EVALUATION OF PHOTOVOLTAIC WATER PUMPING SYSTEMS IN KENYA

CASE STUDY: CHWELE WATER SUPPLY SCHEME

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Page

LIST OF FIGURES

ABSTRACT

The demand for potable water to rural communities in Kenya is greater than the ability to supply it. It is the responsibility of planners to respond with innovative technologies that would ensure a satisfactory provision to a least cost alternative in investment, operation and maintenance expenditures.

This study investigates the current status, of photovoltaic (PV) water pumping in Kenya and a case study is presented. The findings of the case study indicate that photovoltaic water pumping is cheaper than diesel water pumping on a long term basis. The advantage of PV systems is that there are practically no operational costs. However, the key technical factors emerging from the study indicate that the majority of the existing systems lack proper operation and monitoring procedures, resulting in poor performance.

It is recommended that to determine actual performance and economic viability of these installations, a standard monitoring methodology must be utilized. The methodology should include daily records of the global solar radiation, quantity of water pumped, variations in ground water level and malfuctioning of the system. As the data accummulates a criteria can then be formulated to determine the factors that are of utmost importance in the decision to invest in PV systems.

It is further recommended, that PV pumping systems serving communities or villages, financed by donor agencies and other bilateral or multilateral organizations should enlist the cooperation and participation of the Appropriate Technology Section of the Ministry of Water Development, for monitoring purposes. This will essentially reduce the risk of commercial organizations taking advantage of the end users lack of knowledge in this relatively new technology. This recommendation will have the added advantage of ensuring that PV pumping system manufacturers and commercial agents, will work closely with water supply planners to ensure, that the technology is well matched to the water resource charateristics and user

1. INTRODUCTION

Adequate water supplies for growing food, for drinking and sanitation are, without a doubt key requirements for improving the quality of life in many developing countries. For a large proportion of the rural population in these countries, obtaining sufficient water each day is an exhausting and time-consuming task. Traditionally, water is pumped from boreholes or lifted from wells by hand or with the assistance of animals. Occasionally, mechanical power from a diesel or gasoline engine is available, but maintaining the engine in good working order and obtaining the necessary fuel often presents difficulties in rural areas.

Since the majority of the rural population in the developing world live in areas with good solar resources, great efforts have been made in recent years to develop reliable and cost effective solar powered systems.

Solar pumps employ photovoltaic (solar cell) modules which convert solar radiation (sunlight) directly to electricity. This powers an electrically driven pump. After many years of research, development, testing and demonstration programmes, solar pumps are now commercially available and are ready for widespread application. Solar pumps are simple to use and require little maintenance. They offer many advantages over alternatives, such as handpumps and diesel pumps, for rural areas of developing countries.

There has been a good deal of interest in solar water pumping for many years, with the establishment of research and development programmes all over the world. One major initiative came from the United Nations Development Programme and the World Bank, who sponsored a world wide programme to demonstrate and evaluate solar pumping systems from 1978 to 1983 (Halcrow and Partners, 1984). The evaluation included field trials, laboratory testing and economic analysis. The project assembled reliable technical and economic data in order to assess the appropriateness and viability of the systems.

(iv)	Standby generator:	Make/Type	Lister/ST2
		Capacity (rating)	6,4kW/8.0 kVA
		Engine output at site	7,1 kW
(v)	Borehole:	No C 4863 constructed	No. 80/Jan.81
		Depth	94m
		Diameter	200mm(steel casing to/50m)
(vi)	Submersible pump		
		Make	Pleuger (3 phase)
		Capacity (rating)	
		$6m^3/h$ against	87m head
		pump setting level	36m
		pump efficiency (motor) + pump)	33%
		Power demand 40/50 Hz	1.9/3.6 kW
		Pumping capacity max	6 m^3/h at 50Hz
(vii)	Rising Main:	Length 565m, diameter	80mm PVC
		Difference in elevation:	65m
(vii)	Storage Tank:	Elevated steel storage tank	
		Capacity	$45m^3$
		Height of tower	3.5m
		Tank complete with: Diam 2" pipes for inlet, overflow and scour. Diam 3" outlet pipe.	
(viii)	Chlorination:	Displacement doser.	

Kenya has no known resources of crude oil, natural gas or uranium deposits, although in 1980, the Government commissioned an oil exploration programme in the North-Eastern part of the country, which has yet to produce conclusive results.

The hydro-electricity production will be fully exploited within the next fifteen to twenty years and geothermal energy is still in the early stages of development. With the need for energy development of the rural areas, all sources of energy have to be utilized and renewable energies be given further consideration especially because they are available abundantly and readily in Kenya for exploitation.

Renewable energy sources include biomass energy, wind energy and direct solar energy. The direct solar energy include solar thermal systems and solar photovoltaic systems. Therefore, the diversification of both the technology and energy supply for rural water pumping can no longer be overlooked.

The only parameter monitored on a regular basis is the daily volume of water pumped. The data was extracted from the operator's handbook and compiled on a monthly basis (refer to appendix II). A graph of the average volume of water pumped daily for every month was drawn as shown in figure 1. The automatic irradiation recording device has been out of operation and therefore the values of daily insolation are not available. However, irradiation data from the nearest meteorological station, was compiled and drawn on the same graph. This is to relate the variations of amount of water pumped and sunshine availability. The calculated average water demand of $30m^3$/day has been plotted on the graph.

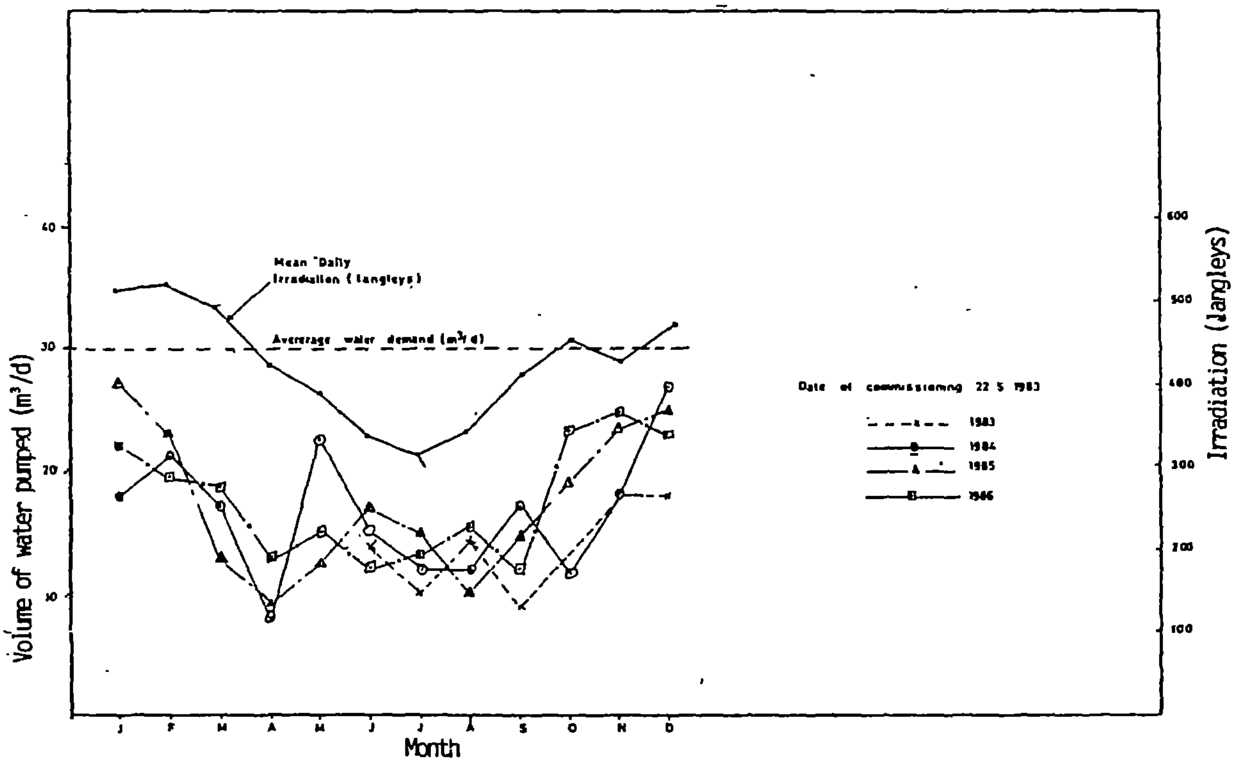


Figure 1. Kiserian solar pump: average volume of water pumped, mean daily irradiation and average water demand

The best performance observed to date has been from cells utilizing semiconductor materials. Essentially all of the solar cells used for solar energy applications have been made of the semiconductor silicon (Backus, 1980)

Silicon solar cells are made by selectively adding minute amounts of impurities to purified silicon. The addition of boron, for example, produces p-type silicon semi-conductor material having an excess of positive charges, while the addition of phosphorous produces n-type silicon, with an excess of negative charges. In the fabrication of a solar cell the surface of a p-type silicon wafer is treated with an n-type dopant and followed by a high temperature diffusion process. The result is a formation of a very thin layer of n-type semiconductor at the surface of the wafer. Figure 1 shows a schematic of a silicon photovoltaic cell showing the physical arrangement of the major components and the principle of the photovoltaic effect.

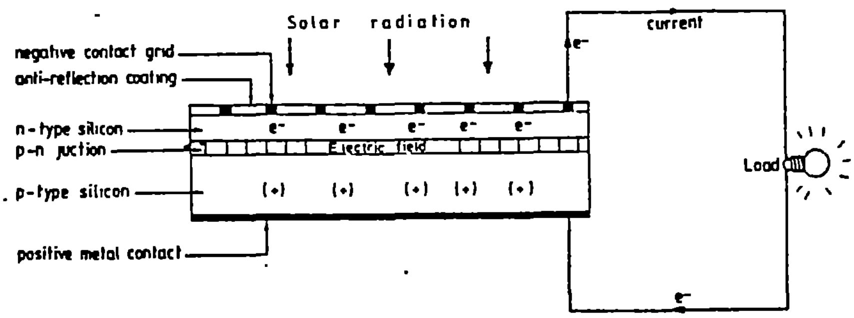


Figure 1. Principles of a silicon photovoltaic cell (Backus, 1980)

The function of the p-type silicon and n-type silicon materials provides an inherent electric field which separates the charges created by the absorption of photons. When a photon of sufficient energy enters a solar cell it can interact with the atoms of the solar cell, creating an electron-hole pair, i.e. negative and positive charge carriers. These charge carriers are then free to move about in the cell. Negative carriers diffuse across the p-n junction into the n-type material; positive carriers diffuse into the p-type silicon. Both are prevented from flowing back

Standby generator - the standby generator is in a mechanically sound condition. It is occassionally utilized to keep the parts in operating condition, since it is not regularly used.

(d) Financial aspects

This solar pump project is an undertaking between the Government of West Germany represented by GTZ, the University of Nairobi and the Ministry of Water Development (MOWD). The funding was undertaken by GTZ for all the equipment supplied and construction of the buildings. The borehole construction was undertaken by MOWD. The maintenance costs are taken care of by the Ministry through funding from GTZ. However, staff wages and collection of revenue is the responsibility of MOWD. Currently a flat rate of Kshs 15/= is charged per month for every connection. The breakdown of the total construction costs (in 1980) as obtained from MOWD is as follows:

	KSHS
Borehole	105,000=
Solar system including pumps and accesories	2,060,000=
Standby generator	215,000=
Building for equipment	88,500=
Operators houses (2 units)	210,000=
Fencing	56,400=
	2,734,900=

The solar radiation incident on solar cells is made up of three components: direct light, diffuse light and reflected light (from sea, lakes etc) as shown on figure 2.

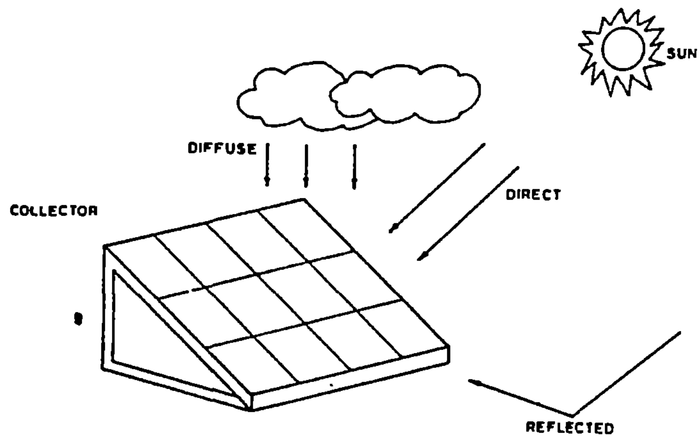


Figure 2. Different components of sunlight (Rosenblum, 1982).

When solar radiation falls on the silicon solar cell, almost all photons with energy greater than 1.1 electron volts corresponding to a wave length of 1.15/um, will be absorbed in the cell and create an electron-hole pair. It can be seen in figure 3 that the region of silicon solar cell spectral response fits within the range of terrestrial solar spectrum as a function of wavelength (Rosenblum, 1982). It shows that only radiation in the visible wave length may be used and approximately 50 per cent of the photons from the sun have wavelengths which are either too short or too long to be used in conjunction with silicon cells.

