80	0,47	17,30
11th Jun	162	36,02	0,43	15,49
17th Jul	198	36,22	0,36	13,04
16th Aug	228	37,08	0,34	12,61
15th Sep	258	37,24	0,37	13,78
15th Oct	288	35,91	0,44	15,80
14th Nov	318	33,78	0,51	17,23
10th Dec	344	32,58	0,48	15,64

6.2.5 Available solar energy on inclined plane (β= 10 degrees)

To compute the available solar radiation on inclined plane, it is necessary to calculate its following components:

- diffuse radiation (H_d) and diffuse radiation coefficient (R_b)
- beam radiation (H- H_d) beam radiation coefficient (R_d)
- reflected radiation (Hxρ) and reflected radiation coefficient (R_r)

Diffuse radiation

After calculating H, the ratio H_d /H is calculated using formula 13a or 13b. Once H_d /H is determined, it is easy to compute H_d values.

$H_d/H = 1+0.28K_T -2.56K_T^2 + 0.85K_T^3$ for $\omega_s > 81.4°$ (13a)

$H_d/H = 1+0.28K_T -2.56K_T^2 + 0.85K_T^3$ for $\omega_s < 81.4°$ (13b)

For the selected location, ω_s is greater than 81.4° for every average monthly day. The formula 13a has then been used to evaluate the ratio H_d/H, which enables to calculate H_d. Table 6.2.5.1 in annex 4 gives values of diffuse radiation for different average days.

Diffuse and reflected radiations coefficients (Rd and Rr)

- **The slope β**

It is the angle between the plane of the surface in question and the horizontal; 0° **≤ β** ≤180°**.** A slope greater than 90° (**β** >90°**)** means that the surface has a downward-facing component (Duffie and Beckman, 2006). The slope plays an important for the good functioning of photovoltaic generator.

Royer et al (1998) state that the inclination of PV modules must be equal to the latitude of the site (take 5°). Furthermore they added that if the latitude of a site is comprised between 0° and 10°**,** one will choose a slope of 10° to ease the cleaning of the panels and the running off of rain. For this study β = 10°.

- **Diffuse radiation coefficient (R_d) and reflected radiation coefficient (R_r)**

The slope is used to calculate the diffuse and reflected radiation coefficients respectively R_d and R_r. Table 19 below gives R_d and R_r values for the selected site.

$$R_d = (1+ \cos\beta)/2 \quad (14a)$$

$$R_r = (1- \cos\beta)/2 \quad (14b)$$

For this study, R_d = 0,9924 and Rr = 0,00756.

Coefficient of beam radiation (Rb)

Table 6.2.5..3 in annex 4 gives the values of R_b for each month. To compute R_b values, formula (15) has been used.

$$R_b = [\cos(\phi-\beta).\cos\delta.\sin\omega s+\omega s.\sin(\phi-\beta).\sin\delta]/[\cos\phi.\cos\delta.\sin\omega s+\omega_s.\sin\phi.\sin\delta] \quad (15)$$

with ω_s in radian.

Available solar energy on inclined plane (β= 10 degrees)

After calculating its different components, sun radiation on inclined surface (H_β) is calculated using formula (16).

$$H_\beta = (H- H_d) R_b + H_d.R_d +H.\rho.R_r \quad (16)$$

Table 20: Available solar energy on inclined surface

Average monthly day	$H_{\beta=0°}$	H_d	$H_{\beta=10°}$
	(kwh/m²/day)	**(kwh/m²/day)**	**(kwh/m²/day)**
17th Jan	4,29	2,87	**4,41**
16th Feb	4,67	3,06	4,78
16th Mar	4,78	3,20	4,80
15th Apr	4,81	3,22	4,74
15thMay	4,79	3,13	4,64
11th Jun	4,28	3,06	4,15
17th Jul	3,61	2,92	3,54
16th Aug	3,50	2,91	3,45
15th Sep	3,83	3,05	3,82
15th Oct	4,40	3,08	4,47
14th Nov	4,81	2,84	5,01
10th Dec	4,37	2,79	4,57

From October to May, the available solar energy varies from 4.41 kWh/m^2 in January to 5.01 kWh/m^2 in November. The less productive month of the year is August with 3.45 kWh/m^2. The annual mean value is 4.37 kWh/m^2. The mean value of the available solar radiation over the period October-Mai is 4.64 kWh/m^2 and the lowest value for the same period is 4.41 Kwh/m$^{2.}$ As this study is dealing with irrigation in dry season, only solar radiation of dry season will be taken into account. For this period (October- May), the less productive month (January) solar radiation will be the basis of all calculations. However, the pumping system can be used in raining season to grow other crops of high economic value and with high water demand such as chilli, carrot, onion and Solanum microcarpum or even maize. Appropriate crop rotation will be one of the selection criteria.

Comparison of recorded and calculated data

Table 21: Comparison of various solar radiation values for similar latitude

Month	**Solar radiation (kWh/ m^2/day)**			**Sunshine/sunset hours**	
	Benin City[2]	Togblo	Bohicon[3]	Togblo	Bohicon
	φ = 6.10° N	φ = 6.48° N	φ = 7.16° N	φ = 6.48° N	φ = 7.16° N
Jan	4,28	4,29	4,60	11,67	11,60
Feb	4,66	4,67	5,00	11,81	11,70
Mar	4,81	4,78	5,10	11,96	11,90
Apr	4,76	4,81	5,10	12,14	12,10
May	4,76	4,79	5,10	12,3	12,30
Jun	4,29	4,28	4,50	12,37	12,40
Jul	3,57	3,61	3,90	12,34	12,40
Aug	3,52	3,50	3,80	12,21	12,20
Sep	3,86	3,83	4,10	12,03	12,00
Oct	4,40	4,40	4,80	11,85	11,80
Nov	4,79	4,81	4,90	11,7	11,60
Dec	4,43	4,37	4,60	11,63	11,60

Table 21 shows that the calculated data comply very well with recorded data from locations which latitude are in the same range as the latitude of the selected site. Therefore, the calculated data will be used.

[2] Values given by Duffie John A. & Beckman William A. (1991)
[3] Values given by Degbe et al. (1989)

7 Selection of photovoltaic pump

Photovoltaic systems without battery are the one suitable for photovoltaic pumping. Here a reservoir is used to store water instead of battery.

In this part two types of water sources will be considered: surface water (River Mono for example) and groundwater as the groundwater of the study area (southern Benin) is relatively shallow. The required data for the design of PV pump are the daily water need or discharge in m^3/day and the Gross Pumping Head.

7.1 Surface water

7.1.1 Plots of 0.5 ha

The plots will be arranged near the river (100 metres) and will have 100 m length and 50 m width. The reservoir will be constructed at 200 meters from the bank. This distance will be used to calculate the difference of height due to the slope.

Daily irrigation water demand

From chapter 5, paragraph 5.7.22 and table 17; the daily irrigation water demand is about 60 m^3/ha. For a plot of 0.5 ha, it is just the half.

$Q_{0.5ha}$ = 30 m^3/day.

Gross pumping head or Gross working head (H_a)

The gross pumping head is the pressure difference (in meter of water column) between the suction head and the delivery head. This head can be calculated as followed:

$$H_a = H_s + H_l \qquad (17)$$

where:

H_s = static head

H_l = head losses.

H_s can be written as follows:

H_s = h1+h2+h3 where:

h_1 = difference between river bank and river bed

h_2 = difference of height due to slope

h_3 = the height of the reservoir

$h_1 = Z_{bank} - Z_{bed} – h_w$ where:

Z_{bank} = altitude of the bank

Z_{bed} = altitude of the bed

h_w = water height in the river at low regime (the lowest water height in the river)

The grid leveling in annex provides:

Z_{bank} = 19.87 m; Z_{bed} = 13.46 m

Since the construction of Nagbeto's dam in 1987, there is always at least 1m water level in the river at Athieme hydrological station, thus h_w is assumed to be 1 m.

h_1= 19.87 – 13.46-1 = 5.41 meters

- Slope

The highest slope noticed on the site is 2.88‰ ((20.21 -19.72)/170 = 0.00288 = 2.88‰). A slope of 3‰ is assumed. The distance from the reservoir to the pump is 200 meters. Thus h_2 has the following value:

h_2 = 3x200/1000 = 0.6 m

The height of the reservoir is 3 m, the diameter will be calculated later asthe quantity of water to be stored is known. Then, h_3 = 3 meters. Finally,

H_s = 5.41 + 0.6 + 3 = 9.01 m.

The pipe diameter will be chosen in such a way that all kind of losses don't exceed 10 % of Hs. Thus is H_l = 0.1x H_s = 1.001 m. In total, H_a = 1.1Hs = 9.01x1.1 m = 9.91 m. H_a is assumed to be 10 metres.

H_a = 10 meters.

Selection of pump type

Two input data are generally used to select the type of pump: the daily water needs (Q) and the gross pumping head (H_a). For a pumping head of 10 meters and a daily water need of 30 meters, centrifugal surface pumps can be used. Figure 7.1.1.3 in annex 5 shows a graph that helps to select the appropriate pump based on Q and Ha.

Estimation of the required energy per day and design of PV array

- Hydraulic Energy required

The hydraulic energy needed to lift a quantity of water (Q) through a height (H_a) is given by the following formula:

$$E_{hyd} = \frac{CH.Q(m^3/day).H_a}{\eta_p} \qquad (18)$$

Where

E_{hyd} is the hydraulic energy required to lift a quantity Q of water through a height Ha.

CH is a hydraulic constant

CH = g.ρ_{water} = (9.81 (m.s^2) x 1000 (kg/m3))/3600 = 2.725 kg.s.h/m^2

ηp is the overall efficiency of the pumping system. For the selected pumping system, the efficiency is higher than 60 %. (88 to 93% at 6,000 rpm). For this study we assume η_p = 70%.

$$E_{hyd} = \frac{2.725x30x10}{0.70} = 1{,}167.85 \text{ Wh}$$

- Definition of the site conditions

The calculated solar radiations or peak sunshine hours and gross pumping head are the main site conditions data needed to size the PV generator and select a suitable pump.

Table 22: Peak sunshine hours (PSH) on the site

Months	**Temperature**	**Solar radiation ($H_{\beta=0°}$)**	**Solar radiation β = ($H_{\beta=10°}$)**	**Peak Sushine Hours (PSH)**
	Degree C	kWh/ m^2.day	kWh/ m^2.day	Hours/day
January	28,3	4,29	**4,41**	**4,41**
February	29,5	4,67	4,78	4,78
March	29,3	4,78	4,80	4,80
April	28,4	4,81	4,74	4,74
May	27,6	4,79	4,65	4,65
June	26,3	4,28	4,15	4,15
July	25,4	3,61	3,54	3,54
August	25,1	3,50	3,45	3,45
September	25,9	3,83	3,82	3,82
October	26,7	4,40	4,47	4,47
November	28	4,81	5,01	5,01
December	28,1	4,37	4,57	4,57

The peak sunshine hours (PSH) are the number of hours with standard irradiance (I) of 1 kW/m^2 to produce the same radiation on a given site irrespective of the season or month. For the site of Togblo and from October to May the PSH for the less productive month (January) is 4.41hours or 4.41 W/m^2.day.

Examples of generators and pumps

There are many companies (manufacturers) involved in solar pumps business. This paragraph will give information gathered from Grundfos solar pumping System. Grundfos products are already in use in Benin where they are used by ABERME (Benin Agency for Rural Electrification and Control of Energy). The BP-SQ pumping systems have an efficiency higher than 60%.

- Examples of photovoltaic generator and modules (Source: Apex BP Solar, 2006)

Photovoltaic generators of BP-SQ range are made of 3 to 10 modules in series of 60 to 80 Wp. The proposed standard configuration are summarised in tables 7.1.1.5a (PV generators) and 7.1.1.5b (Grundfos modules) in annex 6.

- Characteristics of surface pumps

The information given in this paragraph is provided by the pump manufacturer "Sunpumps, USA". It provides a wide range of pumps such as:

- *SDS series*

They are low-cost submersible pumps. They can deliver discharge ranges from 0.5 GPM (0.11 m3/hour) to 5 GPM (1.14 m3/hour) GMP through a height up to 230 feet (70 meters).

- *SCS series*

They are high power submersible pump, 2 to 200 GPM up to 700 feet of lift.

- *Centrifugal surface pumps (SCB, SJT, SCP and SC series)*

They deliver high volume, require low power and are suitable for surface water, 5 to 100 GPM, 120 PSI (17kPa), up to 277 feet of lift above ground.

- *SPB piston pumps*

They are high power and low volume surface water pumps, 0.5 to 12 GPM, 1000 PSI, up to 2300 feet of lift

- *SJD Series*

Jensen or JC brand jack pumps retrofitted for solar power.

Centrifugal surface pumps will be used in this study for surface water lifting.

- Array Power, modules and pump selection

Assuming losses of 20% due to temperature and dust (array mismatching factor F = 0.8), the energy that needs to be provided by the array is then $E_{array} = E_{hyd}/F = 1168/0.8$

E_{array} = 1460 Wh. The available sun energy is 4.41 kWh/m^2.day. Assuming that the overall efficiency from available sun energy to solar electricity is 10%, the usable solar energy is 0.441 kWh/m^2.day. The required area of PV is $A_{array} = E_{array}/0.441 = 3.31\ m^2$. By selecting the module of 80Wp with an area $A_m = 0.65\ m^2$, the number N_m of modules is given by n= $A_{array} / A_m = 3.31/0.65 = 5$ modules in series. The daily water demand 30 m^3/day (5m^3/hour) through a height of 10 m from surface water (river) enables to select the following centrifugal surface: SCB 8-90 60-90 volts. The number N_p of pump for 0.5 ha is 1. A catalogue of surface pumps with prices is given in annex 7. Table 23 below summarises array sizing and pump selection for different plots.

Table 23: Summary of array sizing and pump selection

Plot size	Q	H_a	E_{array}	A_{array}	N_m	N_p
ha	m^3/day	m	kWh	m2	SxP	
0.5	30	10	1,460	3.31	5x1	1 SCB 8-90
1	60	11	3,270	7.41	6x2	1 SCB 21-150
2	120	11.6	6,890	15.62	(6x2)x2	2 SCB 21-150
5	300	12.2	18,101	41.05	(6x2)x5	5 SCB 21-150
10	600	13.7	40,000	90.70	(6x2)12	12 SCB 21-150

➢ Examples of PV arrays for irrigation in Benin


Photo 6: PV arrays in Dunkassa and Bessassi in Kalala – Benin (Photo: Noumon, 2008)

Selection of pipe diameter

Here also two data are used to select the appropriate diameter of the pipe joining the pump to the reservoir: the gross pumping head expressed as head losses (in m/100m) and the discharge (in litres/min).To ease calculations, it is assumed the head losses to be 10% of the net pumping head, this means 1m/100m. Assuming 6 hours maximum pumping per day (9h-15h), the daily discharge of 30 m^3/day is equivalent to 5 m^3/hours or 83.33 litres per minutes. With those two data, the graph of figure 7.1.1.6 in annex 8 gives a diameter D of about 57.5 mm. The diameter of the pipe is assumed to be D = 63 mm.

7.2 Groundwater (boreholes and wells)

Groundwater table in the study area is relatively shallow. Based on results from questionnaires, similar studies and data collected from Ministry of Mines, Energy and Water, the ground water table in dry season in Grand-Popo (Province of Mono) is about 6 meters (Atidegla, 2006) while in Seme-Kpodji (Province of Oueme) this value is 8 m. In Cotonou (province of littoral) the groundwater is very shallow about, 3 m in dry season.

For this study the groundwater level in study area in dry season is assumed to be to be 8 metres.

7.2.1 Plots of 0.5 ha

Gross pumping head or Gross working head (Ha)

Assuming the same characteristics for the reservoir as in part 7.1 and reservoir located just near the borehole, we have:

H^a = (8+3)x1.1 = 12.1 m. We assume, H_a = 12.5 meters.

7.2.2 Estimation of the required energy per day and design of PV array

Motor and pumps (Grundfos, USA)

- Technical characteristics of motor

The pumping system BP-SQ uses only one type of submersible motor MSF3 (effective power: 900W). Those pumps have the advantage of using both direct current (voltage ranged from 30 to 300V) and alternative current (90 to 240V). The table 7.2.2.1a in annex 8 gives the technical characteristics of BP-SQ motor for direct current (DC).