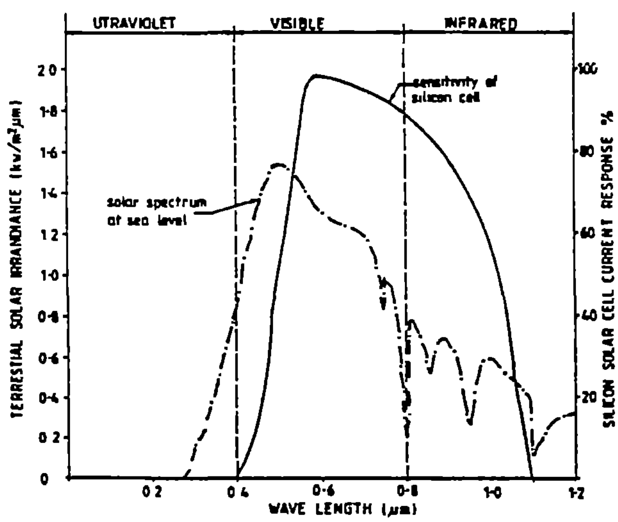


Figure 3. Silicon solar cell response to the terrestrial solar spectrum (Rosenblum, 1982)

1.3 Kahawa solar pump.

This solar pumping system was commissioned in August 1981, with the assistance of the French Government. The system is of French origin and was installed by the manufacturers. It was handed over to the Ministry of Water Development for monitoring, operation and maintenance.

The technical characteristics of the system available are as follows:

Pump type : ALTA x 26045
Total manonetric head: 45m
Pump setting level: 50 m^3/day
Rated motor power: 2.6 kw.

(a) Quantity of water pumped.

The system supplies water to the surrounding low cost residential areas. The Appropriate Technology Section of MOWD, installed a water meter in 1981 to monitor the amount of water pumped daily. The operator was responsible for recording the daily meter readings. During the field visits, the meter readings were extracted from the records book. The data was then analysed and compiled into average daily figures for a particular month as presented in appendix III. The quantities were then transformed into graphical form shown in figure 2. The mean daily irradiation figures from the Jomo Kenyatta meteorological (which is the nearest meteorological station to the site) are also plotted on the graph. The average water demand of 15 m^2/day is plotted on the graph.

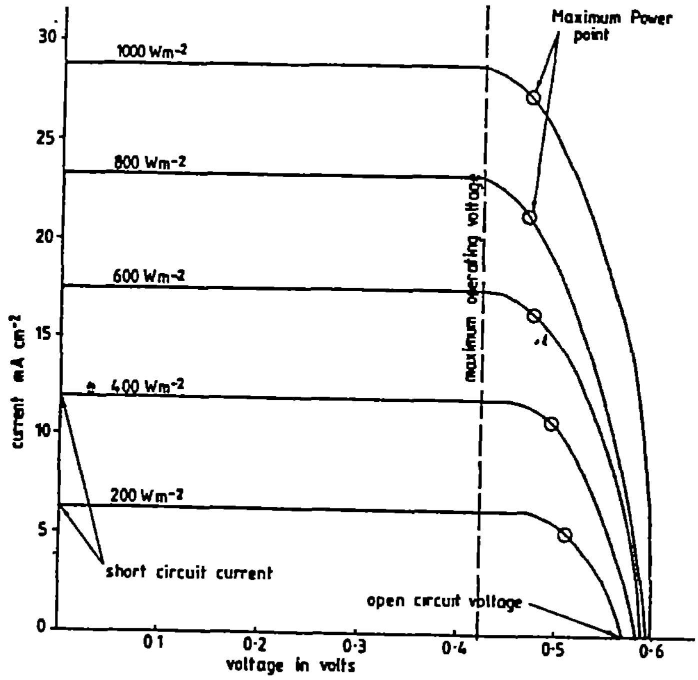


Figure 5. Current-voltage characteristics at different light intensities for a typical silicon solar cell (Kenna and Gillet, 1985).

It can be seen in figure 5 that cells have varying internal resistance depending on their operating point (i.e. the values of current and voltage are determined by the load). The power output of the array is the product of voltage and current; hence for a given solar irradiance it will vary with the operating point. There is a maximum power point which occurs at the knee of the current-voltage curve. Under short circuit or open circuit conditions the power output is zero while the maximum power output is typically about 0.7 times the product of open circuit voltage and short circuit current. The ratio of maximum output power to the product of open circuit voltage and short circuit current is called the 'fill factor' and is an important characteristic in evaluating cell performance (Backus, 1980).

(c) Financial aspects

This solar pump project is an undertaking between the Government of Kenya, the French Government and the Ministry of Water Development (MOWD). The funding was undertaken by the French Government for all the equipment supplied and construction of the buildings to house the equipment. The borehole construction was undertaken by MOWD. The maintenance costs and revenue collection is the responsibility of MOWD.

The breakdown of the total construction costs (in 1981) as obtained from MOWD is as follows:

Borehole	125,000=
Solar system including pumps and accesories	1,040,000=
Building for equipment	42,600=
Fencing	28,000=
	1,235,600=
	=========

(d) Operational and maintenance problems

This system has had no major failures. It has been operating continously since commissioning. However, indications are that routine maintenance procedures have not been undertaken. Investigation revealed that, the operator is not aware of the consequences of the damage to the modules.

(e) Social and institutional aspects

This solar pump is located in Kahawa, some 25 Kilometers from Nairobi. The area consists of low-cost periurban residential housing with the majority of the inhabitants commuting to

Calculations indicate that at best a silicon cell can convert about 22% of terrestrial sunlight into electricity. Present commercial single crystal silicon solar cells for terrestrial use have efficiencies of 11% to 15% at standard test conditions (i.e. at a temperature of 25°C and $1000W/m^2$ solar irradiance). The major energy losses for such cells are in table 1 (Rosenblum, 1982).

Table 1. Energy losses in practical silicon solar cell (Rosenblum, 1982).

Loss due to	Percent not converted into electricity
Low energy photons not absorbed	23%
Excess photon energy not utilized	33%
Internal cell function losses	28%
Reflection, series resistance, contacts	2%
Total	86%

However, with current research and development, it is presumed that terrestrial production type cells could eventually reach about 17 to 20% efficiency. This may appear relatively low, but solar energy is accessible to all and costs nothing (Jesch, 1981).

Solar Generator

Solar generator type (Module)	AEG PQ 10/40/0
Peak power at AM 1.5, 25°C, 100mW/cm^2 acc. to data sheet A47.44 (1183) DE/EN	3763,2 W
Total number of modules	98

Inverter

Inverter type	AEG SOLARVERTE 3 KVA
Rated output power	3,0 KVA
Rated output voltage	14 ... 127 V, 3 phase
Output frequency	5/6 ... 50/60 Hz
Rated input voltage	200 V DC

Submersible Pump

Pump type	CORA 4-89/22
Rated input voltage	127 V 3 phase
Max. pumping height	124.4 m
Rated pumping height	50 - 75 m
Rated pump output at pumping height of 70 m and 50 Hz	4,5 m^3/h

(a) Quantities of water pumped.

The system supplies water to the local villagers, and a secondary school. The operator is responsible for recording daily meter reading. During the various field visits the meter readings were extracted from the records book. The data was then analysed and compiled into average daily figures for a particular month as presented in appendix IV. However, the quantity of water may not be a true represatation of the capacity of the system. Since the project was commisioned at the onset of the study, it is

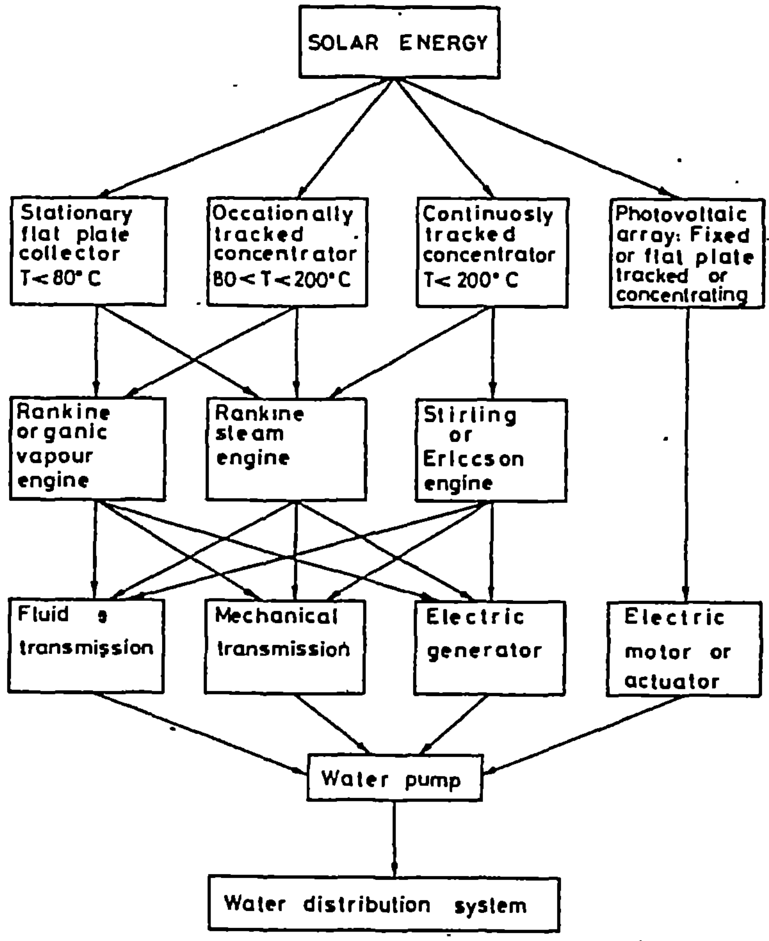


Figure 7. Categories of solar pumping systems (Durand, 1980).

3.2.1 Solar generator

As described in chapter one, the solar generator is the key component of the photovoltaic pumping system. It is composed of solar modules in series and parallel to give the required power output. The module itself is made up of solar cells connected in series and encapsulated for environmental protection.

The main type of photovoltaic cell used commercially for solar water pumping at present is monocrystaline silicon cell although other types of silicon cells, such as amorphorous silicon and polycrystalline silicon cells can be expected to play an increasing role in the market, in the future. The major concern at the present is in reducing the cost of the cells in all aspects and increasing the efficiency of the energy conversion to as near the theoretical 22 per cent as possible (Arbon and Nielsen, 1986).

(c) Financial aspects.

This solar pump project was an undertaking between the Government of Kenya represented by Ministry of Water Development (MOWD) and the Government of Finland. The complete funding of the project, including borehole construction, equipment, buildings, operation and maintenance is currently undertaken by Finnida.

The breakdown of the total construction costs (in 1987) as obtained from MOWD is:

Borehole (2No)	141,000=
Solar system including pumps and accesories	1,250,000=
Building and guard house	74,000=
Fencing	50,200=
Ground level tank (100m^3 Masonary)	210,000=
Total Costs	1,725,200
	=========

(d) Operational and maintenance problems.

Since this is a relatively recent solar pumping installation and the system is still under the maintenance of the financing agency. There are no maintenance problems to be undertaken by the end users, or the Ministry of Water Development.

(e) Social and institutional support

This solar pump is located in a remote rural trading centre. The inhabitants earn a livelyhood from subsistance farming and cattle rearing. Public and infrastructural services at a very low level.

tracking is possible by manually facing the solar generator toward the sun through provision made in the generator mounting structure (Moshar et al, 1977).

In tracking systems, the solar collector follows the motion of the sun across the sky daily and seasonally so that the generator receives direct sunlight perpendicularly. During very cloudy days, the generator would face the brightest point in the sky.

3.2.4 Electric motors

There are two alternative electric motors available for use with solar photovoltaic pumping systems.

Permanent magnet direct current (d.c.) motors
Alternating current (a.c.) motors

The choice of a d.c. motor is attractive because the array provides a d.c. supply. However these are limited to low power applications due to the cost implications of converting d.c. to a.c.

In the a.c. motor system an electronic inverter is necessasry to invert the d.c. to a.c. at the required voltage and frequency. The electronic invertors now commercially avialable have an inversion efficiency of up to 90% (Kenna and Gillet, 1985). The actual figure depends on the invertor design. One of the main advantages of an a.c. output PV system is the ease in matching system power output with commonly available off-the-self pumps, and further, a.c. power allows a simple means of voltage and current transformation, comparative ease of switching and nearly constant motor speed. This is characteristic of a.c. induction motors (Rosenblum, 1982).

The type of motor used by most solar pump suppliers in the past was a brushed permanent magnet d.c. motor, due to their high efficiency. However due to maintenance problems with

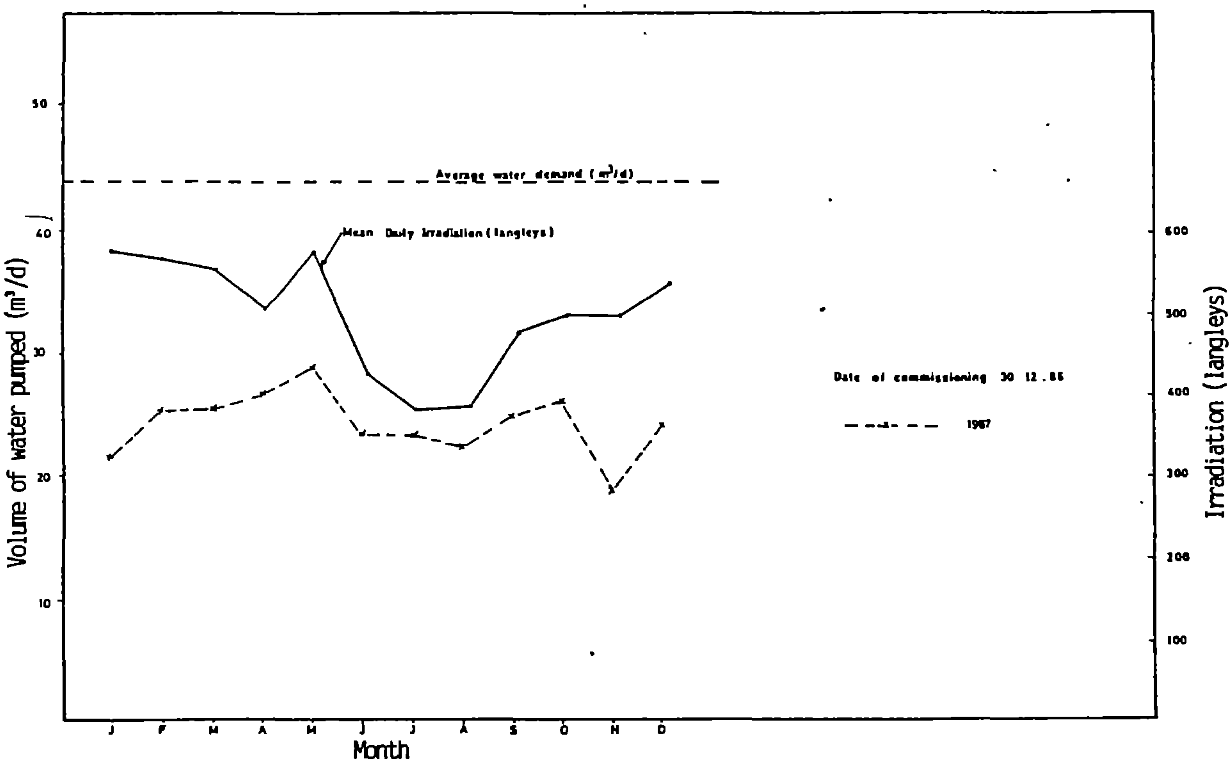


Figure 4.. Ololoitikoshi water supply: average daily volume of water pumped and mean daily irradiation.

(b) Technical condition of the system.

The photovoltaic array is in sound condition, there is no evidence of vandalism or structural failure on the supporting structures.

The convertor is operational and the pumpset is in working condition. The system in general is a good operating condition.

(c) Finance aspects

This solar pump was financed privately by the owners of Ololoitikoshi Ranching farm. The unit was purchased from and installed by a local supplier. The funding was by the management of the farm, including the construction of the buildings. The borehole was sank by a local contractor.

Batteries have four significant disadvantages:

- They are expensive and may be a major financial requirement.
- They need regular topping up with distilled water, with implications of regular maintenance.
- Extra solar cells are required for battery charging thereby increasing the size of the solar generator and hence the costs.
- The useful life of most batteries is limited to about five years under field conditions, which is considerably less than the life of the whole pumping system (Kenna and Gillet, 1985).

3.2.6 Pumps

In photovoltaic pumping systems the design and selection of the pump is crucial in achieving an efficient pumping system. Pumps are broadly divided into two categories depending on the method of transfer of energy to the fluid, centrifigal and positive displacement.

Centrifigal pumps are designed for a fixed head and their water output increases with rotational speed. They have an optimum efficiency at a design head and a design rotational speed. At heads and flows away from the design point their efficiency decreases. However, they offer the possibility of achieving a close natural match with a PV array over a broad range of operating conditions. Centrifugal pumps cannot be used for suction lifts of more than 5 to 6 metres and are more reliably operated in submerged floating motor/pumps sets due to non self-priming characteristics. (Yenamadra, 1987).

Positive displacement pumps have a water output which is almost independent of head but directly propotional to speed. This means that the efficiency of a pump of fixed piston diameter increases with head and therefore for optimum efficiency different diameter pumps need to be used for different heads. At high heads the frictional forces become small relative to the hydrostatic head and therefore positive displacement pumps can be more efficient than centrifugal pumps.

The management is concerned that when the system breaks down, they have to spend several days to try and get the local supplier to come and repair the system. This is a time consuming aspect but however, they expressed satisfaction with the unit because the majority of the repairs are minor.

1.6 Kisingo irrigation scheme.

This solar water pumping unit, was installed with the primary objective of pumping river water to a large tree nursery. The water is utilized for irrigation of the young trees. The location of the nursery is in the dry region 250 kms south-east of Nairobi.

The irrigation method in use is the furrow method. The seedlings are planted and after six months they are distributed to local farmers for planting. The purpose of planting the trees is to reduce soil erosion in the area.

The technical characteristics of the system are:

Solar panels	:	Arco Solar 1.0 KW
Pump type	:	KSB Surface floating type
Max water output	:	$30m^3$/day
Total manometric head	:	10.0m

(a) Quantity of water pumped

The system supplies untreated river water for irrigation purposes. It is operated on a daily basis but the number of pumping hours depends on the water requirements of the plants. It is also used to supply water for domestic purposes to the labourers working on the project. The quantity of water pumped has been plotted and is presented in figure 5.

3.3 Commercial photovoltaic pumping systems

The principal configurations of PV pumps that are commercially available are illustrated in figure 9 (McNelis et al, 1988). These are:

(a) Submerged motor/pump unit, with centrifugal pump, often consisting of several impellers and then termed as 'multistage'. The number of stages is a function of the lift required.

(b) Submerged centrifugal pump (alternatively a rotating positive displacement pump of a progressive cavity type driven by the shaft from a motor mounted on ground level).

(c) Submerged reciprocating positive displacement pump (also known as the jack pump), driven by a shaft from a motor driven crank or beam at ground level.

(d) Floating motor/pump unit with centrifugal pump.

(e) Surface mounted motor/pump unit with centrifugal pump.

3.4 Applications of photovoltaic pumping systems

It is generally acknowledged that there are three main applications, all small scale, for which solar pumps can be most readily used.

These are:

(a) Rural water supplies where water is pumped from a borehole or well to serve drinking requirements and other domestic uses.

(b) Livestock water supplies

(c) Irrigation

The principal differences between these three applications are:

- The value of water for drinking and other domestic uses is of a higher value than for irrigation

(c) Financial aspects

This solar pump project is an undertaking between the Government of Kenya and the Government of Denmark represented by DANIDA. The equipment and construction fo buildings was undertaken by DANIDA. The breakdown of costs is as follows:-

Solar panel pump and accesories	758,000=
Buildings	74,500=
Fencing	32,800=
Total Costs	865,300=

(d) Operational and maintenance problems.

This solar pump is relatively new, and no failures have been experienced. The surface floating pump occassionally is cleaned when the strainer is blocked by floating material and debris.

(e) Social and instituional aspects

This surface water solar pumping unit operates under the supervision of the staff at the nursery. Therefore, day to day operation is well supervised. The unit has the advantage of ease of dismantling, when repairs on the pump are to be undertaken.

This solar unit has proved to be economical to the management of the project. The overhead and running costs are minimal. The labourers who get their supply of domestic water are benefiting greatly and the spouses can now spend their time working at the tree nurseries rather than spend long hours fetching water from the river.

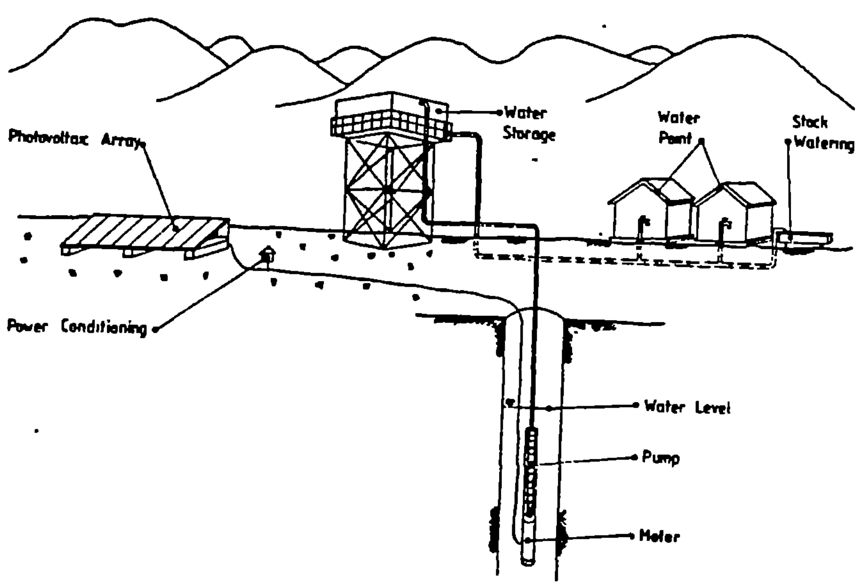
There are plans to install another unit to increase the output at a future date. This indicates the confidence the management has on the pumping system.

- Each application implies a different range of pumping capacities.
- The demand from a village or livestock water supply system is approximately constant, whereas irrigation water requirements vary from month to month and season to season.
- For water supply it is essential to have water on demand, i.e. storage is required.

3.4.1 Photovoltaic pumping for water supply

A schematic of a solar-powered pump installed on a borehole and used for village water supply is shown on figure 10.

Whenever possible, it is safer to take water intended for human consumption from closed boreholes or protected wells. Surface water is not advisable due to the risk of pollution. A typical water requirement in the rural areas is 25 - 40 litre per capita per day (Ministry of Water Development, 1987). It is important to provide sufficient water storage to cover several days of cloudy weather, when the output from the pump will be very low. If a surface water source, such as a lake or stream, has to be used, it is recommended that the water undergoes full treatment before consumption.



Figur 10. Solar powered village water supply (McNelis, 1987)

1.10 Turkana solar pumps

Turkana is located in the arid area of Northern Kenya adjacent Lake Turkana. The area is extremely hot and the mean annual rainfall is 200 mm, which is too low for any meaningful agricultural farming. The inhabitants of the area are generally nomadic and their main occupation is livestock rearing and fishing in the lake.

An Italian Missionary Organization has been undertaking minor projects in the area to uplift the living conditions of the people of this region. The projects have included schools, dispensaries and water projects.

There are three water projects which utilize photovoltaic pumping. These are:

(a) Turkana Girls School
This photovoltaic pumping system supplies borehole water to the school. The pumps were commissioned in 1986 and the borehole pump delivers water to a ground level tank on a hill side approximately 1 kilometer away. From there the water gravitates down to the school and the adjoining village. The total system head is 25m and the maximum output is $5.5m^3$/hr. No major breakdowns have been experienced and the unit is good working condition.

(b) Loarengak village
This photovoltaic pumping system supplies borehole water to the nearby village. The pumps were commissioned in 1986 and the borehole pump delivers water to an elevated concrete tank. From there the water gravitates 9 km to an elevated steel tank at Loarengak. The supply is then conveyed to a health centre, a school and surrounding villages. The total system head is 20m and the maximum output is $5.0m^3$/hr. No breakdowns or failures have been reported and the system is in good working condition.

4. PHOTOVOLTAIC WATER PUMPING TECHNOLOGY IN KENYA

4.1 Solar energy availability

The variability of solar energy is an important aspect which influences system design and economics. Unlike conventional fossil fuel technologies the performance of solar systems can vary markedly from one location to another.

Kenya is a tropical country which lies astride the equator and therefore, the climate is predominantly equatorial/tropical in nature. The movement of the sun between the tropics has a large influence on the seasons and climate in the country.

As discussed in chapter one the determination of the available solar energy is one of the requirements utilized to justify the viability of solar photovoltaic water pumping systems.

The Meteorological Department in Kenya is responsible for the recording and dissemination of meteorological data generated at meteorological stations shown on figure 12. The solar energy data recorded at these stations has been utilized to produce isolines of solar energy radiation distribution as shown on figures 13 and 14 From these figures, high values of solar radiation in Kenya are in the month of February with a monthly mean daily averge insolation of between 5.35 kWh/m^2 day and 7.44 KWh/m^2 day (figure 13). The lowest radiation is received in the cooler month of July as shown in figure 14 during the rainy season and due to cloud cover more than two thirds of the country receives less than 4.12 kWh/m^2 day. Solar insolation values of below 3.58 kWh/m^2 day are attained in some locations (Kenya Meteorological Department, 1984).