- Technical characteristics of pumps

BP-SQ pumps are composed of 3” (3 inches) pumps (diameter of the borehole), which are designed for low discharges and significant total head (Ha). Table 7.2.2.1b in annex 8 gives the technical characteristics of SQF pumps

- Solar pump controller

Solar pump controller is used to ensure that pumps work at maximum power point either by controlling the current (current booster) or the voltage (voltage booster). Its main advantage is that it helps pumps to work even when solar radiation is not enough (in morning for example). However, it also consumes power and this has to be taken into account while designing the whole system, especially PV generators.

Required hydraulic energy

The hydraulic energy needed to lift water from groundwater is given by the same formula as for surface water.

$$E_{hyd} = \frac{2.725x30x12.5}{0.70} = 1460 \text{ Wh}$$

Summary of design components

Table 24: Design elements for different plots (groundwater)

Plot size	Q	H_a	E_{array}	A_{array}	N_m	N_p
ha	m^3/day	m	kWh	m2	SxP	
0.5	30	12.5	1,825	4.14	4x2	1 SQF AC/DC
1	60	13.5	4,000	9.07	(4x2)x2	2
2	120	14.1	8,350	18.93	(6x2)x3	3
5	300	14.7	21,751	49.32	(5x2)x8	8
10	600	16	46,714	105.92	(6x2)14	124

8 Design of the reservoir

8.1 Size of reservoirs

Drip irrigation has the advantage of needing only small pressure (water height pressure). Moreover it is assumed to store about 50% of the daily irrigation water needed and start irrigating the farm only when the reservoir is filled. Instead of installing a reservoir on a support, it is projected to build a reservoir in soil and guarantee 1 m meter height pressure. This means that the tap for irrigation will be set at 1 m above the ground. Putting the tap 1 m above the ground will also favour the settling of some particles before starting the irrigation. In other words, only 2/3 of the volume of the reservoir will be used for irrigation purpose. As the irrigation water requirement is 30 m^3, 50% of this volume is 15 m^3. The theoretical volume of the reservoir is 22.5 m^3, the exact volume will be known after the diameter is calculated. Details about the geometrical design of reservoirs are given in annex 8.1.

V= d^2xπxh/4, where:

V = volume of the reservoir (V = 30 m^3);

h = water height in the reservoir (h = 3 m).

The total height of the reservoir is H = h+0,2 H = 3,2 m

d = inner diameter of the reservoir.

d = $\sqrt{4xV/(\pi xh)}$ = $\sqrt{4x22.5/(3.14x3)}$ = 3.09 m; d is assumed to be 3.2 m. The outer diameter is D = d+2e where e is the thickness of the reservoir. D = 3.2+ 2x0.2;

D = 3.60 m. The volume of water in the reservoir is then 24.13 m^3. Table 25 gives dimensions of various reservoirs.

Table 25: Size of various reservoirs

Size	Dimensions of reservoirs (m)		
ha	**Outer diameter**	**Total height**	**Thickness of wall**
0.5	3.6	3.2	0.2
1	4.2	4.4	0.2
2	5.4	4.8	0.2
5	7.9	5.4	0.2
10	9.90	6.7	0.2

8.2 Filling of the reservoir and starting of irrigation

The daily water need is 30 m^3 (30 m^3 /day) or 5 m^3/h assuming 6 hours (9h00 to 15h00) of maximum power per day . To fill the reservoir (V=24.13 m^3), about 5 hours for the "first filling" and 3.2 hours after the "first filling" are needed (only 16. m^3 that is 2/3 of the reservoir volume is considered as usable volume). This means that if the pump started working at maximum power at 9h00, the reservoir will be filled at about11h30 minutes. The irrigation will then start at 11h30. There is enough time (11h30 to 15h00) to pump again 16 m^3 before a significant decrease of the sun power (after 15h00). Finally the total volume of water pumped per day is about 32 m^3, which totally cover the water need that is 30 m^3

8.3 Structural design of the reservoir

The rules BAEL 91 (Reinforced Concrete at Boundaries States) will be used for reinforced concrete calculations. As the reservoir is designed to store water, no crack is tolerated. The calculations will be conducted at the ELS (Service Boudaries States)

8.3.1 Given data

Inner diameter (d): 3.2 m
Water height (h): 3 m
Wall thickness (e): 0.20 m
Total height of reservoir (H): 3,20 m

8.3.2 Characteristics of construction materials

- Concrete

The compression resistance of concrete (fc28) is 25 MPa after 28 days. The resistance of compressed concrete at ELU (Ultimate Boundaries States) is:

$$f_{bu} = \frac{0.85\,fc28}{\theta x \gamma b}$$

$\sigma_{bc} = 0{,}6f_{c28} = 15$ MPa

θ = 1 as the duration of loading is greater than 24 hours; γb is equal to 1.5. Thus $f_{bu} = 14.2$ MPa

The traction resistance of concrete at 28 days is:

$f_{t28} = 0.6 + 0.06f_{c28} = 2.1$ MPa

The materials (gravel, sand, cement, steel and water) used should be of high quality to ensure that the calculated parameters are fulfilled on the field. Moreover, during the construction, samples will be taken and tested in the laboratory.

- Steel

In this study, we will use available steel on the market. We choose then steel type FeE400 with mechanical resistance (f_e) equal 400 MPa. As cracks are very harmful to the construction, the stress of tension steel is limited to:

σ_s= min [1.2 fe ; 90 $\sqrt{\eta x fc28}$] where:

η is 1.6 for High-Strength (HS) steel, so

$\sigma_s = 202$ MPa.

At ELU, where cracking is less harmful to construction, the stress of tension steel is:

$f_{ed}=\frac{fe}{\gamma s}$ with $\gamma s = 1.15$, so

$f_{ed} = 348$ MPa.

8.3.3 Design of the vertical wall

The design of the reservoir is done following the rules, formulas and state of art edited by Guerrin and Lavaur (1972) on one hand and Perchat and Roux (1999 & 2000) on the other hand. The vertical wall is subject to two different stresses: traction (tension) forces and the vertical bending moment.

- **Traction forces (T)**

The parameter "h^2/ed" is used to structurally design reservoirs. Its value helps to enter tables and calculate tension forces and bending moments as well.

$$\frac{h^2}{ed} = \frac{3^2}{0.2x3,2} = 14.06$$

The traction force in the vertical wall is given by:

$$T = \gamma.\rho.h.r \qquad (19)$$

where:

γ is a parameter that is taken from tables and is function of $\frac{h^2}{ed}$ and the ratio z/h where z is the current depth and h the water level; e and d are defined above.

ρ is density of water

r radius of the reservoir

$T = \gamma x10^{-2}x3x1.6 = 0.048x\gamma$ MN

Guerrin and Lavaur (1972) provide the following values for γ in the table I: "Tension at depth z in a circular ring of a reservoir free on the top and build in ground supporting a triangular load". For the following table, the origin of z axis is on the top of the reservoir.

Table 26: Values of γ for a reservoir free on the top and build in ground supporting a triangular load

z/h	z	γ	T (10^{-3}MN)
0.1	0.3	0.098	4.70
0.2	0.6	0.200	9.60
0.3	0.9	0.306	14.70
0.4	1.2	0.42	18.72
0.5	1.5	0.539	25.87
0.6	1.8	0.639	30.67
0.7	2.1	0.666	31.97
0.8	2.4	0.541	25.97
0.9	2.7	0.241	11.56

- Traction force and selection of required section of steel in successive ferrules

For the first and last cylinder ferrules (0-0.3 m and 2.7 to 3 m), the value of the traction used for calculations is half o the tension in the current ring. For any other ferrule (i), the traction value used for calculation is

$T_i = (T_i\text{-}1 + T_i)/2$ (20)

- Required steel section

The required steel section A_{ser} is given by the following formula.

$A_{ser} = T/\ \sigma_{s.}$ (21)

T is maximal for the 7th ferrule (table 27) and has a value of 31.97 10^{-3}MN

$A_{ser} = 31.3010^{-3}/202 = 1.5510^{-4}\ m^2 = 1.46\ cm^2$

Moreover A_{ser} has to be greater than A_{min}, otherwise A_{min} is used to realise the structure.

$$A_{min} = \frac{Bxft28}{fe}$$ (22)

where B is the section of one ring. As all right has the same size and geometry, B = ex h_1 with the height of each ring. B = 0.20x0.3 = 0.06 m^2

$A_{min} = \frac{0.06x2.1}{400} = 3.15\ 10^{-4}\ m^2 = 3.15\ cm^2$

As A_{ser} for the smaller for A_{min}, we adopt $A_{ser} = A_{min} = 3.15\ cm^2$ for the whole height of the reservoir. This steel section is equivalent to 4HS10

Table 27: Traction force and required section of steel in successive ferrules

Ferrule	Definition	Traction force (10^{-3}MN)	A_{ser} (cm^2)	Nr and □ of steel
1st	0 to 0.30 m	2.35	0.1	4HS10
2nd	0.3 to 0.6m	7.15	0.33	4HS10
3rd	0.6 to 0.9m	12.15	0.56	4HS10
4th	0.9 to 1.2m	16.71	0.80	4HS10
5th	1.2 to 1.5m	22.30	1.06	4HS10
6th	1.5 to 1.8m	28.27	1.31	4HS10
7th	1.8 to 2.1m	31.30	1.46	4HS10
8th	2.1 to 2.4m	28.97	1.38	4HS10
9th	2.4 to 2.7m	18.77	0.9	4HS10
10th	2.7 to 3 m	5.78	0.28	4HS10

- **Vertical bending moment (M)**

The vertical bending moment is given by:

$$M = \gamma^1 .\rho .h^3 \qquad (23)$$

Where γ^1 is a parameter that is taken from tables and is function of $\frac{h^2}{ed}$.

M = $10^{-2}x3^3 = 0.27\gamma^1$ MN.m

In the same way as previously Guerrin and Lavaur (1972) provide the following values for γ^1 in the table III: "Bending moment at depth z in a vertical strip of a reservoir free on the top and build in ground supporting a triangular load". For the following table, the origin of z axis is on the top of the reservoir.

Table 28: Values of γ^1 for a reservoir free on the top and build in ground supporting a triangular load

z/h	γ^1	M (10^{-6}MN)
0	0	0
0.1	0	0
0.2	0	0
0.3	0	0
0.4	0	0
0.5	+0.0001	+27
0.6	+0.0008	+216
0.7	+0.0019	+513
0.8	+0.0023	+621
0.9	-0.0001	-27
1.0	-0.0085	- 2,430

The bending moment has two signs; positive sign means that the section at the concerned depth needs tension steel while the negative sign means that the concerned section needs compressed steel. Basically this means that the section of steel calculated for negative moment will be arranged on the inner side of the reservoir wall while for positive moment it will be arranged on the outside of the wall. Of course, inner or outside steel will be protected by concrete.

- Negative bending moment (inner steel)

Maximal bending moment: M = 2,430 10^{-6} MN.m = 2.43 10^{-3} MN.m

$$\alpha_1 = \frac{15\sigma_{bc}}{15\sigma_{bc} + \sigma_{bc}} = \frac{15x15}{15x15 + 15} = 0.527 \quad (24)$$

$$M_{rb} = \frac{1}{2}\alpha_1\left(1 - \frac{\alpha_1}{3}\right)b_o d^2 \sigma_{bc} \quad (25)$$

M_{rb} = 0.5x0.527 (1-0.527/3)x1x0.18^{2}x15 = 0.106 MN.m

$M<M_{rb}, \Rightarrow A'=0$

Z_b = d (1-α_1/3) = 0.18 (1-0.527/3) = 0.15 m

$$A_{ser} = \frac{M}{Zbx\sigma_s} \qquad (26)$$

$$A_{ser} = \frac{M}{Z_b x \sigma_s} = \frac{0.00243}{0.15x15} = 1.08\ 10^{-3}\ m^2 = 10.8\ cm^2$$

$$A_{min} = 0.23 \frac{f_{t28}}{fe} b_o d \qquad (27)$$

A_{min} = 0.23x(2.1/400)x1x0.18 = 2.17 cm^2

$A_{ser} > A_{min}$, we adopt A= Aser = 10.2 cm^2

This means 10HS12 of 0.75 m height per m of circumference from the bottom of the reservoir. For the remaining height, as the bending moment is very small we arrange $A_{ser} = A_{min}$ = 2.17 cm^2; this means 10HS6.

- Positive bending moment

The maximal positive bending moment is M'= 621 10^{-6} MN.m

A'ser = 0.000621/ (0.15x15) = 2.76 cm^2 > A_{min}=2.17 cm^2

This leads to 10 HS8 per meter of circumference on the whole height of the reservoir.

8.3.4 Design of the foundation

- Load on the circumference
- Vertical wall: $W_1 = \rho_c x \pi x (Re^2-Ri^2)xH = 25.10^{-3}x3.14x(1.8^2-1.6^2)x3,2$ =

  W1= 0.171 MN

Where:

ρ_c = the density of reinforced concrete

Re = the external radius of the reservoir

Ri = the internal radius of the reservoir

H = total height of the reservoir

- Internal coat : W2 = $\rho'_c x\pi x2xRixaxH = 22.10^{-3}x3.14x2x1.6x0.015x3,2$

  W2 = 0.0106 MN
- External coat: W3= $\rho'_c x\pi x2xRexaxH = 22.10^{-3}x3.14x2x1.8x0.015x3,2$

  W3 = 0.0119 MN

Where:

ρ'_c = the density of mortar

a = the thickness of the coat

- Total load: W = 0.194 MN

- Area of the foundation (S)

We assume that the diameter of the foundation is the same as the external diameter of the cylinder (reservoir). Thus

S= ($\pi.D^2$)/4 = ($3.14x3.6^2$) 4 = 10.18 m^2

- Pressure on the foundation

P = 0.194/10.18 = 0.02 MN/m^2

To calculate the required section of steel, we assume a mean height of 0.30 m for the foundation.

- Bending moment

M_f = maximal negative moment x $(h-e)^2/24$ = 0.0023x $(3-0.2)^2/24$ = 7.51 10^{-6} MN.m per meter of the foundation circumference in both direction x and y.

We assume the thickness (height) of the foundation equal to 0.20 m. Also the foundation lies on a concrete layer of 0.20 m height, which overwhelms the foundation of 0.10 m.

In the same way as previously this moment generates steel section of 2.18 cm2, which is equal to A_{min}. We assume 5HS 10 per meter in both directions x and y (cross-ruling).

- Total load transmitted to the underlying ground

Wall:		0.194 MN
Underlying concrete:	$\pi x1.9^2x0.20x2.210^{-3}$ =	0.005 MN
Foundation:	$\pi x1.8^2x0.20x2.210^{-3}$ =	0.0045 MN
Water:	$\pi x1.6^2x3x10^{-2}$ =	0.241 MN
Total:		0.445 MN

- Pressure on the ground:

P = 0.445/10.18 = 0.043 MPa = 0.4 bar = 0.4 daN/m^2.

Assuming that the reservoir itself will be built in soil at a depth of 0.20 a least, we have to check if the bearing capacity of the soil at a depth of 0.6 m (0.2 m + height of foundation +height of underlying concrete) is enough to support this load.

On the site the bearing capacity of the soil at a depth of 0.6 m is 6 bars >> 0.4 bar (see annexes for different of bearing capacity).

8.3.5 Reinforcement of the construction

- **Foundation**

The total length of steel (Ls) is function of the area of the foundation and the spacing of the steel. It is given by

Ls = 2S/e where (28)

e is the distance between two consecutive steel. Here e = 0.20 m (5)

S is the area of the foundation

Ls= 2x10.18/0.2 = 101.18 m. Assuming 10% losses, we can have, Ls = 112 m.

1 m of HS10 corresponds to 0.616 kg. Thus 112 m correspond to 69 kg. The reinforcement is about 33.9 kg/m^3. We assume 40 kg/m^3.

- **The vertical wall**

- Quantity of steel to balance traction forces

The calculations of part 7.4.3.1 show that we need 4HS10 per 30 cm, this means that the space between two consecutive steel is 7.5 cm or 0.075m. So the total number of traction steel is 3.2 m/0.075 = 43. Each steel has a length equal to the external circumference of the reservoir (3.6x3.14 = 11.30 m). The total length of traction steel is 43x11.30 = 486 m. As these are circular steel, losses are higher, 30% losses are assumed. This leads to Ls = 1.3 x 486 = 632 m and the corresponding mass is 390 kg.