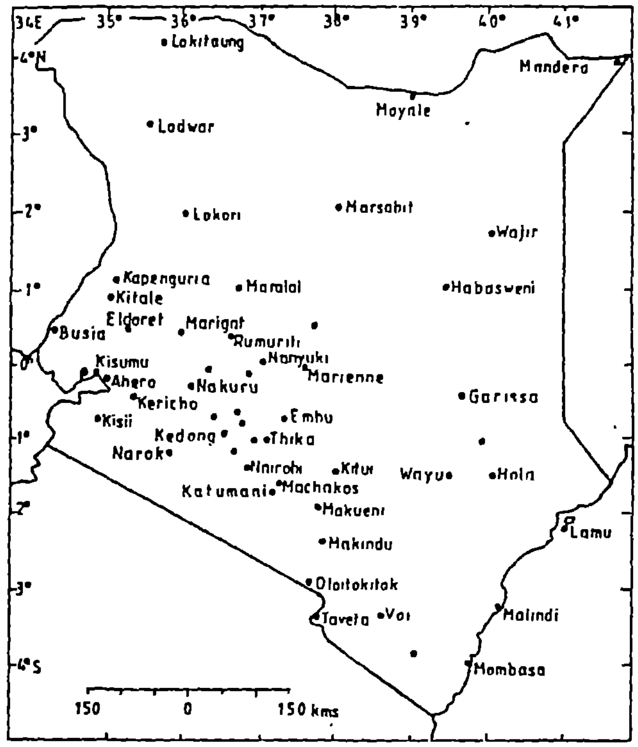


Figure 12. Meteorological stations in Kenya (Kenya Meteorological Department, 1984)

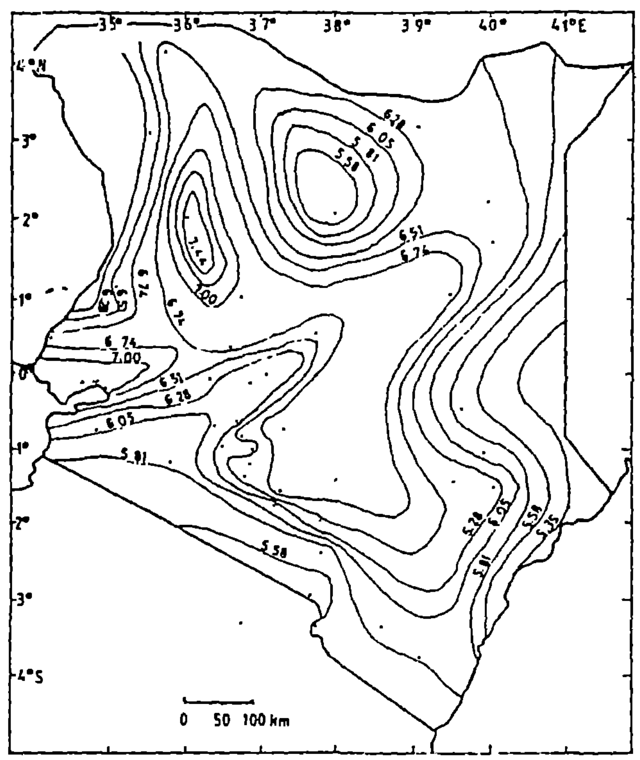


Figure 13. Solar energy radiation distribution in February (in kWh/m^2 day) (Kenya Meteorological Department, 1984).

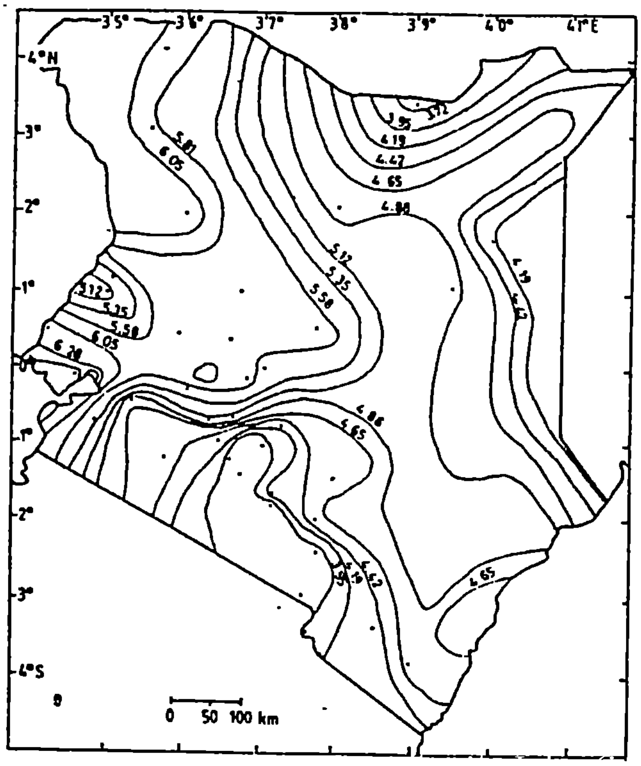


Figure 14. Solar energy radiation distribution in July (in kWh/m^2 day) (Kenya Meteorological Department ,1984)

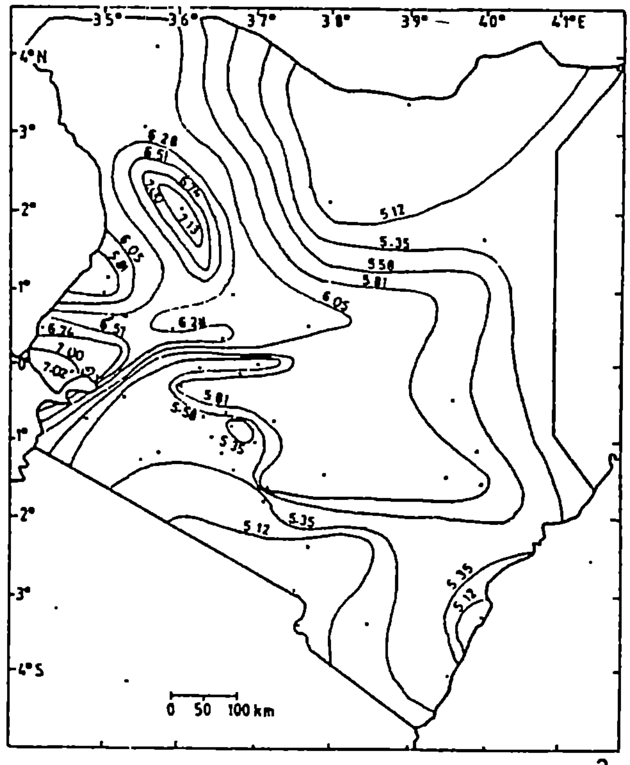


Figure 15. Annual mean radiation distribution (in kWh/m^2 day) (Kenya Meteorological Department, 1984).

The monthly mean daily solar global insolation for other months is lower than that of February due to the increased cloudness cover during the long rains of April-May and the short rains of October-November.

Figure 15 shows the annual mean daily radiation distribution in Kenya. The radiation values in the western half of the country are generally higher than the eastern half of the country with the highest value of 7.0 kWh/m^2 day being obtained in the North - Western Region and the Lake Victoria basin.

The lowest values of less than 5.12 kW/m^2 day are observed in the Central, North-Eastern and Coast Provinces. About one third of the Country has an annual daily radiation above 5.81 kWh/m^2 day.

From the discussion of the available solar energy it is evident that there is adequate solar radiation for exploitation in remote areas which are far from the utility grid. This justies the use of photovoltaic pumping systems for rural water supply in isolated villages. The values of annual radiation distribution indicate that the North-Western Region of Kenya as the most promising area with radiation average of 5.81 kWh/m2 day (Kenya Meteorological Department, 1984).

4.2 Solar pumping installations in Kenya

There are 52 major solar water pumping installations in Kenya according to the Ministry of Water Development. These installations are largely concentrated in the Central and North-Western Region of the country as shown on figure 16. These installations can be categorized according to the end use of the water as follows:

End use of water	No. of units
Domestic/Livestock water supply	40
Domestic/Livestock/Irrigation	1
Irrigation	10
Water purification plant	1

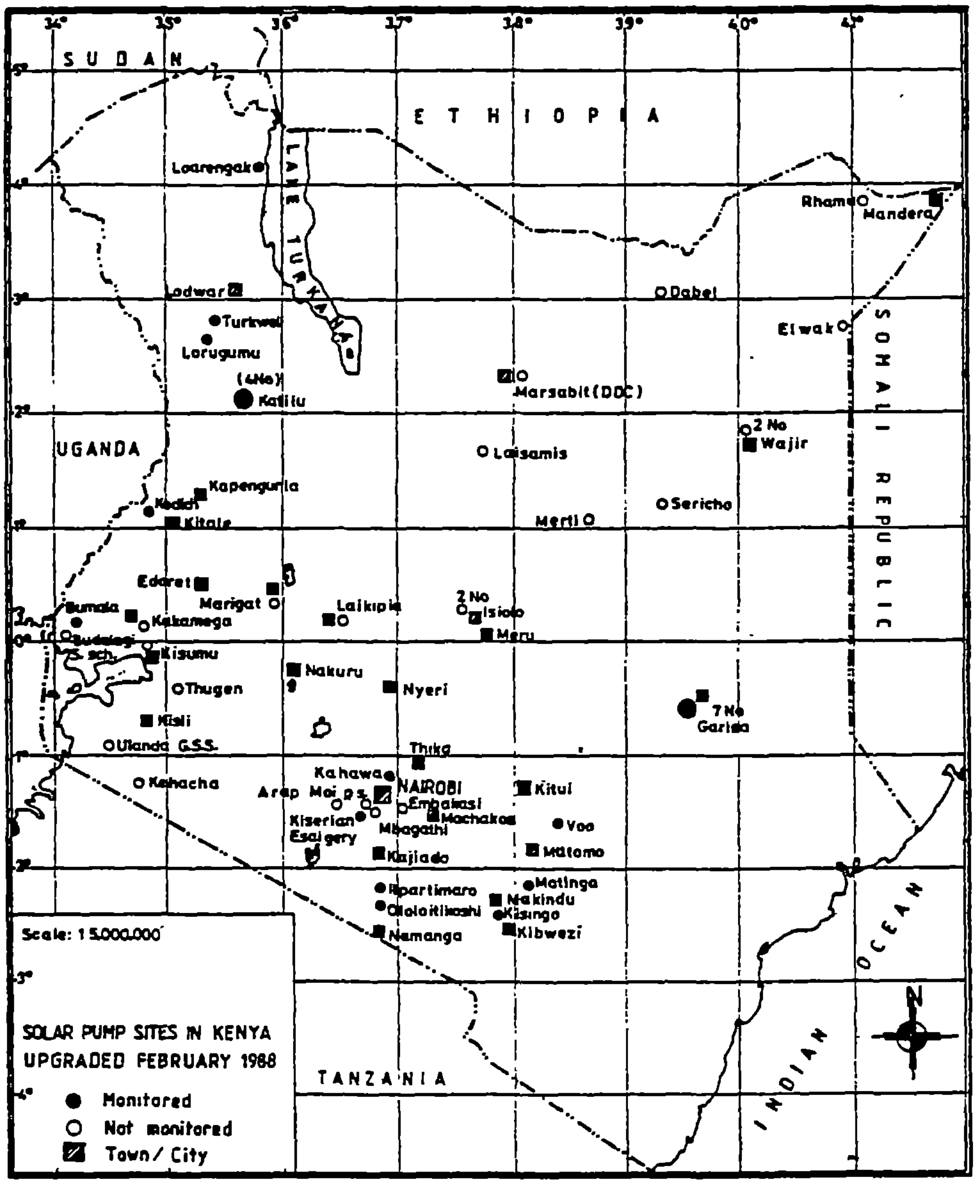


Figure 16. Solar pump sites in Kenya (Moerman, 1988).

Due to the high initial capital outlay associated with solar water pumping systems and lack of local experience in solar pumping systems, the study established that the majority of these systems been financed by foreign governments, bilateral and multilateral aid agencies.

These donor agencies have purchased solar pumping systems from local agents and in most cases the units have been brought to Kenya direct from the country of origin as part of an aid package. The majority of these systems are small due to the experimental nature of the technology vis-a-vis the cutionary attitude of financing bodies. However, the majority of these solar pumping systems have also proved popular in the remote areas, where the rural population has benefited in obtaining potable water, with the advantage of little or no maintenance problems. In mid-1986 an interesting solar pumping system was installed to supply potable water to a rural school. The system consists essentially a solar powered water pump, which pumps the raw water via a sand and active carbon filter under high pressure to eliminate suspended solids and organic matter. The water is then disinfected by use of an ultraviolet radiation column powered by the photovoltaic cells. This is a system which is suited for surface water sources but an economic evaluation is required to support its viability.

5. FIELD DATA COLLECTION AND CASE STUDY SELECTION.

5.1 Methodology

Nine photovoltaic pumping installation were selected for field investigations and data collection. In the dry semi-arid region to the South and South-East of Nairobi four installations were selected. In the central highlands East of the Rift Valley near Nairobi two installations were selected. In the Western region adjacent to lake victoria two installations were selected, and to the arid North near Lake Turkana one installation was selected.

The selection was based on installations with ease of accessability and adequate background technical and financial information for a preliminary assessment.

The preliminary assessment involved investigating the following factors:

- the quantity of water pumped daily on a monthly basis.

- the technical condition of the system.

- the financial arrangements and procurement procedures.

- the operation and maintenance problems of the systems.

- the end user satisfaction.

5.2 Analysis and case study selection

The data collected from the nine installations was analysed. The technical and financial assessment of each installation is presented in Appendix I. The Chwele water supply scheme was selected as a case study. The criteria of selecting a case study was based on a system with adequate technical and economic data for an economic evaluation. The economic evaluation and analysis compares the competitiveness of photovoltaic pumping to an alternative pumping method. The economic evaluation for Chwele Water Supply is presented as a separate study in next chapter. The technical data for the other installations was not available or inadequate for the purposes of a cost comparison. The technical data which must be available for a realistic cost comparison includes; water demand, number of people served, borehole yield, borehole pumping depth, storage tank and capacity. This data facilitates the sizing of an alternative pumping method, for example the size of a diesel generating set or the number of hand pumps required. The Kiserian Water Supply Scheme could have been utilized as an alternative cast study, but due to unaivability of a breakdown of costs for the components of the photovoltaic pumping system, a cost comparison is not feasible.

6. CASE STUDY: CHWELE WATER SUPPLY SCHEME

6.1 Objectives of the case Study

The purpose of this case study is to determine and compare both technically and economically the competitiveness of diesel pumping, as an alternative to the existing photovaltaic (PV) pumping system for Chwele Water Supply Scheme.

The specific objectives are:

(a) to determine and compare the estimated initial capital costs for a diesel pumping system with the actual cost of the existing PV system.

(b) to determine and compare the net present value costs of each system based on a lifetime operation and maintenance requirements.

It should be noted that due to depth of the ground water, it is not feasible to include a comparison with hand pumps in this case study.

6.2 Comparison basis and approach

6.2.1 Service level and quality

For a comparative analysis of PV pumping and diesel pumping, it is assumed that both technologies are providing the same level and quality of service.

Service level and quality will be defined as follows:

(a) the amount of water supplied daily per person is the same for both systems.

(b) the technologies provide water at the same level of reliability so that, water availability throughout the year is the same for both technologies. The same availability levels are attained by using operation and maintenance practices consistent with reliable equipment performance and using adequate water storage in both PV pumping and diesel pumping systems.

Since the level and quality of service is the same for both systems, the evaluation compares the relative costs of replacing the PV pumping system with a diesel pumping system.

6.2.2. Capital costs and Recurrent costs

(a) Capital costs

The capital costs represent the initial cost of purchasing and installition of the system. The capital costs for the existing PV system at Chwele water supply were obtained from Ministry of Water Development. The breakdown of the costs for each component was obtained from Jos Hansen and Soehne, the local representatives for AEG Telefunken, the West German manufacturers of PV pumping systems. Jos Hansen and Soehne were responsible for the procurement and installation of the existing PV pumping system at Chwele. It should be noted that PV system pumps are more expensive compared to off-the-shelf three phase electrical pumps because PV pumps are specifically designed and manufactured to optimize the cost effectiveness of the system.

The capital costs for the supply and installation of the diesel pumping equipment were obtained from various local representatives of diesel engines and borehole submersible pumps. The costs were analysed and found to be in the order of magnitude for capital and recurrent costs under Survey of Photovoltaic Power in Developing Countries (McNelis et al, 1988).

(b) Recurrent costs

The recurrent costs considered consists of three parts:

(i) Replacement costs occur at intervals depending on lifetime of each component as per the manufacturers recommendations, field experience and testing programmes (Cabral, 1987). The economic life time of a system is the time when cost of maintenance make it less economical to use the existing equipment than to purchase improved equipment.

The following period of lifetime have been adopted (Cabral, 1987):

PV array	20 years
Motor/Pump	7.5 years
Diesel engine	5 years

(ii) Maintenance and repair costs occuring each year represent the cost of undertaking normal servicing and change of parts after a certain working period. This period is as per the recommendations of the manufacturers. The maintenance costs for PV Pumping stystems are difficult to estimate due to the limited operating experience. However, the values adopted for this case study were obtained from the field data collection and are comparable to the study on Small Scale Solar Powered Pumping Systems by Sir William Halcrow and Partners in 1983. Operating costs represent the daily running costs. These are attributed to fuel costs. For diesel engines they are calculated on the basis of hours of operation. For the case study an 8 hour per day is adopted as the maximum period as recommended by the manufacturers. The operating costs attributable to wages are considered to be the same for both PV and diesel systems. For the case study there are at present two attendants at the existing PV pumping system. A diesel pumping system would require the same number of attendants for the daily operation of the system.

6.2.3 Economic evaluation and comparison

The economic analysis is based on four factors:

- the period of analysis
- discount rate
- inflation rate
- a sensitivity analysis

The period of analysis has been chosen to be 20 years which is equal to the economic life time of the PV array and coincides with the design period of the project. The PV array is the component with the longest life time and the choice of a 20 years period of analysis is used because it allows for replacement of all major system components. Longer period could be used but would have little effect on the end result.

Discount and inflation rates of 15% and 10% have been utilized. These rates reflect the current (1989) commercial interest rates and inflation rates in Kenya. A sensitivity analysis using discount and inflation rates of 10%, 5% and 20%, 15% were also conducted to assess the impact on PV competitiveness due to uncertainties of the future changes in Kenya's economy. The results of the analysis are presented in section 6.5.3. The net present value unit costs obtained by using these rates is considered realistic for the economic comparison of the two systems. The present worth factors utilized are adopted from Kenna and Gillett, 1985.

The life cycle cost is the lifetime costs associated with the pumping system expressed in terms of present monetary value. The life cycle cost is the life time costs of pumping system expressed as a sum of annual payment.

6.3 Configuration of system to be evaluated

(a) Photovoltaic (PV) pumping system

The principle PV pumping system components are the PV array, power conditioning equipment; motor and pump.

(b) Diesel pumping system

The principle diesel pumping system is identical to the PV pumping system, with the exception that the diesel pump replaces the PV pump. The diesel engine is coupled to a generator set which generates electricity for operating the submerged motor/pump unit. The diesel pumping conponents are the diesel engine, the generator, fuel tank, motor and pump.

6.4 Background information to the case study

6.4.1 General

Chwele water supply project is located approximately 24 kilometers, north of Bungoma Town in Bungoma District of Western Province. It is an undetaking financed by the Government of Finland through the Finnish International Development Agency. The system uses photovoltaic power generated by solar panels to pump water from two horeholes to a ground level storage tank and an elevated pressed steel tank.

The elevated tank supplies water to the higher regions of the village whilst the ground level tank supplies water to the lower areas.

The water project was completed in August 1987 to supply water to Chwele Trading Centre, with a population of approximately 1000 inhabitants. There are approximately 150 consumer connection in a distribution system of 5.2 kilometres of pipeline.

6.4.2 Design criteria and water demand

The design capacity of the water supply according to the project design report (Chwele Water Supply - Final Design Report, 1987) is as follows:

Per capita consumption 60 l/h/day
Population growth rate 4% per annum
The calculated wate demand is:

Year	Population*	Water demand (m^3/day)
1987	800	46
1997	1100	68
2007	1700	101

(* Figures rounded by author)

6.4.3 Sources of water

The source of water is two boreholes situated at Busakala Secondary School. The yield of the two boreholes according to test pumping results is 2.9 m^3/h and 13.1m^3/h for the first and second boreholes respectively. The pump setting depth is 47 metres and 78 metres respectively. The submersible pumps in the two boreholes pump water to the 100m^3 ground level storage tank and when the tank is full, the water continues to be pumped to the 10m^3 elevated storage tank. The water then gravitates to the consumers.

6.4.4 Specification of the system

The photovoltaic pumping system consists of three main components:-

(a) Solar generator

Solar generator type (Module)	AEG PQ 10/40/0
Peak power at AM 1.5, 25°C, 100mW/cm^2 acc. to data sheet A47.44 (1183) DE/EN	3763,2 W
Total number of modules	98

(b) Inverter

Inverter type	AEG SOLARVERTER 3 KVA
Rated output power	3,0 KVA
Rated output voltage	14 ... 127 V, 3 phase
Output frequency	5/6 ... 50/60 Hz
Rated input voltage	200 V DC

Submersible Pump

(c)

Pump type	CORA 4-89/22
Rated input voltage	127 V 3 phase
Max. pumping height	124.4 m
Rated pumping height	50 - 75 m
Rated pump output at pumping height of 70 m and 50 Hz	4,5 m^3/h

6.5 **Cost comparison and economic analysis of the case study**

The results of the economic evaluation and analysis for the case study is presented here in Kenya Shillings (1US$ is approximately Kshs. 20/= at 1989 rates)

6.5.1 **Photovoltaic pumping system**

(a) Capital cost

Photovoltaic array and invertor	928,000/=
Pumps	208,000/=
Installation, testing commissioning	114,000/=
Total capital costs	1,250,000/=

(b) Operating costs (Per annum)

Maintenance costs	1650/=
Fuel costs	-

(c) Data for cost comparison

Period of analysis	20 years
PV array life	20 years
Pump life	10 years

6.5.2 Diesel pumping system

(a) Capital cost

Diesel generating set	265,000/=
Pumps	96,000/=
Installation, testing and commissioning	45,000/=
Total capital costs	474,000/=

(b) Operating costs (Per annum)

Maintenance costs	10,000/=
Fuel costs	50,000/=

(c) Data for cost comparison

Period of analysis	20 years
Diesel gen-set life time	5 years
Pump life	10 years

6.5.3 Results of the present worth costs and sensitivity analysis

(Note: PWF - Present worth factor)

Item	Photovoltaic system			Diesel system		
Capital Costs	1,250,000			474,000		
Discount rate	10%	15%	20%	10%	15%	20%
Inflation rate	5%	10%	15%	5%	10%	15%
PWF for annual costs	12.11	11.78	11.46	12.11	11.78	11.46
PWF for pump replacement	0.6	0.58	0.57	0.6	0.58	0.57
PWF for diesel gen-set (5 years)	-	-	-	0.75	0.73	0.70
PWF for diesel gen-set (10 years)	-	-	-	0.60	0.58	0.57
PWF for diesel gen-set (15 years)	-	-	-	0.47	0.47	0.46
Replacement costs						
Pump after 10 years	124,800	120,640	118,560	57,600	55,680	54,720
Diesel gen-set after 5 years	-	-	-	198,750	193,450	185,500
Diesel gen-set after 10 years	-	-	-	159,000	153,700	151,050
Diesel gen-set after 15 years	-	-	-	124,550	124,550	121,900
Maintenance costs	19,982	19,437	18,909	121,100	117,800	114,600
Fuel costs	-	-	-	605,500	589,000	573,000
Life cycle costs	1,394,782	1,390,077	1,387,469	1,740,500	1,708,180	1,674,700
PWF at zero inflation rate	8.51	6.26	4.87	8.51	6.26	4.87
Annual equivalent life cycle costs	163,899	222,057	284,901	204,452	272,872	343,881
Net present value unit water cost per m^3	4/40	6/00	7/70	5/50	7/40	9/30

The sensitivity of PV system competitiveness to discount and inflation rates indicates that the net present value unit water cost per cubic metre is lower by 20 - 25 per cent.

7. FUNCTIONAL ANALYSIS AND DISCUSSIONS

This case study represents an ideal photovoltaic water pumping installation with a detailed project documentation. It is therefore possible to comment on the engineering design, and the technical aspects which could have been investigated further by the design engineers before implematation of the project. The objective of undertaking a detailed exhaustive design, taking into consideration all available alternatives is to provide a required service at minimum capital outlay. In the following four section comments on the design criteria, water sources, procurement and the economic evaluation for Chwele Water Supply Scheme are discussed in detail. Alternative considerations are suggested and their impact on the system design is presented.

7.2 Design criteria and procedure

The design of any water supply scheme begins with the determination of quantity of water to be supplied (i.e. the water demand) and the availability of water sources to satisfy the demand. The water demand is calculated on the basis of the number and type of consumers to be served. The water source can be either surface water (e.g. rivers) or groundwater.

In this case study a design criteria of 60 litres per head per day was adopted. The estimated future population was calculated on the basis of an average growth rate of 4% per annum. The water demand was then calculated for a ten and twenty year horizon.

The basic design methodology is acceptable, but the designers overlooked certain aspects of determining the water demand, in relation to the type of consumers. Chwele is a small trading centre without any major economic activity. It is basically a service centre, for the surrounding rural community. Therefore, a per capita of 60 litre per day cannot be realistic for consumers using communal water points. Ideally the water consumption pattern should have been based on a broad range of consumers. For example, the designers should have considered the consumption based on:

- households willing to install individual connections
- households to be served by communual water points
- Commercial connections
- institutional connections (e.g. schools, health centres)

The end result of a these considerations is a more realistic water demand. This could create a cost saving, if a smaller capacity pump is required to match a reduction in the water demand.

In the current situation for instance, out of an estimated population of 1,000 inhabitants there are less than 70 individual connections. The current daily consumption varies between 20 m^3/day to 25m^3/day, which does not correspond to the 48 m^3.day as initially envisaged in the design.

7.2.1 Water sources

The source of water is groundwater. There are two boreholes. The yield from the boreholes during test pumping is 2.9 m^3/h and 13.1 m^3/h respectively. In the design report these test pumping rates have been considered as the borehole yields, which is incorrect. In fact, the data on observed drawdonws after 24 hour test pumping, indicate that the maximum borehole yields should be 1.6 m^3/h and 32.6m^3/h respectively, based on the borehole depths.