- Quantity of steel to balance positive bending moment

10 HS8 are needed per meter of inner circumference, this means 10x10.68x3 = 320.4 m of HS8. The corresponding mass is 320.4x0.395x1.1 = 140 kg

- Quantity of steel to balance negative bending moment

10HS12 of 0.75 m + 10HS6 of 3 m are needed. This leads to 10x11.3x0.75 = 85 m of HS12 having a mass of 85x0.888x1.3 = 99 kg. The coefficient is 1.3 because a part of the steel has to enter the foundation to balance the negative moment also developed in the foundation. In total for the negative moment, we have 99 kg (HS 12) + 140 kg (HS6) equal 239 kg. The percentage of steel is Masse of steel/Volume of the wall = 35 kg/m^3. The reinforcement is assumed to be 40 kg/m3.

9 Economic analyses

9.1 Investment costs of various irrigation schemes

The cost estimation is done based on the following parameters and assumptions:

- a unit cost of 6 US $ per watt of power is used to evaluate the cost of PV generator. This unit cost is the current cost applied to PV generator;
- pumps costs are taken from "Grundfos" and "Sumpumps" catalogues offered in July 2008
- Drip pipes costs taken from a similar projects conducted in the USA in 2000 have been converted in 2008 costs
- Drip lines costs are taken from the catalogue of a manufacturer called "NaanDanJian Irrigation" (see annex for details)
- Shipping costs from USA to Benin and transport costs inside Benin to the site have been applied to the above mentioned costs
- Reservoirs have been estimated using the local cost of material and local cost of manpower

Details of all cost calculations are in annexes. Table 29 summarises the investments costs of irrigation schemes using various water source. It also shows the variation of the cost per hectare of different plots.

Table 29: Investment costs for various plot sizes and sources of water

Plot size	**Investment cost (Euros)**			
ha	**Surface water**		**Groundwater**	
	Total	Per hectare	Total	Per hectare
0.5	12,491	24,983	13,272	26,545
1	23,509	23,509	26,916	26,916
2	46,171	23,085	55,659	27,829
5	113,097	22,619	133,802	26,760
10	158,398	15,840	193,681	19,368

By analysing this table, one can conclude that the cost per hectare for larger plots is cheaper than the one for smaller plots. Moreover, despite the fact that the groundwater level in the study area is relatively shallow, the cost per hectare increases significantly from surface water source to groundwater one. Two observations can be made:

a) if one includes the criteria of affordability by farmers and financial institutions, small plots become more economically feasible than larger plots;
b) It is advisable to use surface water for solar irrigation rather than groundwater, except in cases where the groundwater table is shallow and there is no access to surface water.

9.2 Economic analysis

The economic analysis of a pumping system provides two types of information: the revised (updated) costs of pump and the annual charges it generates. For an investor, the updated costs help to compare costs of different options. Its importance is related to the fact that some options call for high investments and relatively low maintenance costs while other options show opposite situations. In those conditions a cost analysis should also include the capital financing cost, the net present value, maintenance and replacement for the life span of the pumping system. This analysis is called life cycle cost.

From the user's point of view, the annual costs of a pump help to ensure its permanence. The users must earn (gain) sufficient revenues to pay or support the annual costs. The main parameters to be considered are:

- cost of solar pumping system: it includes investment and installation costs ; annual running and maintenance costs, replacement of the equipments and the residual value of the system (sale value).
- Cost of water (using solar pumping system): it should cover recurrent costs and service (care) after sale.
- Security measures

9.3 Comparison of solar, electric and power-driving pumps

The comparison of the 3 different pumping systems is done based on the following parameters:

- size: each plot has 0.5 ha (except for the electric pumping where initial calculations where done for 10 ha)
- revenues from vegtables cultivation is the same for all three types of plots
- the same interest rate is applied for the loan
- the same crop or type of crop is grown.

Table 30: Comparison of solar, electric and power driving sytems over a period of two years

Items	**Solar power**	**Electric power**	**Gasoline**
Loan	17448	3078	1891
Farmer's contribution	1790	880	717
Total resources	24264	5235	5044
Total expenses	20634	4204	3510
Incremental cashflow	**2898**	**945**	**1641**

Table 30 shows that gasoline power driven pumping systems can be easily afforded by farmers as they require low investment cost and financial contribution from the farmers side. However, for a medium term economic analysis both solar and electric pumping systems are more profitable than power driven systems. The residual value of gasoline power-driven pump after 2 years is very low compared to the one of solar and electric pumping systems. The power driven pumps in use in Benin have a lifespan of 3 months and cost about 170 euros. Not only is gasoline getting more expensive but also it is possible that there is a lack of fuel that can have a detrimental consequence on the crop growth. The investment cost per 0.5 hectare and per year of gasoline pumping system (1546 euros) is very high compared to the ones of solar pumping system (1372 euros) and electric pumping system (643 euros). Due to the high initial investment cost, the solar pumping sytem appears to yield the highest incremental cashflow. The most interesting advantage of solar pumping system is the fact that the whole system will belong to the farmer after 5 years (based on the cost-benefits analysis provided in annex 11). If one adds to economic considerations, environmental ones it might be reasonable to opt for solar pumping system if the government wants to promote sustainable development.

The comparison of solar pumps to electric pump is more complicated because this depends on the availability of electricity grid and also the source of electricity (hydropower, big diesel generator). Generally, if reliable mains exist solar pumping system may be more expensive than electric pump. It is obvious that investment and running costs of power-driving pumps are much higher than the one of electric pump.

10 Maintenance of the irrigation system

10.1 Maintenance of the solar pumping system

There are mainly two types of maintenance: the preventive maintenance (systematic of conditional) and corrective maintenance (palliative or curative). The common objective of both types of maintenance is to diminish the cost of failure.

10.1.1 Preventive maintenance

The purpose of preventive maintenance is to avoid the breakdown of the whole installation. To achieve this, a regular meticulous inspection of all components of the pumping system is required. It is also important to ensure the availability of spare parts and their replacement for the best functioning of the pumping system.However, one can differentiate two modes of preventive maintenance: the systematic maintenance and conditional maintenance.

- **Systematic preventive maintenance**

It consists of changing spare parts according to a given schedule. It does not immediately yield visible results but it helps to ensure the reliability of the system. Tables 31 and 32 indicate controls (checking) to be done and action to be taken on one hand and reparation tasks on the other.

Table 31: Preventive maintenance at local level (source: Modified after Royer et al., 1998)

Checking to be done	**Action to be taken**
Weekly cleaning of solar panels	• Use a clean wet duster and not coarse detergent or products with abrasive particles
Prevention of shade on the panel	• Remove vegetation around the PV generator • Avoid disposing near the generator of anything that can generate shade • No house construction near the generator that can generate shade
Inspection of cables constituents and of the whole system	• Checking of the cleanness state and blockage of all visible connections (pump, panels, energy conditioner or control box, etc.) • Once a week, checking of cables wherever possible and find out probable deteriorations • Daily checking of the state of all equipment and the whole system

Table 32: Reparation tasks at the local technical structure level (source: Royer et al., 1998)

Technical operator **Daily tasks**	**Pumping system manager** **Daily tasks**
• Before the starting of the pumping station, ensure that all equipments are in good condition (modules, cables, leakages) • Report in a copy book the daily value showed by the discharge recorder (afternoon when stopping pumping or morning before starting pumping)	Protection of equipments: avoid vandalism, animal entrance, stone throwing on the panel, etc.) Sanitation of the pumping station
In case of failure:	
• Inform local mangers of the pumping station • Checking of equipment according to the pre-established procedure • Call for a technician if the repairs cannot be done by the local technical staff	

➢ **Conditional preventive maintenance**

The main purpose of the conditional preventive maintenance is to correct probable problems related to overall efficiency of the pumping system, this is done through a rigorous use of recorded measures and assessment of the situation on the site. It is a preventive maintenance that requires a diagnosis before replacement of spare parts.

10.1.2 Corrective maintenance

There are two corrective maintenance activities:

- repairs: they help to temporarily put a faulty equipment back to its former state before a complete reaping
- repairing: it is the definitive putting back of the whole faulty equipment in its former state. Conversely to repairs, repairing is prepared and generally planned.

10.1.3 Maintenance costs

Despite the fact that they vary depending on activities, the annual costs of maintenance represent generally about 15% of the installation costs and about 9% of global expenses (Royer et al., 1998). The maintenance costs can be divided in four parts:

- wages and tools (costs of average wage and costs of tools)
- purchases and movement from store
- external wages expenses
- general costs.

10.2 Clogging: maintenance of drip pipe and drip lines

Drip pipes and lines need to be maintained regularly to ensure delivery of required discharge. The main problem associated with drip irrigation is the clogging of emitters. Many factors such as salt content of water, source of water, organic matter from water and/or farm, etc. favour the clogging of emitters. However, drip lines using surface water are more subject to clogging than those using groundwater.

To deal with this problem, farmers try, daily, to unblock emitters that clog and cannot release water. In addition to this manual "repair", drip pipes and lines are frequently replaced. The replaced drip pipes and drip lines are immerged in an acid solution to be cleaned. Photo16 shows pipes and drip lines maintenance activities.

Photo 7: Maintenance of drip pipes and drip lines in Kalale (Photo: Noumon, 2008)

10.3 Maintenance of the reservoir

For surface water source pumps are generally equipped with a filter at their end. In addition to that, the reservoir is designed in such away that the pipe outlet to the farm is at least 1 m above the ground (base of the reservoir). This design may be though as not efficient (due to the unusable water permanently stored in the reservoir) but it help to achieve a kind of sedimentation in the reservoir before water is discharged to the farm. For this reason, the reservoir needs to be emptied and cleaned frequently.

10.4 Maintenance committees and involvement of all stakeholders

In Benin, each village benefiting from solar installation has also a local committee composed of technicians and authorities. They call for help outside only when the failure is important and out of their control. However, those committees have shown their limitations and the governmental agency ABERME is currently working on maintenance plan based on Public-Private Partnership (PPP). The maintenance and even the exploitation of solar installation will be given to private companies that are paid according their results on field. The experience with those committees shows that there is enough laxity from their side to warrant this action. However, all activity will be carried with the participation and involvement of the beneficiaries.

There is a need for politicians (government) to show interest in for solar energy in the case of Benin, the government is doing its best to ensure drinking water and electricity in remote areas using solar equipment. In fact the two governmental companies SBEE (Benin Society of Energy and Electricity) and SONEB (Nation Society of Benin Water) are not yet able to ensure electricity and potable for the whole Benin. It is why the government is exploring solar installations. It is expected that, with the new PPP, there will be an improvement in the functioning of solar installations in Benin.

11 Environment considerations for solar gardening projects

It is obvious that solar pumping systems, conversely to power-driving pumps produce no atmospheric pollution. For electric pumps the comparison is not so obvious. When the mains are supplied with a renewable energy such as hydropower, electric pump becomes environmental friendly pumps but when they are supplied with big gasoline or gas oil generators, they generate a delocalised atmospheric pollution.

11.1 Effects of irrigation project on the soil

If there is almost no air pollution with solar pumping systems, no hasty conclusion can be drawn from soil and water contaminations. Because solar pumping system costs are very high, farmers will tend to get the highest possible profit to quickly pay back the investment costs. This can lead to an uncontrolled use of mineral fertilizer and pesticide. As mineral fertilizers generally provide only macro-nutrient, soils can be exhausted in micro-nutrients after a period of time. Lack of micro nutrient can cause soil infertility that can also induce the disappearance of some plants species. On the other hand pesticides and fertilizer used on the farm can easily contaminate surface and/or groundwater.

11.2 Effects of irrigation of groundwater level and flow regimes of surface water bodies

If large irrigation projects (or numerous small projects concentrated in one area) are coupled with inefficient irrigation techniques, this will certainly lead to modification of rivers flow regimes or the deepening of the groundwater table. Changes in a river flow regime can have influence on available fish species and vegetables as well. The aquatic flora and fauna would be subject to strains. The lowering of the groundwater table can induce also other phenomena such as sea water intrusion or land slide. It is important is important to carry out an Environmental Impact Assessment for large irrigation projects to avoid disasters such as the ones of lac Chad (lost 90% of its area in less than 40 years) and River Niger (change in flow regime and associated wetland areas).

This study focuses on the arrangements of small schemes along water bodies or using groundwater. The irrigation water demand of those schemes is about 60 m^3/ha/day and the annual mean flow of river Mono is 101 m^3/s i.e. 8.7 10^6 m^3/day. To use 10% of this quantity of water, one would have arranged about 15,000 ha. Actually the only big project using river Mono as a complementary source of water is 105 ha of rice cultivation in Deve (district of Dogbo). Another project of rice cultivation is planned in Adjove (district of Athieme) for 500 ha of rice cultivation. Even though the actual consumption of water from River Mono is not important, it is important to pay attention in order to avoid environmental disasters.

The quantity of groundwater in Benin is estimated to 2 10^9 m^3 (2km^3). Currently 95 % of drinking water is supplied in Benin using groundwater and many other private uses are exploiting groundwater (wells for livestock, well and boreholes for irrigation ,etc.). At the opposite of drinking water that is charged, private users pay nothing for the extraction of water. Consequently, there is enormous waste of groundwater. It is essential to control the use of this precious source of water together with charges for both surface and groundwater exploitation.

12 Social organisation and training of users

The experience of solar pumping systems projects that had been conducted for almost 3 decades in numerous of countries, among others, Sahel countries very often showed that the technical success criterion masked the viability and permanence of projects. (Royer et al., 1998). In fact many projects that were technically sound failed and many pumping stations were abandoned. Many factors linked one to the others are sources of those failure:

- lack of information and campaign of awareness of the beneficiaries
- very low involvement level of populations at the implementation phase of the project
- lack of effective sense of responsibility in regards to equipment management, in particular for the payment by users of the recurrent costs due to the utilisation of the pump
- a technological environment less favourable for interventions (repairs and repairing) in rural areas.

For all those reasons, it is important, right from the beginning of the pumping system to see to it that the campaign of awareness of beneficiaries is conducted in a good way. This campaign of awareness must be done through different phases.

12.1 Before pump installation

- Site identification phase: it leads to the preliminary selection of the pumping station.
- Information phase: here populations or farmers (beneficiaries) have to take the decision to opt for solar pumping without appeal and being aware of advantages and disadvantages.
- Training phase: it helps the beneficiaries to get skills to organise and manage the pumping station.

12.2 At the moment of installation

Training: it helps the beneficiaries to get used to current maintenance and the main parts of the PV pumping system.

12.3 After installation

Post-installation follow up phase: to strengthen skills and help for a good control of the management of the pumping system. For the purpose of this project, in addition to training of beneficiaries, there will be in each village skilled people that are able to repair the current failure. Complicated repairs and repairing will be done by a private company through Private-Public Partnership to ensure the quality of service and avoid incommensurable failures. ABERME (public institution) and ENERDAS (private institution) in Benin are already working to install in all 77 districts of the countries well skilled and permanent technicians for the maintenance of solar systems.

13 Discussions

For the successful implementations of this study many points and information provided in this work need to be discussed to find out their validity, their limitations and required adaptations.

13.1 Climatic and hydrological data

To carry out this study, climatic data and hydrological data have been collected. While the hydrological are provided by a gauging station near the selected site, climatic data have been taken from a meteorological centre far from the study area. The meteorological centre (Bohicon) is situated at about 200 km from the study area. However, the study area and Bohicon are situated in the same climatic zone. Moreover they are all situated on the continent. Thus the variation of climatic data due to the difference of location has been assumed to be negligible. However, it would have been good if there was a meteorological centre in the study area. Maybe the government should re-establish the meteorological centre of Athieme to ease study in the lower part of southern Benin as data from the meteorological centre of Cotonou can be used for the whole region (Cotonou is situated in a coastal zone and benefits from a particular climate).