Therefore, further considerations should have been made on the viability of using both boreholes or to use the borehole with the higher yield. Water demand calculations indicate that the borehole with a higher yield was adequate to satisfy the forcasted demand. If these technical alternatives were considered at the design stage, the need of equipping the borehole with the lower yield could have been eliminated. Thus resulting in a saving on the initial capital cost of the system, bearing in mind that the PV system accounts for 60% of the initial costs. The safety factor of two boreholes is clearly not a sound engineering investment.

7.3 Procurement and installation

For the procurement and installation of the photovoltaic pumping system for this case study, borehole characteristics and location data was sent to two local agents suppliers for design, system specifications, installation, guarantees, delivery time and terms of payment.

The quotations were received and analysed. The first supplier offered a system with a nominal power output of 1.48 KW at an irradiation of 6.3 KWh/m^3/day with a pumping capacity of 2.5 m^3/h at 55 meters head. The conditions of this supplier included; no installations, a two year guarantee for the pumps, a ten year gurantee on the panels and a delivery time of four weeks.

The second supplier offered a system with a nominal output of 3.76 KW at an irradiation of 6.3 KWh/m^3/day with a pumping capacity of 4.5 m^3/h at 55 meters head. The conditions of this supplier included; to undertake installation, a one year guarantee for the pumps, a five year guarantee on the panels and a delivery time of ten weeks.

The terms of payment were the same for both suppliers with 85% payment against documents and 15% after commissioning. However, the cost for the first supplier was 52% lower than that of the second supplier. Subsequently, a decision was made to award the second supplier the contract of supplying and installing of the photovoltaic pumping system. This decision was based on two factors; the capacity of the system and the undertaking of the installation work.

The two key issues emerge from the procurement procedure adopted by the design engineers. Firstly, in Kenya there are more than seven suppliers/agents currently dealing in photovoltaic pumping systems. A larger number of these suppliers should have been invited to quote for the supply of the PV system. This could then offer a wider range of selection on a more competitive basis. Secondly the design engineers should have included a general questionnaire for each prospective suppliers indicating past experience of similar work in Kenya, capacity of the system installed, and whether the equipment is officially certified by the European Solar Test Installation for the Commission of the European Community. These factors could then form a sound basis of selection before technical and financial are taken into account.

7.4 Economic evaluation

The summary of the economic analysis presented in chapter 6 indicate that the initial unit water costs for the photovoltaic pumping is 62% higher than a diesel pumping system. The corresponding per capita initial capital cost is Kshs. 625 and Kshs. 237 respectively. The net present value unit water costs are Kshs. 6/00 and Kshs. 7/40, at a discount and inflation rates of 15% and 10% respectively.

The implications of these unit water costs are that photovoltaic systems have a high initial costs, but due to minimal replacement and operation costs, the photovoltaic system is a cheaper alternative on a lifetime basis. It can be seen that photovoltaic water pumping is competitive to diesel pumping especially in remote village where availability of diesel is a major problem.

7.5 Social and institutional factors

The photovoltaic pumping system has generally been well-received in Chwele and the surrounding community. The supply is greater than demand and this is the main reason for user satisfaction.

The water supply scheme is still under the management of the Finnish International Development Agency. There have been no problems reported on the photovoltaic system except for one broken module due to vandalism. This module was promptly replaced by the supplier and the water supply was not adversely affected.

Nevertheless, it is observed that the local community was not involved at the planning and installation stage. Hence, any major problems will have to be referred to the local Water Office, when the project is finally handed over to the local community.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The photovoltaic pumping technology has improved significantly, with the emphasis on better matching of system components, increase in reliability and reduced maintenance requirements. However, the type and size of system needs to be chosen carefully on the basis of a systems approach to the problem, taking into account all the relevant technical and economic factors. The results of the case study indicate that the decision to invest in photovoltaic pumping must be based on sound judgement of the following factors:

(a) Technical aspects

The performance of a photovoltaic pumping system is dependent on the assumptions made and criteria used at the design stage regarding solar and water resource characteristics. Considerations of the solar input to the array, the well yield and water demand should be assessed in detail. Failure to do this can result in the system being undersized so that they fail to meet the demand, or excessively oversized with associated additional capital cost.

(b) Economic evaluation and procurement

There are certain basic stages which are generally followed before awarding a tender for any contract. Photovoltaic water pumping systems are not an exception to this rule and the recommended procedures should include:

(i) an assessment of photovoltaic pumping alternative pumping methods with estimated costs

(ii) preparation of tender documents which should contain the specification for design, manufacture (including material and workmanship), environmental conditions, spare parts, tools, guarantees, previous experience and including installation of the system.

(iii) a detailed assessment of each supplier to ensure compliance with the specification, suitability of design, capital costs and overall experience in photovoltaic pumping technology.

(c) Social and institutional aspects

Photovoltaic pumping systems, being a new technology, need institutional support to enable them to be intergrated into the social and environmental conditions of the rural communities. It is important to involve the local community from the planning stage and encourage them to organize a management committee.

The local organization must then be assited to organize appropriate arrangements for distribution of the water and levying charges. An operator should be appointed to administer the system and he will need basic training in routine maintenance and locating technical faults.

8.2 Recommendations

This study recommends that further work on monitoring and evaluation of Chwele Water supply should be undertaken. It is essential to obtain continuous data on performance and to build up information for long term technical and economic appraisal.

The performance evaluation will increase the data base of the system performance, component lifetimes and maintenance requirements. The simplest method of performance evaluation is to take daily reading of:

- global solar radiation in the plane of the photovoltaic array
- value of water pumped
- variations in ground water level

This will enable the hydraulic energy and hence system efficiency to be obtained for different values of daily solar irridiation and over a period of several years.

In Chwele, flow meters have been installed to record the daily flow rate. However, there is a need to install a pyranometer or solarimeter to measure solar irradiance and to purchase a well dipper to permit measurements of water level in the boreholes.

In addition a log book should be used to record problems, breakdowns and maintenance requirements.

It is further recommended, that PV pumping systems serving communities or villages, and are financed by; donor agencies and other bilateral and multilateral organizations should enlist, the cooperation and participation of the Appropriate Technology section of the Ministry of Water Development for monitoring purpose.

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APPENDIX I

1. **Data from solar installations.**

1.2 **Kiserian solar pump**

This is one of the earliest photovoltaic water pumping systems installed in Kenya. It was a prototype solar pumping unit, installed in 1980 as a demonstration and research project with a joint undertaking between the Government of West Germany, the University of Nairobi and the Ministry of Water Develpment (MOWD).

(a) The technical specification and description is as follows.

Solar generator

(i) for power production.

Area	$48m^2$
Voltage	46 to 280V
Amperes max	9A
Solar radiation	1 kW/m^2
Efficiency of the generator	9 to 10%
Net output	45kW

(ii) for recording purpose

Area	$4.6\ m^2$	
Voltage (with regulator)	12 V	
Available Ampere hours (average)	150 Ah/day	
Net output	0.46 kW	
Batteries 6 Nos @ 2V	]	
Voltage 12V	]	Operation of
Capacity900 Ah	]	the recording
	]	system.

(iii) Conversion

DC-AC output	5 kVA
Efficiency	95%
Frequency	40 to 60Hz

Overall efficiency of the solar generator 4 to 5%

(iv)	Standby generator:	Make/Type	Lister/ST2
		Capacity (rating)	6,4kW/8.0 kVA
		Engine output at site	7,1 kW
(v)	Borehole:	No C 4863 constructed	No. 80/Jan.81
		Depth	94m
		Diameter	200mm(steel casing to/50m)
(vi)	Submersible pump		
		Make	Pleuger (3 phase)
		Capacity (rating)	
		6m^3/h against	87m head
		pump setting level	36m
		pump efficiency (motor)	
		+ pump)	33%
		Power demand 40/50 Hz	1.9/3.6 kW
		Pumping capacity max	6 m^3/h at 50Hz
(vii)	Rising Main:	Length 565m, diameter 80mm PVC	
		Difference in elevation: 65m	
(vii)	Storage Tank:	Elevated steel storage tank	
		Capacity	45m^3
		Height of tower	3.5m
		Tank complete with:	
		Diam 2" pipes for inlet, overflow and scour.	
		Diam 3" outlet pipe.	
(viii)	Chlorination:	Displacement doser.	

The University of Nairobi undertook a research into this prototype solar photovoltaic water pumping system in 1980 over a period of one year. The objective of the research was to establish the performance of the various electrical units with particular attention to the overall system efficiency.

This installation is also, equipped with a diesel generation set as a standby unit, but however, the set has been non-operational. This is because the solar pumping, has not experienced any major breakdowns to warrant, the use of the standy generator, as explained by the operator-in-charge. This installation is extremely advanced and sophisticated in nature. It is equipped with extra panels, which are used separately for charging batteries and to provide current to the analog. The analog consists of chart recording and indicating instruments for monitoring the individual performance of the solar modules, solaverted and submersile pump system.

b) Quantity of water pumped.

After the completion of the University of Nairobi research work, the project was officially handed over to the Ministry of Water Development (MOWD) for the day to day running of the scheme. The operation and maintenance staff of MOWD were charged with the overall responsibility of the solar generator, batteries, convertor, pumps and data recorder. The staff is required to report any malfuctioning to the MOWD headquarters, so that the equipmnent manufacturers in West Germany could be informed.

The only parameter monitored on a regular basis is the daily volume of water pumped. The data was extracted from the operator's handbook and compiled on a monthly basis (refer to appendix II). A graph of the average volume of water pumped daily for every month was drawn as shown in figure 1. The automatic irradiation recording device has been out of operation and therefore the values of daily insolation are not available. However, irradiation data from the nearest meteorological station, was compiled and drawn on the same graph. This is to relate the variations of amount of water pumped and sunshine availability. The calculated average water demand of $30m^3$/day has been plotted on the graph.

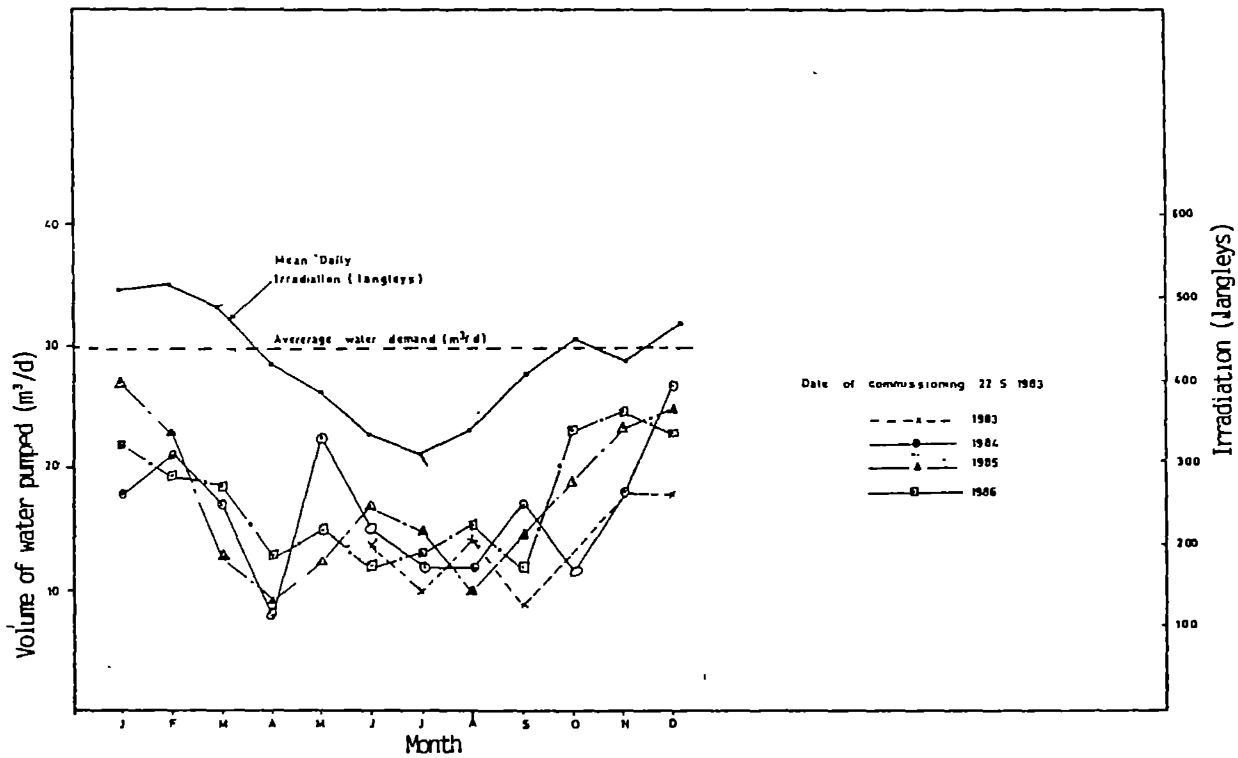

Figure 1. Kiserian solar pump: average volume of water pumped, mean daily irradiation and average water demand

(c) Technical condition of the system.

During a visit made to this solar pump the technical condition of the components was as follows:-

Solar generator - which consists of the modules is generally in good condition. However, it was noted that the perspex glass covering the modules on one of the panels was cracked. Investigation revealed that this was an act of vandalism.

Batteries - the batteries were in good condition

Convertor - the original convertor had previously broken down and this was a second one fitten by the manufacturer. This second convertor has been operational for more than three years without any problems.

Pump and motor - the pump and motor combination were operating satisfactorily and no failures have been experienced since they were installed.

Data recorder - the data recorder was out of operation due to broken down electrical components. Investigation revealed that, it has not worked for the past four years. Efforts to repair it, have not been successful due to delays in obtaining spare parts from the manufacturer. Furthermore, this component of the system does not affect the actual water pumping, and it is not considered as extremely important by the operators.

Standby generator - the standby generator is in a mechanically sound condition. It is occassionally utilized to keep the parts in operating condition, since it is not regularly used.

(d) Financial aspects

This solar pump project is an undertaking between the Government of West Germany represented by GTZ, the University of Nairobi and the Ministry of Water Development (MOWD). The funding was undertaken by GTZ for all the equipment supplied and construction of the buildings. The borehole construction was undertaken by MOWD. The maintenance costs are taken care of by the Ministry through funding from GTZ. However, staff wages and collection of revenue is the responsibility of MOWD. Currently a flat rate of Kshs 15/= is charged per month for every connection. The breakdown of the total construction costs (in 1980) as obtained from MOWD is as follows:

	KSHS
Borehole	105,000=
Solar system including pumps and accesories	2,060,000=
Standby generator	215,000=
Building for equipment	88,500=
Operators houses (2 units)	210,000=
Fencing	56,400=
	2,734,900=

(e) Operational and maintenance problems

The operational problems of the system are minimal, since water pumping commences automatically when the thresh hold voltage is attained. It is also reported that the system is occassionally switched off when the elevated tank is full. The system is generally reliable and no major maintenance procedures have been undertaken, apart from the changing of the convertor.

(f) Social and institutional aspects

This solar pump is located near Kiserian Trading Centre, some 50 kilometres from Nairobi. The inhabitants are generally peri-urban in nature, with the majority earning a livelyhood from subsistance farming. However, due to its proximity to Nairobi, public services and infrasfructure is modest. The area has several seasonal streams which renders surface water usage impracticable. The borehole was drilled by MOWD and original proposals were to equip the borehole with and electrical submersible pump.

The solar pumping system has been well received by the local people, even though there was lack of local involvement at the planning stage. There are about 1500 people benefitting directly from the project. However, during the drier months of the year demand is usually greater than supply causing user dissatisfaction.

The technical support in terms of training the local operators is non-existant. MOWD technicians have yet to be trained to carry out repairs and routine maintenance.

1.3 Kahawa solar pump.

This solar pumping system was commissioned in August 1981, with the assistance of the French Government. The system is of French origin and was installed by the manufacturers. It was handed over to the Ministry of Water Development for monitoring, operation and maintenance.

The technical characteristics of the system available are as follows:

Pump type : ALTA x 26045
Total manonetric head: 45m
Pump setting level: 50 m^3/day
Rated motor power: 2.6 kw.

(a) Quantity of water pumped.

The system supplies water to the surrounding low cost residential areas. The Appropriate Technology Section of MOWD, installed a water meter in 1981 to monitor the amount of water pumped daily. The operator was responsible for recording the daily meter readings. During the field visits, the meter readings were extracted from the records book. The data was then analysed and compiled into average daily figures for a particular month as presented in appendix III. The quantities were then transformed into graphical form shown in figure 2. The mean daily irradiation figures from the Jomo Kenyatta meteorological (which is the nearest meteorological station to the site) are also plotted on the graph. The average water demand of 15 m^2/day is plotted on the graph.

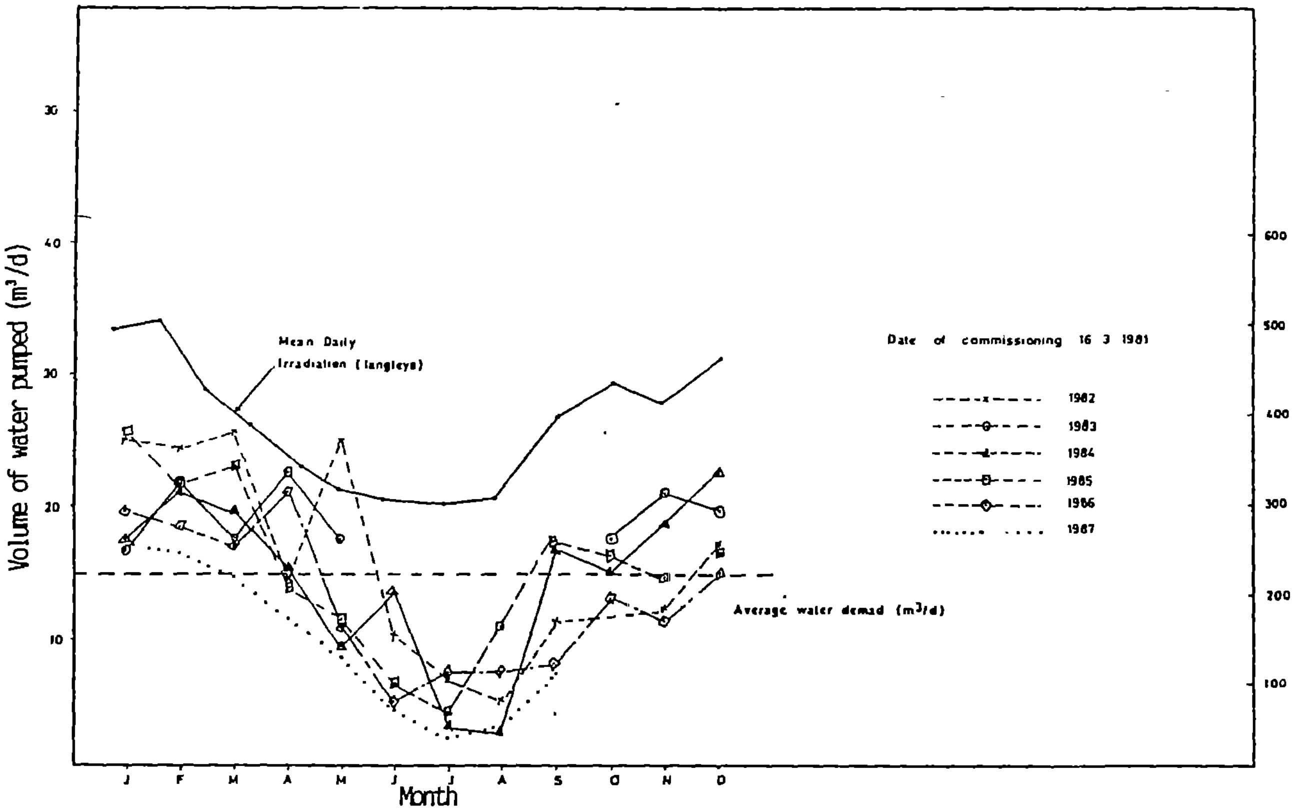

Figure 2. Kahawa solar pump: average volume of water pumped daily and mean daily irradiation and average water demand.

(b) Technical condition of the system

Solar generator - The concrete base foundation of the panel has failed in one corner. This has caused the array to tilt and three of the modules have cracked.

Convertor - The convertor is in sound condition and no failure has been reported.

Pump and motor - There has been no major failure and the pump is still operating. However, the operator noted that servicing of the pumping unit, has not been undertaken since the system was commisioned in 1981.

(c) Financial aspects

This solar pump project is an undertaking between the Government of Kenya, the French Government and the Ministry of Water Development (MOWD). The funding was undertaken by the French Government for all the equipment supplied and construction of the buildings to house the equipment. The borehole construction was undertaken by MOWD. The maintenance costs and revenue collection is the responsibility of MOWD.

The breakdown of the total construction costs (in 1981) as obtained from MOWD is as follows:

Borehole	125,000=
Solar system including pumps and accesories	1,040,000=
Building for equipment	42,600=
Fencing	28,000=
	1,235,600=
	=========

(d) Operational and maintenance problems

This system has had no major failures. It has been operating continously since commissioning. However, indications are that routine maintenance procedures have not been undertaken. Investigation revealed that, the operator is not aware of the consequences of the damage to the modules.

(e) Social and institutional aspects

This solar pump is located in Kahawa, some 25 Kilometers from Nairobi. The area consists of low-cost periurban residential housing with the majority of the inhabitants commuting to

Nairobi for their daily occupation. Public Services such as roads and electricity are available. The area is located at a distance from the Nairobi water supply, and hence MOWD drilled a borehole to supply water to the area.

This pumping system has been well received by the consumers. There are approximately 600 people supplied with water from this solar unit. Complaints of water shortages occur occassionaly during the cold period of May-August when the amount of water pumped cannot satisfy the demand.

The system is administered by MOWD and the general technical support is non-existant. This is reflected by the lack of routine maintenance procedures.

1.4 Chwele water supply

Chwele water supply project is located approximately 24 kilometers, north of Bungoma Town in Bungoma District of Western Province. It is an undetaking financed by the Government of Finland. The system uses photovoltaic power generated by solar panels to pump water from two horeholes to a ground level storage tank and an elevated pressed steel tank.

The elevated tank supplies water to the higher regions of the village whilst the gound level tank supplies water to the lower areas.

The water project was completed in August 1987 to supply water to Chwele Trading Centre, with a population of approximately 1000 inhabitants. There are approximately 150 consumer connection on a distribution system of 5.2 kilometres of pipeline.

The technical characteristics of the system are:

Solar Generator

Solar generator type (Module)	AEG PQ 10/40/0
Peak power at AM 1.5, 25°C, $100 mW/cm^2$ acc. to data sheet A47.44 (1183) DE/EN	3763,2 W
Total number of modules	98

Inverter

Inverter type	AEG SOLARVERTE 3 KVA
Rated output power	3,0 KVA
Rated output voltage	14 ... 127 V, 3 phase
Output frequency	5/6 ... 50/60 Hz
Rated input voltage	200 V DC

Submersible Pump

Pump type	CORA 4-89/22
Rated input voltage	127 V 3 phase
Max. pumping height	124.4 m
Rated pumping height	50 - 75 m
Rated pump output at pumping height of 70 m and 50 Hz	4,5 m^3/h

(a) Quantities of water pumped.

The system supplies water to the local villagers, and a secondary school. The operator is responsible for recording daily meter reading. During the various field visits the meter readings were extracted from the records book. The data was then analysed and compiled into average daily figures for a particular month as presented in appendix IV. However, the quantity of water may not be a true represatation of the capacity of the system. Since the project was commisioned at the onset of the study, it is

possible that as the number of individual connections increases, there shall be a corresponding increase in water consumed. Longer pumping hours will then be required to satisfy the demand. Figure 3 respresents the average volume of water pumped daily for every month since the installation of the system. The mean daily irradiation figures from the Mumias Sugar Factory (which is the nearest meteorological station to the system) are also plotted on the graph.

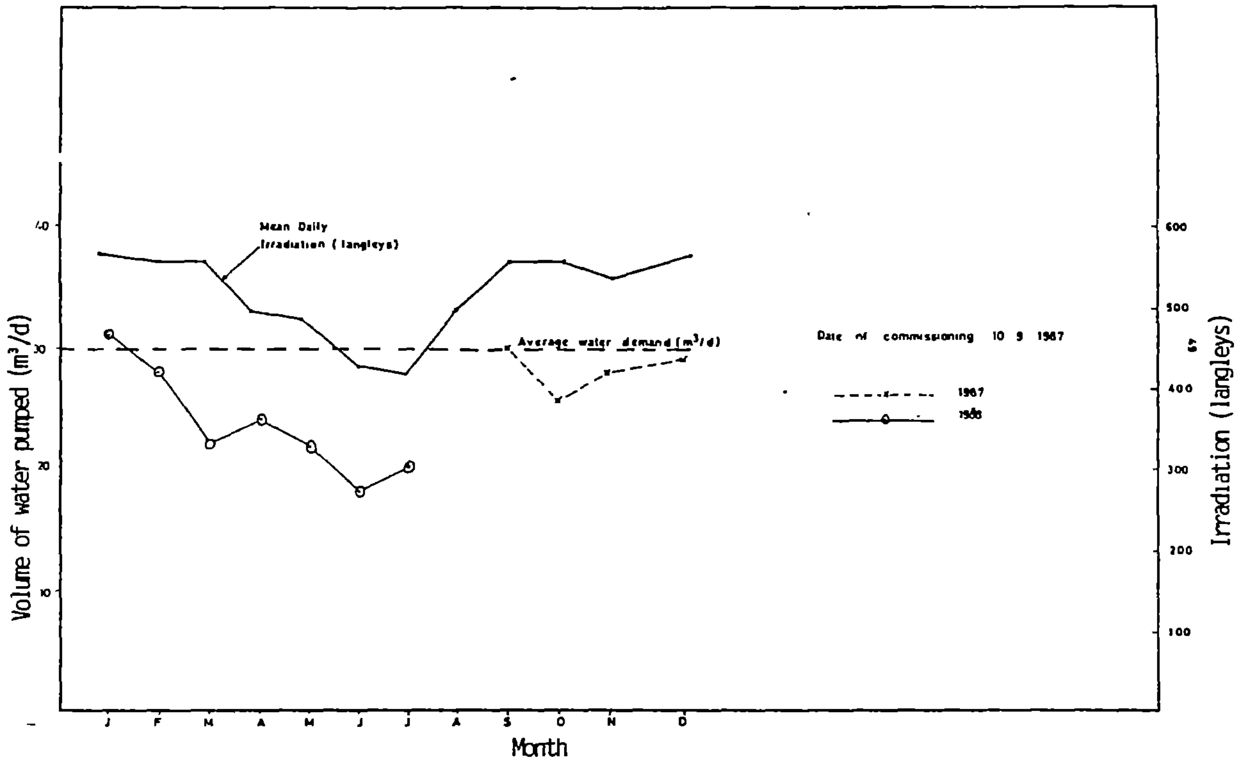

Figure 3. Chwele water supply - average volume of water pumped daily, mean daily irradiation and average daily demand.