13.2 Affordability of solar drip irrigation

The investment costs of solar drip irrigation designed in this study are quite high for low income farmers (about 12,941 to 13,272 euros for 0.5 ha plots and 23,509 to 29,912 euros for 1 ha plots). The costs of 0.5 ha plots (12,941 to 13,272 euros) are lower than the cost invested in northern Benin for the same plot (about 13,333 to 16,666 euros). The difference in cost can be attributed to a slight reduction in solar panel costs, transportation cost from southern to northern Benin, price of construction material, availability of qualified manpower (The southern Benin is more developed than the northern part). But the main factor that can explain such a great difference is the fact that the NGO SELF was obliged to pay duties and other taxes to the government of Benin.

The majority of farmers (80%) declare to earn less than 1000 euros per year per hectare. It is clear that it will be difficult for such farmers to self-finance such projects. The main question is how to make farmers acquire this technology while ensuring the paying back of the investment costs. If the government decides to go for irrigation to ensure self-sufficiency, then initiatives such as drip solar irrigation should be encouraged and funds should be raised to support farmers. The following steps can be followed:

- identification of all farmers involved in irrigation
- selection of most productive and efficient farmers
- attribution of low interests loans to those farmers to cover a part of the investment costs
- Repayment period of at least 5 years with 1 year differed
- in return, farmers should give a guarantee (land, farm, any valuable property)
- establishment of good repairs and repairing service throughout the country for solar equipment

The affordability has also to be seen from technical point of view. Drip irrigation systems are said to be complicated. Fortunately there are nowadays simple systems that require no higher level skills. The system that is being currently experimented in northern Benin is very simple. Farmers learnt quickly how to operate the system. They are assisted by 1 mechanical technician (for maintenance), one agricultural technician and one hydraulic technician. In absence of those technicians, farmers (mainly women) are able to operate the routine tasks. The technical affordability is not a major problem.

13.3 Suitability of solar drip irrigation to meet farmers expectations

All interviewed farmers complained about the continuous increase of oil price that makes their running costs increasingly expensive. On the other hand the mains do not provide reliable electricity. Consequently farmers that are connected to grid have two types of pumps: electric and power-driving pumps (waste of money). Moreover, they complain about the large amount of man power needed and difficulty associated with manual and motorised irrigation systems. Some of them said that they are looking for an automated and independent irrigation system with high efficiency. The efficiency of the sprinkling actually in use in the study is about 50-60%. Farmers are also facing pest and diseases and have to apply frequently pesticide (more than the normal quantity and frequency).

Apart from the high investment costs required, frequent clogging and some other minor disadvantages, solar drip irrigation is the best choice because:

- it has the highest possible efficiency (90 to 95%)
- it is an environment friendly (no atmospheric pollution)
- it reduces the vulnerability of plants to fungi diseases (water is applied in drops on the root of the plant not on the whole surface of the farm and on leaves)
- it promotes sustainable use of water
- it requires low water pressure (1-2m can be sufficient) and is adapted to all landscape
- it provides increased yields

13.4 The future of PV systems in Benin

It is difficult to predict the future, especially in energy field. There are many contingencies that cannot be yet correctly understood and may affect any projections.

- **Assets of PV systems success in Benin**

There are many assets for the development of PV systems in Benin:

- sufficient sun radiation throughout the year (4 -6kWh/m2/day)
- existence of a governmental agency ABERME
- existence of local private enterprise
- high interest from government side
- private users are interested in having the own systems (there are many private using solar energy for their daily need)
- relative cheap shipping costs (existence of a harbour)
- Possibility of making part of the system (array support, etc) in Benin because there exist skilled manpower
- Benin can also learn from developing and developed countries such as Germany (Germany encourages installation and connection to the grid of solar panels by buying the PV electricity higher than the normal price from private)

- **Weaknesses of PV systems success in Benin**

The main problem is the cost of solar equipment that is still very high for low or medium income people from Benin. However, if the current trends continue i.e. lowering of the costs of solar equipment and continuous increase of fossil fuel prices, solar PV systems will have a promising future in Benin.

- **Limitations of this study**

Despite all information provide in this study there are some limitations:

- the study focus only on the cultivation of one vegetable (tomato). This work could have studied various vegetables if there was enough time for field work.
- only farmers involved in irrigation were interviewed: the questionnaire (see annexes) is designed for all kind of farmers (involved or not in irrigation) but once again, due to time restrictions, only farmer that are already experiencing irrigation were interviewed. The other lack associated with this limitation is the fact no cereal such as maize (staple food in the south and is not too water demanding crop) is considered in this study
- the results from this study are compared only with one existing project: this is due to the fact it is sometimes dangerous to compare projects from different contexts on one hand and the almost impossibility to have all information about an existing project in books or on internet. The irrigation project carried out currently in northern Benin comply somehow with this study and can be taken as a valid comparison basis even though it is single.

III VERIFICATION OF HYPOTHESES AND RECOMMENDATIONS

14 Verification of hypotheses and recommendations

The purpose of this paragraph is to check if the hypotheses put forward are verified and to formulate some recommendations to improve the situation of irrigation in Benin.

14.1 Solar pumping for irrigation is suitable for small schemes and irrigation techniques with high efficiency.

It is has been shown throughout this study, especially in the cost estimation part, that smaller plots have small total cost but larger cost per hectare. For rich farmers it might be advantageous to go for larger plots than smaller ones. However, the disadvantage of larger plots is that any failure of one element will block the whole system. It might therefore be wise for rich farmers to divide their farm in small units (of 1ha for example as the cost per ha for 1 ha plot are smaller than for 0.5 ha) and design an irrigation system for each plot.

The hydraulic energy needed to lift water is proportional to the volume of water times the height by which water is lifted. Then given the same size of farm and lifting height, a crop with high water demand will lead to high water volume and consequently larger size of PV panels. This does not automatically mean that the system is not adapted to high water demanding crop because the crop can have higher economic value. However, due to the fact that solar energy is expensive compared to electricity and to a lesser degree to fossil fuels, it is advisable not to use it for high water demanding crops, as the high investment costs will negate the benefits generated. For those types of crops (for example sugar cane), it is advisable to use either electric or power-driving pumps.

The available solar radiation determines the overall cost of PV panels. Particularly, areas or countries with almost constant solar radiation allow an economic design of PV panels. Generally, for irrigation schemes, PV panels are designed using the PSH (Peak Sunshine

Hour) of the less productive month to meet the highest water demand. This leads to a huge oversizing if the solar variation varies too much from one month to another. The higher the solar radiation, the lower the array surface needed and the lower are the costs.
Dealing with solar energy, it is very important to select an irrigation system with the highest possible efficiency not only to save cost but also to save water that is becoming more and more scarce.
Based on these, one can conclude that "hypothesis 1" is verified.

14.2 With the continuous increase of the oil price and a poor electrification level in rural areas of Benin, solar pumping may be a good alternative.

The socio-economic field surveys conducted in the framework of this study show that the awareness level of Benin populations about environmental problems is low. Even if farmers were aware, their incomes are so low that they can not afford a self-financing of a solar drip irrigation system. However, if the government continues with the same interest it is showing presently for solar projects, farmers can benefit from soft loans and subsidies that can help them to opt for solar drip irrigation.
Based on these arguments, "hypothesis 2" can only partially/restrictedly be verified.

14.3 Solutions and recommendations

Proposing solutions and recommendations to meet farmers' expectations is a difficult task as a solution to a problem can create another problem. Most of solutions and recommendations have to involve the participation of government, farmers, financial and technical institutions. However, some the following ideas may be useful to improve the actual situation of irrigation in Benin:

- Enactment of a law defining clearing the land tenure
- Government should identify and release locations that suitable for irrigation (fertile soil and availability of water), also in suburban areas, where there is lack of land

- Construction and maintenance of roads to ease the transportation of agricultural products to the market (well maintained earth or gravel roads are sufficient)
- More involvement in technical and financial assistance from government side
- Low interest loans and long periods of payment (for farmers with enough experience and/or with enough guarantee in term of land, houses or other goods)
- Ease of importation of solar pumps (duty free and specific loans for importation)
- In every district establishment of a centre being in charge of maintaining solar installations (in public property)
- Development of food processing industry (when there is abundance) or explore the possibility to export outside the country
- Improve access to electricity as running costs of electric power are lower than the one of power-driven pumps.
- Incentives for research in agronomy (resistance against plants diseases, identification of suitable cultivars)
- Incentives for mechanisation of agriculture (including importation of tractors and encouraging local manufacturing of tract.

15 Conclusion

The purpose of this study is to investigate the possibility to introduce new and relatively modern irrigation techniques – in this case solar pumping systems – in southern Benin in order to ensure a sustainable use of land and water. Quite interesting results are obtained. Drip irrigation using solar energy can be afforded by southern Benin populations if there are technical and financial assistance. The type of drip irrigation suggested in this study is not so modern and complicated and can easily be managed by farmers. Farmers, technical and financial institutions in the study area are very interested in the new technology.

The study shows that smaller plots are more economically feasible and affordable by farmers than larger plots. Moreover despite the relatively shallow depth of groundwater, the study shows a small difference in prices for the same plot using surface or groundwater source. It is then advisable to use groundwater as source water only when there is no reliable surface water available. Due to the high costs involved, PV pumping system for irrigation purposes is more suitable for crop with high economical values with low water demand. The cost benefit analysis shows that a farmer working on 0.5 ha or 1 ha plot can afford contracting a loan and pay it back easily.

If results of this study are followed, farmers will gain a lot in terms of independence from weather hazards and fossil fuel. They will also improve their yields and develop their land in a sustainable way. However, this can be done only if there is a visible manifestation of interest from government, financial and technical institutions and farmers' side. Despite the fact that this study focuses mainly on the growth of tomato in dry season it can be adapted to other crops that have similar requirement and yield similar revenues like tomato.

Even though this study suggests solutions to improve the state of irrigation in Benin and sketches out ways to make the use of solar pumping system a reality, it does not intend to cover all aspects related to irrigation and solar pumping systems. Further information may be required on:

- the quality of soil (laboratory tests)

- the effect of long term drip irrigation of soil salinisation
- the possibility to construct a part or a the whole PV system on site to decrease the transport and overall costs and create jobs locally
- the long term effect of fertilizer on groundwater or surface water bodies.

Besides these, it may be interesting to also explore the field of solar PV for domestic use as Benin benefits from a relatively good sunshine throughout the year.

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17 Annex

Annex 1: Questionnaire used to interview farmers

Promotion de l'irigation au Sud Benin

Avril - Mai 2008 - IWG- Université de Karlsruhe (TH)

A- Identification de l'exploitation agricole

1. Numéro de l'enquete

La réponse doit être comprise entre 1 et 150.
La réponse est obligatoire.

2. Date et heure de début de l'enquête

3. Nom de l'enquêteur

4. Nom de la personne interrogée

5. Sexe de la personne interrogée

○ 1. M ○ 2. F

6. Age de la personne interrogée

La réponse doit être comprise entre 18 et 100.

7. Ethnie et origine de l'enqueté(e)

8. Taille du menage

9. Nombre de femmes

Sans objet si la personne interrogéee est une femme

10. Nombre d'enfants à charge du chef de ménage

11. Lieu de residence

La réponse est obligatoire.

12. Quel est votre niveau d'instruction?

- ☐ 1. N'a jamais fréquenté l'école
- ☐ 2. Primaire
- ☐ 3. Secondaire
- ☐ 4. Universitaire
- ☐ 5. Autres (à preéciser)

Vous pouvez cocher plusieurs cases.

13. Lieu où se deroulent les activités agricoles

La réponse est obligatoire.

B- Caracteristiques de l'exploitation

14. Quelle distance sépare votre champ de votre lieu de residence?

1. 0-1km 2. 1-4km 3. >4km

☐ ☐ ☐

Ordonnez 3 réponses.
La réponse est obligatoire.

15. Quel moyen de transport utilisez-vous pour vous rendre au champ?

- ☐ 1. A pied
- ☐ 2. Moto privée
- ☐ 3. Taxi-Moto (Zemidjan)
- ☐ 4. Vehicule taxi
- ☐ 5. Voiture privée
- ☐ 6. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

16. Depuis quand exploitez-vous ce domaine? (Nombre d'année)

La réponse doit être comprise entre 1 et 100.

17. Quelle est la superficie de votre exploitation?

1. 0-1ha 2. 1-5ha 3. 5-10ha 4. >10ha

☐ ☐ ☐ ☐

Ordonnez 4 réponses.
La réponse est obligatoire.

18. Sous quel régime de droit à la terre exploitez-vous votre domaine?

- ☐ 1. Proprietaire
- ☐ 2. Locataire
- ☐ 3. Mise à disposition gratuite par une autorité (à préciser)
- ☐ 4. Autres (à preciser)

Vous pouvez cocher plusieurs cases (3 au maximum).
La réponse est obligatoire.

19. Quelles sont les cultures que vous pratiquez?

- ☐ 1. Laitue
- ☐ 2. Carotte
- ☐ 3. Choux, Amarante(Têtê)
- ☐ 4. Venonia (loman, amanvivê
- ☐ 5. Tcahyo
- ☐ 6. Gboman
- ☐ 7. gboyanmi
- ☐ 8. Fleurs Riz
- ☐ 9. Mais
- ☐ 10. Palmeraie
- ☐ 11. Cocoteraie
- ☐ 12. Haricot
- ☐ 13. Aures (a preciser)

Vous pouvez cocher plusieurs cases.
La réponse est obligatoire.

20. Quelles sont les superficies emblavées pour chaque culture?

- ☐ 1. Laitue
- ☐ 2. Carotte
- ☐ 3. Choux, Amarante(Têtê)
- ☐ 4. Venonia (loman, amanvivê
- ☐ 5. Tcahyo
- ☐ 6. Gboman
- ☐ 7. gboyanmi
- ☐ 8. Fleurs Riz
- ☐ 9. Mais
- ☐ 10. Palmeraie
- ☐ 11. Cocoteraie
- ☐ 12. Haricot
- ☐ 13. Aures (à preciser)

Vous pouvez cocher plusieurs cases.

21. Quels sont les produits vendus? Précisez en pourcentage la proportion vendue.

- ☐ 1. Laitue
- ☐ 2. Carotte
- ☐ 3. Choux, Amarante(Têtê)
- ☐ 4. Venonia (loman, amanvivê
- ☐ 5. Tcahyo
- ☐ 6. Gboman
- ☐ 7. gboyanmi
- ☐ 8. Fleurs Riz
- ☐ 9. Mais
- ☐ 10. Palmeraie
- ☐ 11. Cocoteraie
- ☐ 12. Haricot
- ☐ 13. Aures (à preciser)

Vous pouvez cocher plusieurs cases.

22. Combien de fois cultivez-vous chaque produit dans l'année?

- ☐ 1. Laitue
- ☐ 2. Carotte
- ☐ 3. Choux, Amarante(Têtê)
- ☐ 4. Venonia (loman, amanvivê
- ☐ 5. Tcahyo
- ☐ 6. Gboman
- ☐ 7. gboyanmi
- ☐ 8. Fleurs Riz
- ☐ 9. Mais
- ☐ 10. Palmeraie
- ☐ 11. Cocoteraie
- ☐ 12. Haricot
- ☐ 13. Aures (à preciser)

Vous pouvez cocher plusieurs cases (7 au maximum).

23. Quel est le prix de vente unitaire moyen de chacun des produits?

- ☐ 1. Laitue
- ☐ 2. Carotte
- ☐ 3. Choux, Amarante(Têtê)
- ☐ 4. Venonia (loman, amanvivê
- ☐ 5. Tcahyo
- ☐ 6. Gboman
- ☐ 7. gboyanmi
- ☐ 8. Fleurs Riz
- ☐ 9. Mais
- ☐ 10. Palmeraie
- ☐ 11. Cocoteraie
- ☐ 12. Haricot
- ☐ 13. Aures (à preciser)

Vous pouvez cocher plusieurs cases.

24. Quel est votre revenu moyen annuel? ☐

25. Existe-il des infrastructures fiables pour avoir accès aux marchés en saison sèche comme en saison pluvieuse?

○ 1. Oui ○ 2. Non

26. Comment acheminez-vous les produits au marché?

- ☐ 1. Port sur la tête
- ☐ 2. bicyclette
- ☐ 3. moto
- ☐ 4. traction animale
- ☐ 5. véhiclue
- ☐ 6. Les acheteur(euses) viennet chercher les produits au jardin
- ☐ 7. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

27. Quelles sont les diverses dépenses engagées du labour jusqu'à la vente des produits?

- ☐ 1. Frais pour pépinière
- ☐ 2. Frais de labour et sarclages
- ☐ 3. Frais de désherbage
- ☐ 4. frais de buttage
- ☐ 5. Frais d'engrais
- ☐ 6. Frais de pesticides
- ☐ 7. frais pour récolte
- ☐ 8. frais de transport
- ☐ 9. frais d'rrigation
- ☐ 10. Amortissement de la motopompe
- ☐ 11. carburant pour la motopompe
- ☐ 12. entretien de la motopompe
- ☐ 13. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

28. A combien s'élèvent vos dépenses annuelles? ☐

29. Quel(s) frais est (sont) le(s) plus important(s) en matière de coût?

- ☐ 1. Frais pour pépinière
- ☐ 2. Frais de labour et sarclages
- ☐ 3. Frais de désherbage
- ☐ 4. frais de buttage
- ☐ 5. Frais d'engrais
- ☐ 6. Frais de pesticides
- ☐ 7. frais pour récolte
- ☐ 8. frais de transport
- ☐ 9. frais d'rrigation
- ☐ 10. Amortissement de la motopompe
- ☐ 11. carburant pour la motopompe
- ☐ 12. entretien de la motopompe
- ☐ 13. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

30. Quel est votre bénéfice net annuel? ☐

31. Quels moyens utilisez-vous pour vos travaux?

- ☐ 1. Houe ☐ 2. Machette
- ☐ 3. Pioche ☐ 4. Rateaux
- ☐ 5. Arrosoir ☐ 6. charrue
- ☐ 7. Tracteur ☐ 8. binette
- ☐ 9. Motopompe ☐ 10. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

32. Faites-vous usage d'engrais chimique, organique ou quelque autre produit?

○ 1. Oui ○ 2. Non

33. Si oui, lesquels?

- ☐ 1. NPK ☐ 2. Urée
- ☐ 3. Pesticide ☐ 4. Urée
- ☐ 5. Composte ☐ 6. fiante de poulet
- ☐ 7. Excrement d'animaux ☐ 8. Autres (à préciser)

Vous pouvez cocher plusieurs cases.
La question n'est pertinente que si Faites-vous usage d'engrais chimique, o = "Oui"

34. Quelle quantité d'engrais, de pesticide appliquez-vous par unité de parcelle? Précisez si c'est à l'hectare, par planche ou tout autre unité de parcelle.

- ☐ 1. NPK ☐ 2. Urée
- ☐ 3. Fiante de poulet ☐ 4. Excrément d'animaux
- ☐ 5. Pesticide ☐ 6. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

35. Quels sont les problemes que vous rencontrez dans l'exercise de votre activite?

- ☐ 1. Manque d'eau
- ☐ 2. Puits trop profonds
- ☐ 3. inexistence de motopompe
- ☐ 4. mauvaise qualite de l'eau
- ☐ 5. Baisse du rendement malgre l'usage d'engrais et de pesticide
- ☐ 6. Manque ou mauvais etat des voies d'acces au champ
- ☐ 7. Mévente
- ☐ 8. Manque d'espace
- ☐ 9. Restrictions du au fait que l'exploitant n'est pas propriétaire de la terre
- ☐ 10. Autres (à preciser)

Vous pouvez cocher plusieurs cases.

C- Autres champs et/ou autres activités

36. Possedez-vous d'autres champs?

○ 1. Oui ○ 2. Non

La réponse est obligatoire.

37. Si oui, quelle revenu moyen annuel en tirez-vous? ☐

La question n'est pertinente que si Possedez-vous d'autres champs? = "Oui"

38. Quelle(s) autre(s) activité(s) pratiquez-vous?

- ☐ 1. Peche ☐ 2. Elevage
- ☐ 3. Artisanat ☐ 4. Location de chambre
- ☐ 5. Autres (à preciser)

Vous pouvez cocher plusieurs cases.

39. Quel bénéfice moyen annuel tirez-vous de chacune de ces activités? ☐

40. Quel est le bénéfice tolal annuel du ménage? ☐

D- Technique agricole et planification de l'exploitation

41. Quel type d'agriculture pratiquez-vous?
- ☐ 1. Culture a plat
- ☐ 2. Culture sur billons
- ☐ 3. Buttes
- ☐ 4. Planches
- ☐ 5. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

42. Quelles autres techniques agricoles pratiquez-vous?
- ☐ 1. Rotation des cultures
- ☐ 2. Agro-foresterie
- ☐ 3. Jachère
- ☐ 4. Protection des cultures contre le vent
- ☐ 5. Autres (à préciser)

Vous pouvez cocher plusieurs cases (4 au maximum).

43. Pendant quelle periode de l'année pratiquez-vous l'agriculture?
- ☐ 1. Grande saison des pluie
- ☐ 2. petite saison des pluie
- ☐ 3. Les deux saisons pluvieuses
- ☐ 4. En saison(s) sèche(s)
- ☐ 5. Toute l'année
- ☐ 6. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

44. Avez-vous déjà une fois entendu parlé de l'irrigation?
- ○ 1. Oui ○ 2. Non

E- Pré-requis pour l'irrigation

sans objet si l'enquete a repond "Oui" a la question 44

45. Avez-vous accès a une source d'eau a proximité ou dans votre champ?
- ○ 1. Oui ○ 2. Non

46. Si oui, laquelle/lesquelles?
- ☐ 1. Fleuve
- ☐ 2. Lac
- ☐ 3. Riviere
- ☐ 4. Puits
- ☐ 5. Etang marécageux
- ☐ 6. Autres (a preciser)

Vous pouvez cocher plusieurs cases.
La question n'est pertinente que si Avez-vous accès a une source d'eau a pr = "Oui"

47. A quelle profondeur à peu près trouve-t-on l'eau en saison pluvieuse?
- ☐ 1. 0-2 metres
- ☐ 2. 2-5 metres
- ☐ 3. 5-10 metres
- ☐ 4. >10 metres

Vous pouvez cocher plusieurs cases.

48. A quelle profondeur trouve-t-on l'eau en saison sèche?
- ☐ 1. 0-2 metres
- ☐ 2. 2-5 metres
- ☐ 3. 5-10 metres
- ☐ 4. >10 metres

Vous pouvez cocher plusieurs cases.

49. Quelles caractéristiques presentent cette eau?
- ☐ 1. Salée
- ☐ 2. fade
- ☐ 3. polluée
- ☐ 4. trop riche en calcium (depot de pellicule blanc
- ☐ 5. presque sans problème
- ☐ 6. Autres (à preciser)

Vous pouvez cocher plusieurs cases.

50. Pour les points d'eau utilisés, comment se fait l'accès à l'eau? (droit de l'eau)
- ☐ 1. L'état est propriétaire de l'eau et c'est payant
- ☐ 2. le paysan est libre d'utiliser l'eau gratuitement
- ☐ 3. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

F- Facteurs pouvant influencer l'introduction de l'rrigation.

Sans objet si la personne interrogée répond oui à la question 44

51. Connaissez-vous des produits agricoles qui coûtent plus chers en saison sèche qu'en saison pluvieuse?
- ○ 1. Oui ○ 2. Non

52. Si oui, lesquel(s)?
- ○ 1. Tomate
- ○ 2. Piments
- ○ 3. Legumes
- ○ 4. Mais
- ○ 5. Autres (a preciser)

53. Que coûte le kilogramme de chacun de ces produits en saison pluvieuse? (Vous pouvez aussi donner le coût par rapport a une autre unité de mesure, mais dans ce cas, il faut donner l'equivalence entre cette mesure et le Kilogramme)
- ☐ 1. Tomate
- ☐ 2. Piments
- ☐ 3. Legumes
- ☐ 4. Mais
- ☐ 5. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

54. Que coûte le kilogramme de chacun de ces produits en saison seche? (Vous pouvez aussi donner le coût par rapport a une autre unité de mesure, mais dans ce cas, il faut donner l'equivalence entre cette mesure et le Kilogramme)

☐ 1. Tomate ☐ 2. Piment
☐ 3. Legumes ☐ 4. Mais
☐ 5. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

55. Quel est en pourcentage, le ratio cout saison seche par cout saison pluvieuse? ▭

56. Souhaiteriez-vous cultiver ces produits en saison seche?

○ 1. Oui ○ 2. Non

57. Si oui, comment comptez-vous vous approvisioner en eau?

☐ 1. Puisage et arrosage manuels
☐ 2. motopompe puis arrosage manuel
☐ 3. motopompe puis distribution automatique
☐ 4. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

58. Si motopompe, quel genre de motopompe souhaiteriez-vous avoir?

☐ 1. A essence ☐ 2. A diesel
☐ 3. utilisant l'electricite ☐ 4. Energie solaire
☐ 5. Energie eolienne ☐ 6. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

59. Comment comptez-vous acquerir la motopompe?

☐ 1. Achat sur fonds propres ☐ 2. Fonds propres et prêts
☐ 3. prêts ☐ 4. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

60. En cas de prêt ou financement partiel, quelle proportion du montant total pouvez-vous payer pour une motopompe se situant dans les fourchettes de prix ci- après en FCFA?

☐ 1. 100.000 à 200.000 ☐ 2. 200.000 à 500.000
☐ 3. 500.000 à 1.000.000FCFA ☐ 4. 1.000.000 à 2.500.000
☐ 5. 2.500.000 à 5.000.000 ☐ 6. 5.000.000 à 7.500.000
☐ 7. 7.500.000 à 10.000.000 ☐ 8. > 10.000.000

Vous pouvez cocher plusieurs cases (7 au maximum).

61. Pour la fourchette de prix qui vous intéresse, quel taux d'intérêt annuel souhaiteriez-vous qu'on vous applique?

☐ 1. Zéro(0%) ☐ 2. Un (1)%
☐ 3. Deux (2)% ☐ 4. Troi(3)%
☐ 5. Quatre (4)% ☐ 6. Cinq (5)%
☐ 7. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

62. Quelle la periode de remboursement de prêt souhaitée?

○ 1. 0-1an ○ 2. 1-2ans ○ 3. 2-3ans ○ 4. 3-4ans
○ 5. 4-5ans ○ 6. 5-10ans ○ 7. >10ans

G- Description des systèmes d'irrigation existants

sans objet si la personne interrogée repond "Non" a la question 44

63. Quelle source d'eau utilisez-vous pour vos activités d'irrigation?

☐ 1. Fleuve ☐ 2. Lac
☐ 3. Rivière ☐ 4. Puits
☐ 5. Autres (à preciser)

Vous pouvez cocher plusieurs cases.

64. Depuis quand pratiquez-vous l'irrigation?

▭

65. De quel reseau d'irrigation disposez-vous?

☐ 1. Arrosoir
☐ 2. tranchees et canaux
☐ 3. canalistions (tuyaux PVC etc.)
☐ 4. aspersion
☐ 5. irrigation goutte à goutte
☐ 6. Autres

Vous pouvez cocher plusieurs cases.

66. Pendant quelle periode de l'année irriguez-vous?

☐ 1. Saison(s) sèche(d) ☐ 2. Petite saison pluvieuse
☐ 3. Grande saison pluvieuse ☐ 4. Toute l'année

Vous pouvez cocher plusieurs cases.

67. Quelle(s) culture(s) irriguez-vous?

☐ 1. Prouduits maraîchers ☐ 2. Riz ☐ 3. Mais
☐ 4. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

68. Comment est-ce que vous vous approvisionez en eau?

☐ 1. Puisage manuel ☐ 2. Motopompe
☐ 3. Autres (a preciser)

Vous pouvez cocher plusieurs cases.

69. Si vous utilisez une motopompe, quelle energie utilise -t-elle?

☐ 1. Essence ☐ 2. Diesel
☐ 3. Electricité ☐ 4. Energie solaire
☐ 5. Energie éolienne ☐ 6. Autres (à preciser)

Vous pouvez cocher plusieurs cases.
La question n'est pertinente que si Comment est-ce que vous vous approvisio = "Motopompe"

H- Coûts, rentabilités et diagnostic des problemes rencontrés

sans objet si la personne interrogée repond "Non" à la question 44

70. Combien vous a coûté la motopompe? ☐

71. Pendant combien d'années (à compter de l'annéee d'achat) comptez-vous utiliser la motopompe avant de procéder à son remplacement? ☐

72. A combien s'élèvent les frais de carburant et lubrifiant par an? ☐

73. A combien s'élèvent les frais de reparation et pièces de rechange par an? ☐

74. A combien s'élèvent les frais de main d'oeuvre par an? ☐

75. A combien s'élèvent les frais de transport pour l'ecoulement des produits par an? ☐

76. A combien s'élèvent les divers (autres frais)? ☐

77. A combien s'élèvent vos charges annuelles? ☐

78. A combien s'élèvent vos revenus annuels? ☐

79. Quel est votre bénéfice annuel net? ☐

80. Etes-vous satisfaitsde la productivite de votre systeme d'irrigation?

○ 1. Oui ○ 2. Non ○ 3. Ne sait pas

81. Sinon, Etes-vous pret a l'ameliorer? Justifier votre reponse.

○ 1. Oui ○ 2. Non

La question n'est pertinente que si Etes-vous satisfaits de la productivité = "Non"

82. Que voulez-vous ameliorer dans votre systeme?

- ☐ 1. L'approvisionnment en eau
- ☐ 2. Le systeme de distribution
- ☐ 3. Reduire les pertes en eau
- ☐ 4. accroitre le rendement
- ☐ 5. Une motopompe plus puissante
- ☐ 6. Autres (à preciser)

Vous pouvez cocher plusieurs cases.

83. Combien est-vous prêt à investir dans l'achat d'une nouvelle motopompe? Quelle est la puissance désirée? ☐

84. A quel moment de la journée irriguez-vous?

☐ 1. Matin ☐ 2. Midi ☐ 3. Soir

Vous pouvez cocher plusieurs cases.

85. Combien de fois irriguez-vous par semaine en saison seche?

○ 1. Tous les jours ○ 2. Tous les deux jours
○ 3. tous les 3 jours ○ 4. Autres (a preciser)

86. Comment irriguez-vous?

- ☐ 1. Juste au pied de la plante
- ☐ 2. Toute la plante (feuille comprise), Toute la suface du champ ou de la planche
- ☐ 3. Autres (a preciser)

Vous pouvez cocher plusieurs cases (2 au maximum).

87. Quels problèmes particuliers rencontrez-vous dans l'exercise de votre activité?

- ☐ 1. Manque d'eau
- ☐ 2. Puits trop profonds
- ☐ 3. inexistence de motopompe
- ☐ 4. Baisse du rendement malgre l'usage d'engrais et de pesticide
- ☐ 5. Manque ou mauvais etat des voies d'acces au champ
- ☐ 6. Mevente
- ☐ 7. Autres (A preciser)

Vous pouvez cocher plusieurs cases.

I- Evaluation des chances de la pompe solaire

88. Avez-vous déjà une fois entendu parlé de l'énergie solaire?

○ 1. Oui ○ 2. Non

89. Si oui, pour quelle application?

☐ 1. Electricité ☐ 2. poste radio
☐ 3. lampe torche ☐ 4. Autres (à préciser)

Vous pouvez cocher plusieurs cases.
La question n'est pertinente que si Avez-vous déjà une fois entendu parlé dl = "Oui"

90. Avez-vous deja entendu parlé de la pompe solaire?
- ○ 1. Oui ○ 2. Non

91. Savez-vous que l'énergie solaire (la pompe solaire) protège l'environnement car n'émet aucune pollution?
- ○ 1. Oui ○ 2. Non

92. Savez-vous que les installation solaire (pompe solaire par exemple) ont une durée de vie d'au moins 20 ans, et donc plus rentables à moyen, long voire court terme selon les cas?
- ○ 1. Oui ○ 2. Non

93. A quelles conditions seriez-vous prêts à opter pour la pompe solaire?
- ☐ 1. Coût d'investissement pas trop élevé (préciser le montant maximum que vous seriez prêt a débourser pour une motopompe solaire)
- ☐ 2. Subvention de l'état
- ☐ 3. Facilités d'accès au crédit
- ☐ 4. Frais d'entretien raisonnable (préciser le montant que vous seriez prêt a pyer par an)
- ☐ 5. Autres (à préciser)

Vous pouvez cocher plusieurs cases.

94. Si toutes ces conditions sont remplies, seriez-vous prêts opter pour une motopompe solaire au detriment des autres types de motopompes?
- ○ 1. Oui ○ 2. Non

95. Date et heure (fin de l'enquête)

Annex2: Questionnaire used to interview Key persons

Promotion de l'irrigation au Bénin: Avis des personnes ressources et institutions concernées

Avril- Mai 2008 - IWG- Université de Karlsruhe (TH)

A- Identification de l'institution

1. Numéro de l'enquête

2. Nom de l'enquêteur

3. Nom de l'institution

4. Nom du Ministère de tutelle (s'il y a lieu)

5. Nom de la personne intrerrogée

6. Fonction occupée par la personne interrogée dans l'institution

7. Depuis quand occupez-vous cette fonction? (Nombre d'années)

B- Activites de l'institution

8. Quels sont les domaines dans lesquels votre institution intervient?
   - ☐ 1. Maraichage
   - ☐ 2. Riz
   - ☐ 3. Cultures non-irriguees (a preciser)
   - ☐ 4. Cultures irriguables (a preciser)
   - ☐ 5. Peche
   - ☐ 6. Elevage
   - ☐ 7. Chasse
   - ☐ 8. Autres (a preciser)

   Vous pouvez cocher plusieurs cases.

9. Pensez-vous que l'état de l'irrigation au Bénin est satisfaisant?
   ○ 1. Oui ○ 2. Non ○ 3. Ne sait pas

C- Rôle de l'institution dans le développement de l'agriculture irriguée au Bénin.

10. Intervenz-vous deja dans des projets d'irrigation?
    ○ 1. Oui ○ 2. Non

11. Si oui, combien de projets avez-vous deja finance, encadre et/ou supervise ces 5 derniers annees?
    La question n'est pertinente que si Intervenz-vous deja dans des projets d' = "Oui"

12. Sinon, etes-vous prêt à soutenir les programmes et/ou projets visant à développer l'irrigation au Bénin?
    ○ 1. Oui ○ 2. Non
    La question n'est pertinente que si Intervenz-vous deja dans des projets d' = "Non"

13. Portez-vous actuellement assistance aux paysans?
    ○ 1. Oui ○ 2. Non

14. Si oui, quels genres d'assistance leur portez-vous?
    ☐ 1. Financière ☐ 2. formarion et encadrement
    ☐ 3. (Autres à préciser)
    Vous pouvez cocher plusieurs cases.

15. Ses faciltés prennent-elles compte les paysans pratiquant l'irrigation?
    ☐ 1. Oui ☐ 2. Non ☐ 3. Ne sait pas?
    Vous pouvez cocher plusieurs cases.

16. Etes-vous prêts à faciliter l'accès au crédit aux paysans pratiquant l'irrigation ou dérireux de s'y engager?
    ○ 1. Oui, Non

17. Si oui, quelles conditions doivent remplir ces paysans?
    ○ 1. Avoir un projet bien ficeler et bancable
    ○ 2. Avoir fait ses preuves dans l'agriculture en général et dans l'irrigation en particulier
    ○ 3. Autres (à préciser)

18. Savez-vous que la pompe solaire peut être d'une grande utilité aux paysans si les coûts d'investissement et d'entretien sont maintenus dans des limites acceptables?
    ○ 1. Oui ○ 2. Non

19. Si les conditions énumérées à la question 17 sont respectéées, seriez-vous prêt à faciliter l'accès au crédit aux paysans pour l'achat de pompe solaire?
    ○ 1. Oui ○ 2. Non

20. Si oui, quels taux appliqueriez-vous?
☐ 1. Un (1%) ☐ 2. Deux(2%) ☐ 3. Trois(3%)
☐ 4. Quatre(4%) ☐ 5. Cinq(5%)
Vous pouvez cocher plusieurs cases.

21. Quelle durée proposeriez-vous pour le remboursement du prêt?
○ 1. 1 an ○ 2. 2 an ○ 3. 3 ans ○ 4. 4 ans
○ 5. 5ans ○ 6. >5ans

22. Seriez-vous prêts à exhonérer les systèmes de pompage solaire des frais de douanes et autres taxes?
○ 1. Oui ○ 2. Non

D- Activites de micro-finance

Sans objet si ce n'est pas une institution de micro-finance

23. Depuis quand intervenez-vous dans la micro-finance? (Nombre d'annee) ☐

24. Quelle la duree de votre projet de micro-finance? ☐

25. Qui sont les beneficiaires de de vos credits?
☐ 1. Paysans
☐ 2. Eleveurs
☐ 3. Pecheurs
☐ 4. Artisans
☐ 5. Activites de transformation de produits agricoles
☐ 6. Autres (A preciser)
Vous pouvez cocher plusieurs cases.

26. Combien de projets avez-vous finance depuis le debut de vos activites? ☐

27. Quelle est la grille des credits que vous accordez?
☐ 1. Montant minimum
☐ 2. Montant Maximum
☐ 3. Montant de la majorite des projets (moyenne)
☐ 4. Autres (a preciser)
Vous pouvez cocher plusieurs cases.

28. Quelle proportion du montant total des projets financez-vous? Preciser dans quels cas vous appliquez tel ou tel autre pourcentage.
☐ 1. 100% ☐ 2. 80 a 90%
☐ 3. 70 a 80% ☐ 4. 60 a 70%
☐ 5. Autres (a preciser)
Vous pouvez cocher plusieurs cases (2 au maximum).

29. Quel taux d'interet pratiquez-vous?
☐ 1. 1 a 5% ☐ 2. 5 a 10% ☐ 3. 10 a 15%
☐ 4. Autres (a preciser)
Vous pouvez cocher plusieurs cases.

30. Quelle est la periode de remboursement du credit?
☐ 1. 0 a 2 an ☐ 2. 1 a 2 a 5ans ☐ 3. > 5 ans
Vous pouvez cocher plusieurs cases.

31. Les taux et periodes de remboursement dependent -t-ils du montant des credits? Expliquez?
○ 1. Oui ○ 2. Non

Annex 3: List of interviewed farmers

Province	District	Sub-district	Village	Nr.	Name	Sex	Water extraction mean	Water source
LITTORAL	Cotonou	12th sub-district	Cadjehoun	1	Adjasso Donatien	Masculine	Power driving pump	Water body
		12th sub-district	Cadjehoun	2	Idossou Lazarre	Masculine	Water scanning	Water body
		12th sub-district	Cadjehoun	3	Dossa Felicite	Feminine	Water scanning	Borehole
		13th sub-district	Agla	4	Codjo Remi	Masculine	Water scanning	Well
		13th sub-district	Agla	5	Djossou Constante	Feminine	Power driving Pump	Well
		13th sub-district	Agla	6	Adjibade Raimi	Masculine	Power driving pump	Borehole
MONO	Athieme	Athieme	Atchontoue	7	Lakoussa Bertin	Masculine	Power driving pump	River Mono
		Athieme	Agbobada	8	Bossou Pascal	Masculine		
		Athieme	Atchontoue	9	Bossa Edgar	Masculine	Power driving pump	River Mono
		Atchannou	Atchannou	10	Folly Randolphe	Masculine	Power driving pump	Well
		Atchannou	Tadocome	11	Sessou Cyril	Masculine	Power driving pump	Well
		Atchannou	Tadocome	12	Mesanh Dansi	Masculine	Power driving pump	Well
		Kpinnou	Azonlihoue	13	Vignon Coffi	Masculine	Electic & power driving	Borehole
		Kpinnou	Kpinnou	14	Tossa Seraphine	Feminine	Electic & power driving	Borehole
		Kpinnou	Kpinnou	15	Bessanh Afiavi	Feminine	Power driving	Well
	Grand-Popo	Agoue	Nikoue Kondji	16	Vlavo Cocouvi	Masculine	Power driving pump	Borehole
		Agoue	Nikoue Kondji	17	Tchahoun Marie	Feminine	Power driving pump	Borehole
		Agoue	Nikoue Kondji	18	Oumarou Mariam	Feminine	Power driving pump	Borehole
		Agoue	Nikoue Kondji	19	Amoussou Patrice	Masculin	Power driving pump	Borehole
		Agoue	Nikoue Kondji	20	Hougnagan Armand	Masculin	Power driving pump	Borehole
		Agoue	Ayiguinnou	21	Agoglovi Koudolo	Feminine	Electic & power driving	Borehole
		Agoue	Ayiguinnou	22	Kassa Felix	Masculine	Power driving pump	Borehole
		Agoue	Ayiguinnou	23	Abalo Bruno	Masculine	Treadle pump	Borehole
		Agoue	Ayiguinnou	24	Amoussou C. Hugges	Masculin	Treadle pump	Borehole
		Agoue	Ayiguinnou	25	Zinsou Hyppolite	Masculine	Electric pump	Borehole
		Agoue	Ayiguinnou	26	Amegbleto Claude	Masculine	Water scanning	Well
		Agoue	Ayiguinnou	27	Amegbleto Kuassi	Masculine	Power driving pump	Borehole

		Agoue	Ayiguinnou	28	Amoussou Adjehoda	Masculine	Electric pump	Borehole
		Grand- popo	Ewe Condji	29	Djimezo Cocou	Masculine	Water scanning	Well
		Grand-pop	Ewe Condji	30	Zingan Coffi	Masculine	Power driving pump	Borehole
OUEME	Seme Kpodji	Ekpe	Deffa	31	Sekpenou Conforte	Feminine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	32	Gokpon Christophe	Masculine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	33	Amoussou Frank	Masculine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	34	Hotegni Jean	Masculine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	35	Zoumenou Paterne	Masculine	Water scanning	Well
	Seme Kpodji	Ekpe	Deffa	36	Ahoussinou Raphael	Masculine	Treadle pump	Borehole
	Seme Kpodji	Ekpe	Deffa	37	Zannou Colette	Feminine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	38	Houeto Parfait	Masculine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	39	Hazoume Elvis	Masculine	Power driving pump	Borehole
	Seme Kpodji	Ekpe	Deffa	40	Ahoudji Gabriel	Masculine	Power driving pump	Borehole
Interviews outside the study area								
COUFFO	Dogbo	Deve*	Deve	41	Dosse lucien	Masculine	Power driving pump	River Mono
BORGOU	Kakale	Dounkassa**	Dounkassa	42	Chabi. Y. Gannedji	Feminine	Solar pumping system	Borehole
	Kakale	Bessassi***	Bessassi	43	Amadou Satou	Feminine	Solar pumping system	Permanent flowing water body

* 1 Cooperative of 315 men and women for rice cultivation on 105 ha
** 1 Cooperative of 40 persons (38 women and 3 men) for market gardening on 0.5 ha
*** 2 Cooperative of 34 persons each (33 women and 1 man) for market gardening on 2 plots of 0.5 ha each.

Annex 4 : Women cooperatives of Bessassi and Dunkassa

Farmers of women cooperative of Bessassi (Photo: Noumon, 2008)

The agricultural technician giving advises to farmers (Photo: Noumon, 2008)


Farmers of women cooperative of Dunkassa


A farmer ploughing on Dunkassa farm (photo: Noumon, 2008)

Annex 5: Details on assessment of solar radiation

Table 6.2.1: Values of declination in Togblo for monthly average days

Month	For ith day	Date	n	Declination δ (°)
January	i	17	17	-20,92
February	31+i	16	48	-12,62
March	59+i	16	75	-2,42
April	90+i	15	105	9,41
May	120+i	15	135	18,79
June	151+i	11	162	23,09
July	181+i	17	198	21,18
August	212+i	16	228	13,45
September	243+i	15	258	2,22
October	273+i	15	288	-9,60
November	304+i	14	318	-18,91
December	334+i	10	344	-23,05

Table 6.2.2: Zenith angle at solar noon for average monthly days

Average day	Declination δ(°)	Latitude ϕ (°)	Zenith angle θ_z (°)
17th January	-20,92	6,48	27,40
16th February	-12,62	6,48	19,10
16th March	-2,42	6,48	8,90
15th April	9,41	6,48	-2,93
15th May	18,79	6,48	-12,31
11th June	23,09	6,48	-16,61
17th July	21,18	6,48	-14,70
16th August	13,45	6,48	-6,97
15th September	2,22	6,48	4,26
15th October	-9,60	6,48	16,08
14th November	-18,91	6,48	25,39
10th December	-23,05	6,48	29,53

Table 6.2.3: Sunset/sunshine angle (ω_s) and sunshine hours (T) in Togblo

Days	Declination	Latitude	ω_s (radian)	ω_s (degree)	T (hours)
17th Jan	-0,37	0,11	1,53	87,51	11,67
16th Feb	-0,22	0,11	1,55	88,54	11,81
16th Mar	-0,04	0,11	1,57	89,73	11,96
15th Apr	0,16	0,11	1,59	91,08	12,14
15thMay	0,33	0,11	1,61	92,21	12,30
11th Jun	0,40	0,11	1,62	92,77	12,37
17th Jul	0,37	0,11	1,61	92,52	12,34
16th Aug	0,23	0,11	1,60	91,56	12,21
15th Sep	0,04	0,11	1,58	90,25	12,03
15th Oct	-0,17	0,11	1,55	88,90	11,85
14th Nov	-0,33	0,11	1,53	87,77	11,70
10th Dec	-0,40	0,11	1,52	87,23	11,63

Table 6.2.5.1: Diffuse radiation in Togblo

Average monthly day	K_T	H_d/H	H (kWh/m2/day)	H_d (kWh/m2/day)
17th Jan	0,46	0,67	15,44	10,35
16th Feb	0,47	0,65	16,82	11,01
16th Mar	0,46	0,67	17,19	11,52
15th Apr	0,46	0,67	17,32	11,60
15thMay	0,47	0,65	17,24	11,28
11th Jun	0,43	0,71	15,42	11,02
17th Jul	0,36	0,81	12,99	10,51
16th Aug	0,34	0,83	12,58	10,48
15th Sep	0,37	0,80	13,78	10,97
15th Oct	0,44	0,70	15,85	11,09
14th Nov	0,51	0,59	17,32	10,21
10th Dec	0,48	0,64	15,74	10,049

***** K_T is called the clearness index and is has been given by Duffie and Beckman (2006)

Table 6.2.5.3: Beam radiation coefficient (Rb)

Average monthly day	Latitude (ϕ)	Slope (β)	R_b
17th Jan	0,11	0,17	1,09
16th Feb	0,11	0,17	1,07
16th Mar	0,11	0,17	1,02
15th Apr	0,11	0,17	0,96
15thMay	0,11	0,17	0,91
11th Jun	0,11	0,17	0,89
17th Jul	0,11	0,17	0,9
16th Aug	0,11	0,17	0,94
15th Sep	0,11	0,17	0,99
15th Oct	0,11	0,17	1,05
14th Nov	0,11	0,17	1,1
10th Dec	0,11	0,17	1,13

Annex 6: Selection of pump type

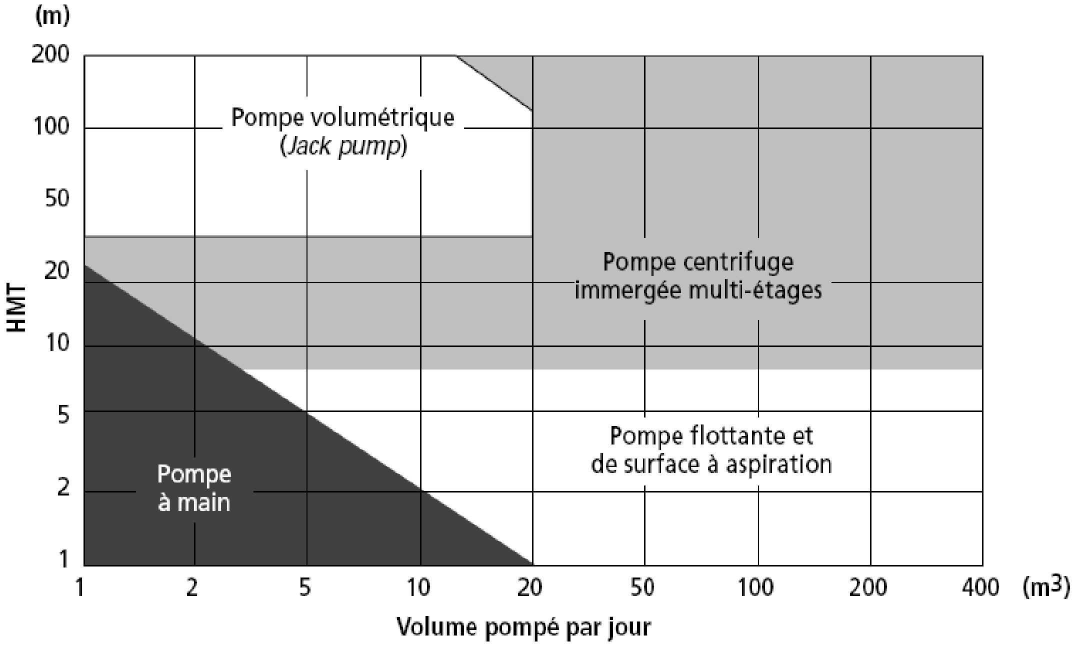


Figure 7.1.1.3: selection of pump giving Ha and Q as inputs (Source: Royer, 1998)

Annex 7

Table 7.1a: Costs of solar pumps : *centrifugal surface pumps (Sunpumps, USA)*

Type	**Cost range (US $)**		**Remarks**
	Sale price	Regular price	
SCB 8-90 60 - 90 Volt Panel Direct System	1,341.33	**1,059.65**	They deliver high volume and require low power and are suitable for surface water, 5 to 100 GPM, 120 PSI (17kPa), up to 277 feet of lift above ground.
SCB 10-185 90 - 135 Volt Panel Direct System	1,412.39	**1,115.79**	
SCB 20-45 60 - 105 Volt Panel Direct System	1,323.56	**1,045.61**	
SCB 20-150 75 - 105 Volt Panel Direct System	1,465.68	**1,157.89**	
SCB 21-150 90 - 120 Volt Panel Direct System	1,465.68	**1,157.89**	
SCP 47-25-07 Pool Pump 3/4 HP	1,234.73	**975.44**	
SCP 55-50-10 Pool Pump 1 HP	1,288.03	**1,017.54**	
SCP 70-37-10 Pool Pump 1 HP	1,288.03	**1,017.54**	
SCP 87-28-10 Pool Pump 1 HP	1,323.56	**1,045.61**	
SCP 95-35-15 Pool Pump 1 1/2 HP	1,643.35	**1,298.25**	
SJT 12-40 1/2 HP Jet Pump (SJT-05)	1,288.03	**1,017.54**	

Source: Wind and Sun (2008)

Table 7.1b: Costs of solar pumps: Grundfos SQflex solar submersible pumps *(Grundfos, USA)*

Type	**Cost range (US $)**		**Remarks**
	Sale price	Regular price	
AC/DC solar submersible pumps	2,733.00	**1,568.00**	Grundfos SQF pumps are more expensive than some other submersible solar pumps, but they also are much more tolerant of water that is not perfectly clean. All SQ-Flex pumps can operate from 90 to 240 Volts AC, and/or 30 to 300 Volts DC.
Grundfos IO-101 Generator Interface For generator/solar combo	586.00	**359.97**	
CU-200 Solar pump Control Box	462.00	**283.80**	
Grundfos Low-Level Float Switch for CU-200 Only	33.00	**28.50**	

Source: Wind and Sun (2008),

Table 7.1.1.5a: Range of PV generators BP-SQ

BP-SQ	60Wp	**180Wp**	80Wp	**240Wp**	**320Wp**	**400Wp**	**480Wp**	**560Wp**	**640Wp**	**800Wp**
Number of modules		3		3	4	5	6	7	8	10
Structure		SRE4		SRE4	SRE4	SRE5	SRE6	SRE7	2xSRE4	2xSRE5

Table 7.1.1.5b: Grundfos modules performances

Type de modules	**BPSX-60**	**BP380**
Puissance (Wp)	60	80
Vco (V)	21	22.1
Icc (A)	3.87	4.8
Vmp (V)	16.8	17.6
Imp (A)	3.56	4.55
Cell size (mm)	114x152	125x125
Number of cell	36/1	36/1
Module dimensions	1105x502x50	1204x537x50
Area of module	0.55	0.65
Weight (kg)	1.72	7.7

Annex 8: Selection of pipe diameter

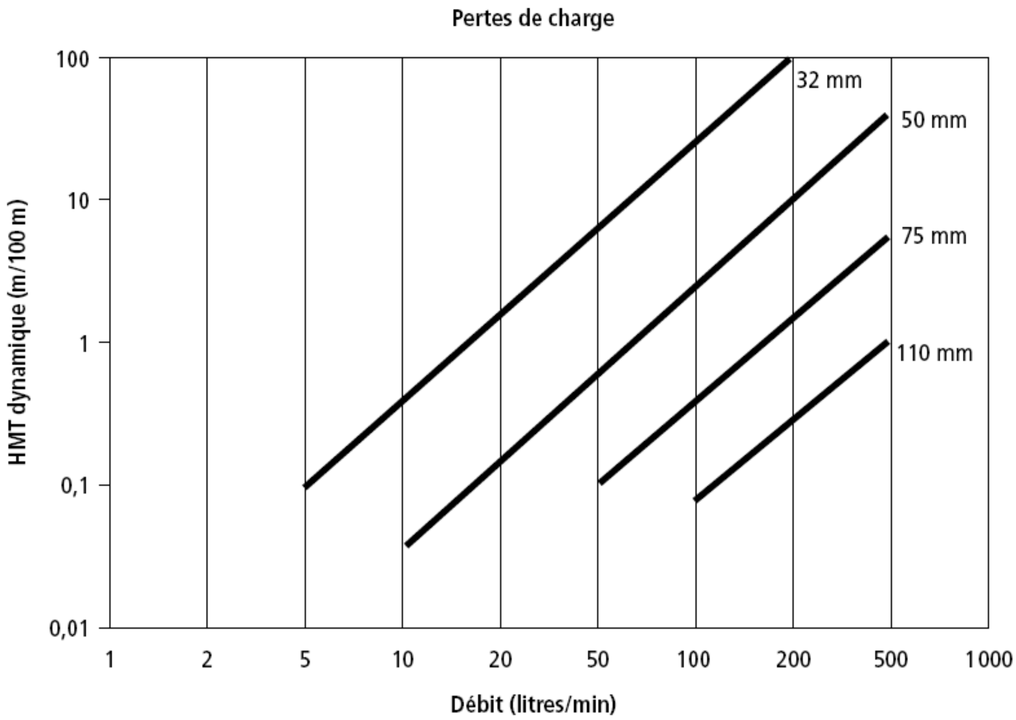


Figure 7.1.1.6: Head losses on pipes as a function of the discharge (Source: Royer et. Al, 1998)

Annex 9: Details on SQF pumps and example of reservoir and drip line

Table 7.2.2.1a: Characteristics of the pump motor

Range of motor power	Watt	900
Nominal power	Watt	650
Nominal Angular speed	Tr/min	500-3000
Nominal frequency	Hz	50
Efficiency of the nominal couple	%	85
Maximum motor tension	V	300
Range of starting tension	Vdc	30-300
Nominal current	A	7
Maximal current	A	7
Components, enveloppe		Stainless steel 304
Envelope dimensions	mm	245
Axe and rotor		Stainless steel 304
Weight	Kg	10

Table7.2.2.1b: Technical characteristics of SQF pumps

Type	SQF 0.6-2	SQF 1.2-2	SQF 2.5-2	SQF 5A-3	SQF 5A-6	SQF 8A-3	SQF 14A-3
Maxi speed (rpm)	3000	3000	3000	3000	3000	3000	3000
Maxi Pressure (kPa)	1500	1500	1500	1500	1500	1500	1500
Pipe length (mm)	1185	1225	1247	815	875	920	975
Diameter of delivery	1”1/4	1”1/4	1”1/4	1”1/2	1”1/	2”	2”
Mini drilling diameter (mm)	76	76	76	104	104	104	104
Indice of protection	IP68	IP68	IP68	IP68	IP68	IP68	IP68
Weight (Kg)	7.6	7.9	8.2	8.1	8.8	9.5	10.9
Type	helical	helical	helical	centrifugal	centrifugal	centrifugal	centrifugal

Annex 9.1: General dimensions for classical circular reservoirs (Fonlladosa, 1937 & Guerrin-Lavaur 1972)

Fonlladossa gave the following formula to, a priori, design a reservoir of a volume V m3

- diameter of the tank:

$$d = 1.405\sqrt[3]{V}$$

- useful height:

$$h = 0.460\ d$$

- free height from water level until the ring of skull cap

$$h_0 = 0,10\ d$$

- deflexion of the dome (coupola)

$$f = 0.104\ d$$

- thickness of the skull cap

$$e_1 = 0.112\ d \text{ (d in m, } e_1 \text{ in cm)}$$

- maximal thickness of the wall at the base

$$e_{max} = 0.207d$$

- For reservoir with diameter larger than 2 m, the minimal thickness of the wall should be 12 cm

Annex 9.2: Example of reservoir and drip line

Figure 8.3.6: Reservoir and drip irrigation in Kalale in northern Benin (Noumon, 2008)

Annex 10

Annex 10.1: Running and personal cost for 0.5 ha horticultural enterprise (tomato cultivation)

Nr.	**Item**	**Unit**	**Quantity**	**Unit Price**	**Total (Euro)**
1	**Fertilizer**				
1.1	Manure	sacs	600	0,99	594,55
1.2	Fertilizer (first application)	kg	300	0,40	118,91
1.3	Fertilizer 2nd application)	kg	400	0,40	158,55
	Sub-total 1				***872,01***
2	**Protection**				
2.1	Herbicide	liter	4	15,24	60,98
2.2	Insectide	liter	7	15,24	106,71
2.3	Fongicide	kg	7	10,67	74,70
	Sub-total 2				***242,39***
3	**Land preparartion activities**				
3.1	Land preparation	plot	200	0,76	152,45
3.2	Seedling	plot	200	0,15	30,49
3.3	Ploughing	plot	400	0,15	60,98
3.4	Weeding	plot	600	0,23	137,20
3.5	Replacement	plot	200	0,08	15,24
	Sub-total 3				***396,37***
4	**Seeds**	All together	1	182,94	182,94
	Sub-total 4				***182,94***
5	**Occasional manpower**	All together	1	350,63	350,63
	Sub-total 5				***350,63***
	Total running costs				***2044,34***
6	Permanent employees				
6.1	Technician	Months	6	114,34	686,02
6.2	2 Guards	Months	12	38,11	457,35
	Sub-total 5				***1143,37***
	Total				**3187,71**

Annex 10.2: Summary of economic analyses for other plots

a) Projected cash flow for plots of 0.5 ha using surface water as water source

Category	**Year1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
	Euros	Euros	Euros	Euros	Euros	Euros
Loan	17448					17448
Farmer's contribution	1790					1790
Net cash flow	5026	5026	5375	5985	6073	27484
Residual value (resale value)					10040	10040
Resources	***24264***	***5026***	***5375***	***5985***	***16113***	***56762***
Investment	12949					12949
Running costs	6289					6289
Repayment of capital + interest	1396	5758	5409	4798	4711	22071
Costs (uses)	***20634***	***5758***	***5409***	***4798***	***4711***	***41309***
Solde of cash flow	3630	-732	-34	1187	11402	15453
Incremental solde	3630	2898	2864	4051	15453	

b) Projected cash flow for plots of 0.5 ha using groundwater water as water source.

Category	**Year1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
	Euros	Euros	Euros	Euros	Euros	Euros
Loan	18412					18412
Farmer's contribution	1607					1607
Net cash flow	4870	4870	5239	5883	5975	26838
Residual value (resale value)					10040	10040
Resources	***24890***	***4870***	***5239***	***5883***	***16015***	***56897***
Investment	13730					13730
Running costs	6289					6289
Repayment of capital + interest	1473	6076	5708	5063	4971	23291
Costs (uses)	***21492***	***6076***	***5708***	***5063***	***4971***	***43310***
Solde of cash flow	3397	-1206	-469	820	11044	13587
Incremental solde	3397	2192	1723	2543	13587	

Annex 10.3: Investment costs for various plots (solar panel, pump, reservoirs etc.)

The lifespan of the whole system is the longest lifespan of the different components of the system. Twenty (20) years is adopted as lifespan of the whole system. This means that for a full cycle, the pump will be replaced two times while the irrigation network (pipe and drip lines) will be replaced only one time.

Lifespan of different components of the system	**Years**
PV generator	20
Drip pipe et drip lines	10
Pump	7

	Groundwater			
0,5 ha	**Unit**	**Quantity**	**Unit cost**	**Total (US$)**
Generator	wh	360	6	2160
Pump	u	1	3228	3228
Pump for replacement	u	2	3228	For reference
Irrigation network	all together	1	8590	8590
Irrigation network for replacement	all together	1	8590	For reference
Total without shipping				*13978*
Shipping and transport to the site				*2796*
Cost reservoir	all together	*1*	*2120*	*2120*
Fences and pump house	all together	*1*	*1015*	*1015*
Total with shipping for 0,5 ha				*19909*
Total with shipping for 0,5 ha				***39817***
1 ha				
Generator		960	6	5760
Pump		2	3228	6456
Pump for replacement	u	2	3228	For reference
Irrigation network		1	17179	17179
Irrigation network for replacement	all together	1	17179	For reference
Total without shipping				*29395*
Cost reservoir	u	1	*3069*	*3069*
Shipping and transport to the site				*5879*
Fences and pump house	all together	*1*	*2031*	*2031*
Total with shipping for 1 ha				***40374***

2 ha				
Generator		2880	6	17280
Pump		3	3228	9684
Irrigation network		1	34358	34358
Cost reservoir		1	4867	4867
Total without shipping				*66189*
Shipping and transport to the site				*13238*
Fences and pump house	all together	***1***	*4061*	*4061*
Total with shipping for 2 ha				*83488*
Total with shipping for 1 ha				***41744***
5 ha				
Generator		6400	6	38400
Pump		8	3228	25824
Irrigation network		1	85895	85895
Cost reservoir		1	8673	8673
Total without shipping				*158792*
Shipping and transport to the site				31758
Fences and pump house	all together	1	10153	10153
Total with shipping for 5 ha				200703
Total with shipping for 1 ha				**40141**
10ha				
Generator		13440	6	80640
Pump		14	3228	45192
Irrigation network		1	85895	85895
Cost reservoir		1	13453	13453
Total without shipping				*225180*
Shipping and transport to the site				45036
Fences and pump house	all together	1	20306	20306
Total with shipping for 10 ha				290522
Total with shipping for 1 ha				**29052**

2 ha				
Generator		2880	6	17280
Pump		3	3228	9684
Irrigation network		1	5883	5883
Cost reservoir		1	4867	4867
Total without shipping				*37714*
Shipping and transport to the site				*11314*
Fences and pump house	all together	***1***	*4061*	*4061*
Total with shipping for 2 ha				*53089*
Total with shipping for 1 ha				***26545***
5 ha				
Generator		6400	6	38400
Pump		8	3228	25824
Irrigation network		1	14707	14707
Cost reservoir		1	8673	8673
Total without shipping				*87604*
Shipping and transport to the site				26281
Fences and pump house	all together	1	10153	10153
Total with shipping for 5 ha				124038
Total with shipping for 1 ha				**24808**
10ha				
Generator		13440	6	80640
Pump		14	3228	45192
Irrigation network		1	14707	14707
Cost reservoir		1	13453	13453
Total without shipping				*153992*
Shipping and transport to the site				46198
Fences and pump house	all together	1	20306	20306
Total with shipping for 10 ha				220496
Total with shipping for 1 ha				**22050**

	Surface water			
0,5 ha	**Unit**	**Quantity**	**Unit cost**	**Total (US$)**
Generator	w	400	6	2400
Pump (lifespan = 7 years)	u	1	2012	2012
Pump for replacement	u	2	2012	For reference
Irrigation network (lifespan = 10 years)	all together	1	8590	8590
Irrigation network	all together	1	8590	For reference
Total without shipping				*13001*
Shipping and transport to the site				*2600*
Cost reservoir	all together	1	*2120*	*2120*
Fences and pump house	all together	*1*	*1015*	*1015*
Total with shipping for 0,5 ha				*18737*
Total with shipping for 0,5 ha				***37474***
1 ha				
Generator		960	6	5760
Pump		1	2198	2198
Pump for replacement		2	2198	For reference
Irrigation network		1	17179	17179
Irrigation network for replacement		1	17179	For reference
Total without shipping				*25137*
Shipping and transport to the site				*5027*
Cost reservoir	u	1	*3069*	*3069*
Fences and pump house	all together	*1*	*2031*	*2031*
Total with shipping for 1 ha				***35264***
2 ha				
Generator		1920	6	11520
Pump		2	2198	4395
Irrigation network		1	34358	34358
Total without shipping				*50273*
Shipping and transport to the site				*10055*
Cost reservoir		1	***4867***	*4867*
Fences and pump house	all together	***1***	*4061*	*4061*
Total with shipping for 2 ha				*69256*
Total with shipping for 1 ha				***34628***

5 ha				
Generator		4800	6	28800
Pump		5	2198	10988
Irrigation network		1	85895	85895
Total without shipping				*125683*
Shipping and transport to the site				25137
Cost reservoir		1	8673	8673
Fences and pump house	all together	1	10153	10153
Total with shipping for 5 ha				169645
Total with shipping for 1 ha				**33929**
10ha				
Generator		9600	6	57600
Pump		12	2198	26370
Irrigation network		1	85895	85895
Total without shipping				*169865*
Shipping and transport to the site				33973
Cost reservoir		1	13453	13453
Fences and pump house	all together	1	20306	20306
Total with shipping for 10 ha				237597
Total with shipping for 1 ha				**23760**

Annex 11 Cost-benefit analysis

Annex 11.1: Economic analysis of solar pumping system for 0.5 ha using surface water

- **Cost-benefit analysis**

The cost-benefit analysis will be carried out for a plot of 0.5 ha using surface water source. This will be done though the following points: project cost, revenues, payback of capital and interest, projected results count and projected cash flow count. Table 33 shows details about the total costs.

- **Cost of the project**

Table 33: Project cost of 0.5 ha irrigated using surface water

Category	**Total cost (Euros)**	**Farmer's contribution**	**Loan (Euros)**	**Remarks**
1 Investment				
1.1 Solar pumping system	12491	677	11814	
1.2 Insurance for the first 3 years	381	0	381	
1.3 Agricultural materials	76		76	
Total investment	***12949***	***677***	***12272***	
2 Running costs				
2.1 Runing costs for 4 months	5146	1113	4033	
2.2 Permanent personnal for 6 months	1143	0	1143	The farmer pays for seeds and occasional manpower and land preparation
Total running costs	***6289***	***1113***	***5176***	
TOTAL	**19238**	**1790**	**17448**	

The total cost of the project is 19238 Euros of which 1790 Euros are financed by the farmer. This represents about 15%of the total cost. This percentage does not include the cost of the land. The rest, 17448 Euros will be financed by financial institutional such as PADMOC or PADRO through the Regional Bank of Solidarity (BRS)

Annex 11.2: Revenues from production

If all requirements are fulfilled, a tomato farm in southern Benin climatic conditions yields about 16 to 20 tons per hectare in dry season. This range is even lower than recrdeded yields in west African countriesbenefiting the same climate. According to Philips (1977) in Guinea and sudan zone, yields ranging from 20-25 tons can be achieved in dry season. In soutern Benin, tomato is sold with baskets of 40 kg each. This means that a satisfactory yield will give 425 baskets. In average, the cost of a basket in shortage (dry season) ranges from 15 000 F CFA (23 Euros) to 24 000 FCFA (37 Euros). In other words1 kg costs between 375 FCFA (about 0.6 Euro) and 600 Euros (0.9 euros). The unit price can reach even 1.5 euros in shortage on market. For the purpose of this study and in order to in order to avoid risks of overestimation, we assume the cost of 1 kg of tomato in dry season to be 0.69 Euro and 16 tons/ha as reasonable yield. Farmers can sell two times their product before the abundance period (June-October) arrives. It is then assumed that the farmer can grow tomato 2 times per year:

a) starting in October and ending in January

b) and starting in February and ending in May (when tomato has the highest price)

We assume the production to be the same each year. Table 34shows the production from selling tomato.

c) Carrot will be grown in the raining season

Table 34: Revenues from tomato cultivation

Item	**Unit**	**Quantity**	**Unit Price**	**Total (Euro)**
Tomato (1 season)	kg	8000	0,69	5488
Tomato (2 seasons)				10976
Carrot (raining season)	ha	0,5	12080	6040
Total per year				**17016**

Annex 11.3 Payback of loan and interests

To encourage initiatives in agriculture, the governement of Benin has created a fund through the Regional Bank of Solidary. This fund gives loans from 1,000 euros up 62,000 euros to farmers with a preferential interest of 8%. The loans are generally paid back in one year from the small one and up to 5 years for average and larger amount. For this study, we assume a payback period of 5 years with 1 year deferred. Table 35 below shows payback of capital and interest.

Table 35: Payback of loan and interests

Years	**Current amount**	**Capital paying off**	**Interests paying off**	**Annuity**
	Euro	**Euro**	**Euro**	**Euro**
0	17448	0	0	0
1	17448	0	1396	1396
2	13086	4362	1396	5758
3	8724	4362	1047	5409
4	4362	4362	436	4798
5	0	4362	349	4711
Total		**17448**	**4624**	**22071**

Annex 11.4: Projected results count

Table 38 shows that the net benefit and cash flow increase with time. However, the net benefit and cashflow are not sufficient to know if the project is profitabble. It is important that the net benefits generated each year cover , in addition to the running costs, the payback a of part of capital and interest (loan). This is why the project cashflow account (table 39) is required.

Table 36: Projected results count

Category	Year1	Year 2	Year 3	Year 4	Year 5
	Euros	Euros	Euros	Euros	Euros
1 Production					
Turnover	17016	17016	17016	17016	17016
Total I	17016	17016	17016	17016	17016
2 Costs					
Running costs	6716	6716	6716	6716	6716
Permanent personal	2287	2287	2287	2287	2287
Maintenance of the investment	1249	1249	1249	1249	1249
Depreciation*	1299	1299	1299	1299	1299
Financial costs	1396	1396	1047	436	349
Social security for p. personnal	343	343	343	343	343
Total II	13290	13290	12941	12330	12243
Net benefit**	3726	3726	4075	4686	4773
Net cash flow	5026	5026	5375	5985	6073

* the annual depreciation cost is calculating by using the life cycle of the irrigation system. The lifespan of solar panel, drip pipe (line) and pumps are respectively 20, 10 and 7 years and thus higner than 5 years.

** After the 5th the benefit will increase more as the farmer would have paid the loan (and interest) back. An attempt to carry the economical study for 20 years shows that the farmer cannot survive economically as he will pay more interest cost and will find him/herself unsecured for 20 years. By paying earlier, he can afford extending his farm by reinvesting the benefits

Annex 11.5: Projected cashflow count

Table 37: Projected cashflow account

Category	**Year1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
	Euros	Euros	Euros	Euros	Euros	Euros
Loan	17448					17448
Farmer's contribution	1790					1790
Net cash flow	5026	5026	5375	5985	6073	27484
Residual value (resale value)					10040	10040
Resources	***24264***	***5026***	***5375***	***5985***	***16113***	***56762***
Investment	12949					12949
Running costs	6289					6289
Repayment of capital + interest	1396	5758	5409	4798	4711	22071
Costs (uses)	***20634***	***5758***	***5409***	***4798***	***4711***	***41309***
Solde of cash flow	3630	-732	-34	1187	11402	15453
Incremental solde	3630	2898	2864	4051	15453	

At the end of the 5th year, the farmer will have a finacial capacity (cashflow and investment) of 15453 Euros of which almost 10040 euros represent the value of the pumping system after 5 years. This is an important asset for the farmer as he can ensure the continuation and even the perennity of the project by replacing the equipments.

Annex 12: Drip lines and accessories costs

NaanRON 16 mm

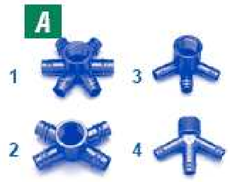
Hard tubing; 0.9 mm wall thickness; integrated labyrinth drippers
***Flow rates:** 2.0 l/h*

Dripper Spacing m	Item # 2.0 l/h	Unit Price/m	Packing Coil (m)	Packing Qty (m) 20' cont.	Packing Qty (m) 40' cont.
0.20	941430200	$0.582			
0.25	941430250	$0.531			
0.30	941430300	$0.510			
0.40	941430400	$0.493	500	82,500	175,000
0.50	941430500	$0.482			
0.60	941430600	$0.474			
0.75	941430750	$0.467			
1.00	941431000	$0.460			
Blind pipe	941300	$0.439			

NaanRON 20 mm

Hard tubing; 0.95 mm wall thickness; integrated labyrinth drippers
***Flow rates:** 2.0 l/h*

Dripper Spacing m	Item # 2.0 l/h	Unit Price/m	Packing Coil (m)	Packing Qty (m) 20' cont.	Packing Qty (m) 40' cont.
0.20	945440200	$0.725			
0.25	945440250	$0.655			
0.30	945440300	$0.633			
0.40	945440400	$0.615	400	54,000	120,000
0.50	945440500	$0.604			
0.60	945440600	$0.597			
0.75	945440750	$0.590			
1.00	945441000	$0.583			
Blind pipe	945400	$0.561			

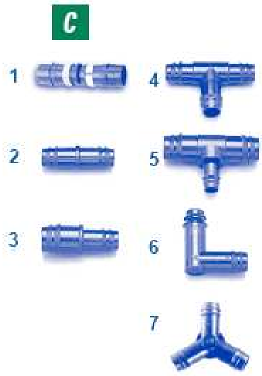


A Barbed/Threaded Multi-Outlets

Fig.	Description	Item # 20 mm	Unit Price	Item # 16 mm	Unit Price	Qty/Bag
1	6-Way 3/4" female	6424045020	$1.94	6424045010	$1.94	50
2	4-Way 3/4" female	6424234000	$1.94	6424044010	$1.94	
3	3-Way elbow 3/4" female	6424042050	$1.89	6424042010	$1.89	
4	3-Way straight 3/4" male	6424043030	$0.68	6424043010	$0.68	

B Barbed/Threaded Connectors

Fig.	Description	Item # 20 mm	Unit Price	Item # 16mm	Unit Price	Qty/Bag
1	Tee barb 3/4" female	6424040230	$1.84	6424040210	$1.84	50
2	Tee barb 3/4" male	6424040050	$0.63	6424040040	$0.63	
3	Y connector 3/4" male	6416040600	$0.63	6416040200	$0.63	
4	Barbed connector 3/4" male	6424040635	$0.57	6424040615	$0.57	100
4	Barbed connector 1/2" male	6424040630	$0.57	6424040610	$0.57	
5	Elbow barb 3/4" male	6424040450	$0.68	6424040445	$0.68	



C Barbed Connectors

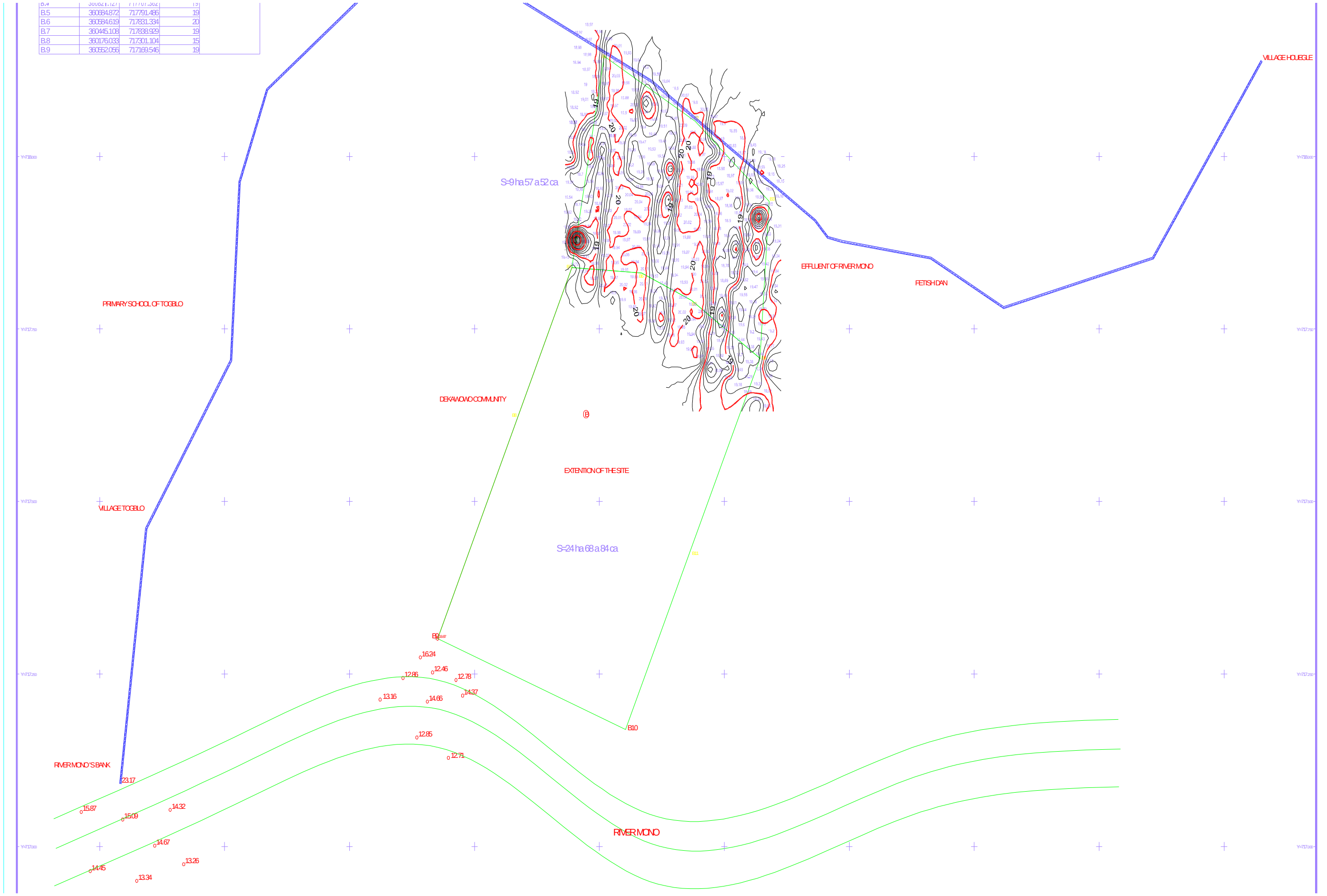
Fig.	Description	Item #	Unit Price	Qty/Bag
1	Barbed connector silver ring 20x20	483222	$0.37	100
2	Barbed connector 16x16	483161	$0.23	
2	Barbed connector 17x17	6423040620	$0.42	
3	Barbed reducer 20x17	6423040830	$0.57	
3	Barbed reducer 20x16	6423040850	$0.57	
3	Barbed reducer 17x16	6423040820	$0.57	

Fig.	Description	Item # 20 mm	Unit Price	Item # 16mm	Unit Price	Qty/Bag
4	Tee barbed	6423040030	$0.68	6423040010	$0.34	100
5	Tee reducer barbed	6423040250	$0.89	6423040220	$0.89	
6	Elbow barb	6423040440	$0.63	6423040410	$0.34	
7	Star 3-way	–	–	6423049900	$1.05	

D Start Connectors & Accessories

Fig.	Description	Item # 20 mm	Unit Price	Item # 16mm	Unit Price	Qty/Bag
1	Quick start for PE & PVC	6431041000	$0.51	6431040400	$0.40	100
2	Grommet for quick start for PVC	6431999900	$0.17	6431999900	$0.17	
3	Start connector with band+o-ring	6431301000	$1.58	6431300400	$1.58	
4	End line	6419300420	$0.17	6419300410	$0.17	
5	Snap clip	6720150825	$0.53	6720150815	$0.53	
6	Dripper clip seal	480920	$0.19	480916	$0.19	
7	Vine drip clip	809000	$0.11	-	-	

Annex 13: Grid leveling of the selected site



STATEMENT

I herewith state that I prepared my Master of Science thesis independently and that I did not use any other than the stated sources and aids.

Karlsruhe, Tete Comlan Ago Bienvenu Noumon