(b) Technical condition of the system.

At the time of the field visits made to this installation, the scheme had been operating for a few months. Therefore, all the equipment was new and in sound operational condition.

(c) Financial aspects.

This solar pump project was an undertaking between the Government of Kenya represented by Ministry of Water Development (MOWD) and the Government of Finland. The complete funding of the project, including borehole construction, equipment, buildings, operation and maintenance is currently undertaken by Finnida.

The breakdown of the total construction costs (in 1987) as obtained from MOWD is:

Borehole (2No)	141,000=
Solar system including pumps and accesories	1,250,000=
Building and guard house	74,000=
Fencing	50,200=
Ground level tank (100m^3 Masonary)	210,000=
Total Costs	1,725,200

(d) Operational and maintenance problems.

Since this is a relatively recent solar pumping installation and the system is still under the maintenance of the financing agency. There are no maintenance problems to be undertaken by the end users, or the Ministry of Water Development.

(e) Social and institutional support

This solar pump is located in a remote rural trading centre. The inhabitants earn a livelyhood from subsistance farming and cattle rearing. Public and infrastructural services at a very low level.

This water scheme has been well received by the villagers of Chwele Trading Centre. The hardships of collecting water from the streams will be a thing of the past. The local community was partly involved with the project at the planning stage. However, their major involvement was on the issue of payment for individual connections and the procurement of the distribution pipework. A local committee was formed to collect revenue from consumers at the gazetted flat rate of Kshs 15/= per month. The institutional support is lacking, even though the operators are conversant with the system, they cannot be in a position to locate and rectify breakdowns without the specific training. The local supplier in Nairobi is responsible for undertaking the repairs.

1.5 Ololoitikoshi water supply

This water supply is located aplproximately 160 kilometres south of Nairobi. It is basically a private water system on a ranch rearing cattle. It was installed in early 1987.

The technical characteristics of the system is:
Rising main 50mm dia. UPVC
Suction pipe 50 mm dia UPVC
Storage 45 m^3 storage tank
Type of panels Arco Solar
Power output 1.5 KW
Pump grundfos SPZ-18
Max. pumping capacity 20 m^3/day
Manometric head 55m

(a) Quantity of water pumped.

The system supplies water for domestic and livestock consumption. During the field visits the meter readings were extracted from the records book. The data was analysed and compiled into average daily volumes for each month as presented in appendix V. The quantities were then plotted into graphical form as shown on figure 4. The mean daily irradiation figures for the nearest meteorological station are also plotted on the graph.

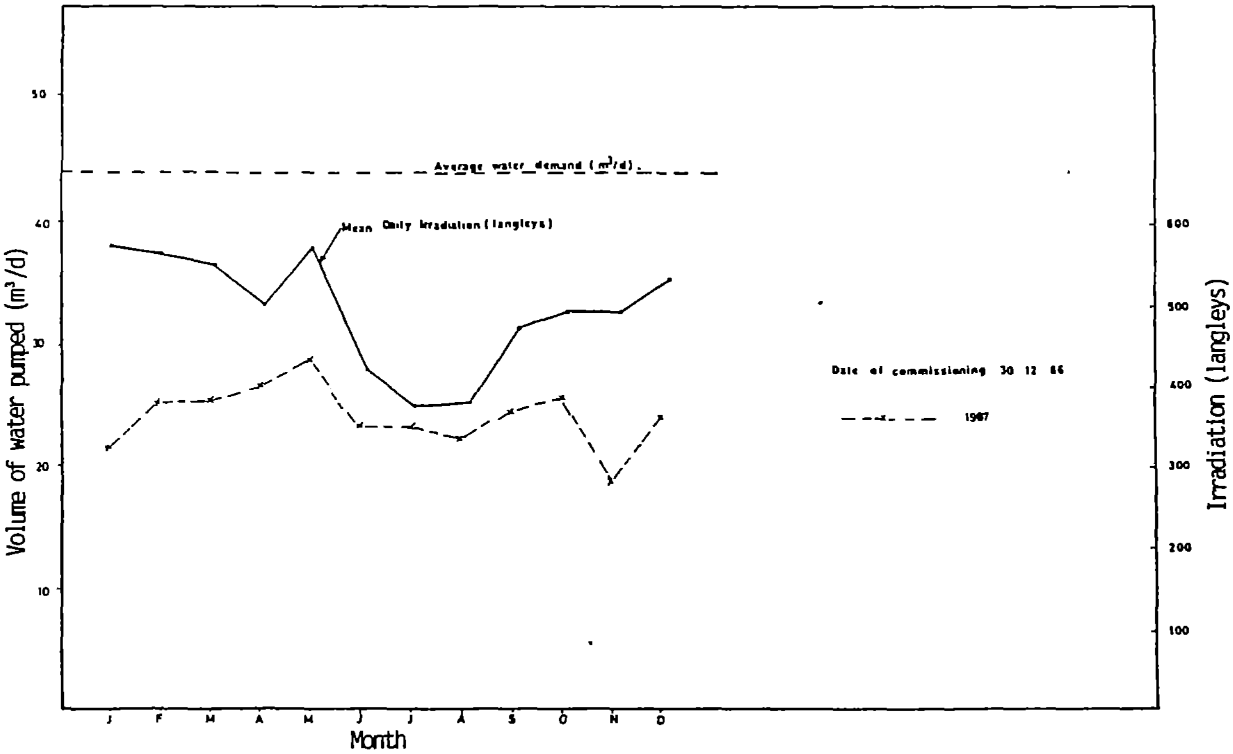

Figure 4.. Ololoitikoshi water supply: average daily volume of water pumped and mean daily irradiation.

(b) Technical condition of the system.

The photovoltaic array is in sound condition, there is no evidence of vandalism or structural failure on the supporting structures.

The convertor is operational and the pumpset is in working condition. The system in general is a good operating condition.

(c) Finance aspects

This solar pump was financed privately by the owners of Ololoitikoshi Ranching farm. The unit was purchased from and installed by a local supplier. The funding was by the management of the farm, including the construction of the buildings. The borehole was sank by a local contractor.

The total costs of the project according to the management is as follows:

Borehole	150,000=
Solar system including pumps and accesories	822,600=
Building and guard house	36,000=
Fencing	15,200=
Total Costs	1,023,600=

(d) Operation and maintenance aspects.

The system has had a number of failures. These have been confined to the electrical system. The converter has blown out two times and some electrical connections have frequently failed. The local suppliers however, have repaired the breakdowns. The operator however has not been able to pin-point the problem. The management expressed dissappointment over the long delays before the local suppliers repair the system, which is complicated for their local technicians.

(e) Social and institutional aspects

This solar pumping unit is located approximately 300 kilometers south-east of Nairobi near the Kenya/Tanzania border. The general climate is semi-arid with a relatively low annual reainfall. The unit is for domestic and cattle consumption. It is administered by the management of the ranch.

This solar pumping unit, has been a relief to the management of the ranch, which is rearing about 2500 head of cattle in the semi-arid region of Masailand. The end users are grateful that water for domestic and cattle consumption is not a daily problem. However, the supply is not able to meet the demand, especially in the dry months when the water table drops and water consumption increases.

The management is concerned that when the system breaks down, they have to spend several days to try and get the local supplier to come and repair the system. This is a time consuming aspect but however, they expressed satisfaction with the unit because the majority of the repairs are minor.

1.6 Kisingo irrigation scheme.

This solar water pumping unit, was installed with the primary objective of pumping river water to a large tree nursery. The water is utilized for irrigation of the young trees. The location of the nursery is in the dry region 250 kms south-east of Nairobi.

The irrigation method in use is the furrow method. The seedlings are planted and after six months they are distributed to local farmers for planting. The purpose of planting the trees is to reduce soil erosion in the area.

The technical characteristics of the system are:

Solar panels	:	Arco Solar 1.0 KW
Pump type	:	KSB Surface floating type
Max water output	:	$30m^3$/day
Total manometric head	:	10.0m

(a) Quantity of water pumped

The system supplies untreated river water for irrigation purposes. It is operated on a daily basis but the number of pumping hours depends on the water requirements of the plants. It is also used to supply water for domestic purposes to the labourers working on the project. The quantity of water pumped has been plotted and is presented in figure 5.

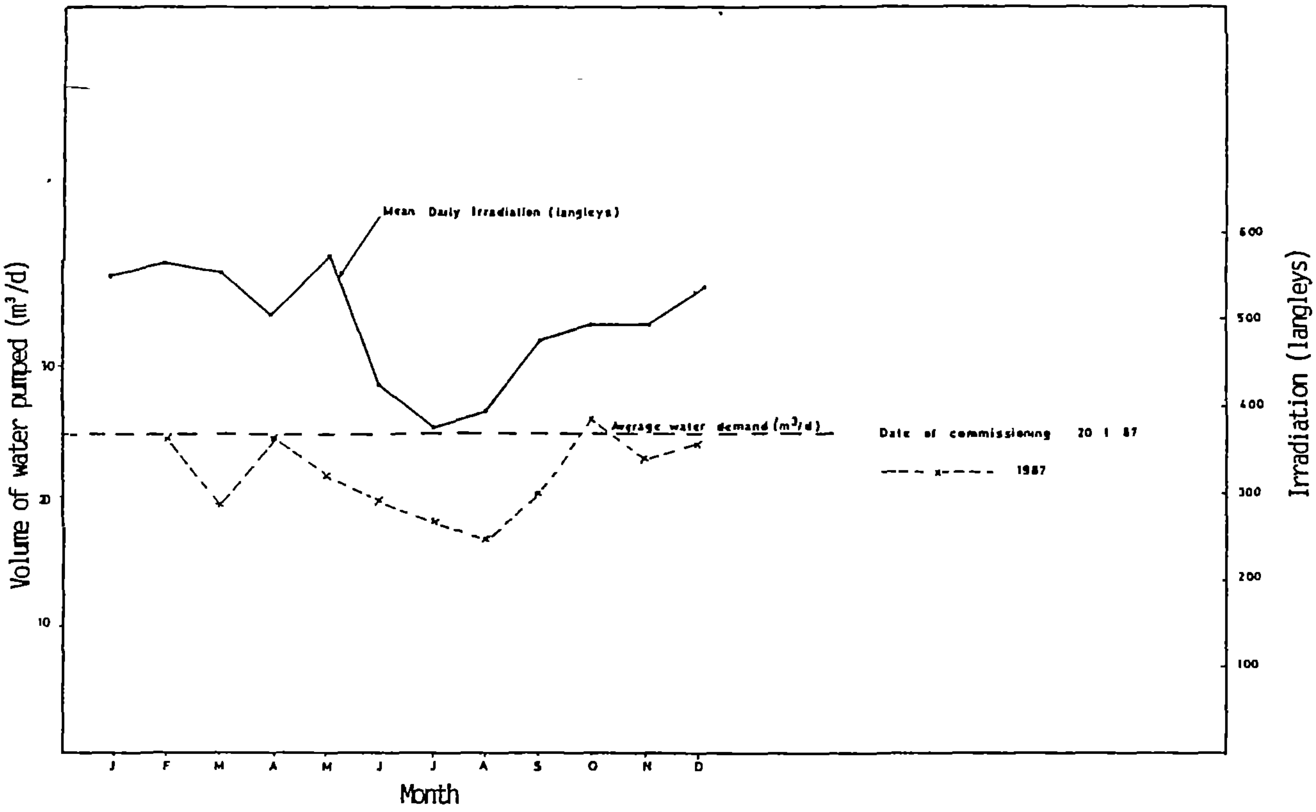

Figure 5. Kisongo irrigation scheme: average daily water pumped and mean daily radiation.

(b) Technical conditon of the system.

The system is in sound operating condition. The surface motor pump is portable and after operating during the day, it is dismantled and taken to the store. During the drier months when the water level in the river drops, the pump is fixed in a sump which has been constructed on the river bank. This ensurers that the water depth is adequate for abstraction by use of a pump.

(c) Financial aspects

This solar pump project is an undertaking between the Government of Kenya and the Government of Denmark represented by DANIDA. The equipment and construction fo buildings was undertaken by DANIDA. The breakdown of costs is as follows:-

Solar panel pump and accesories	758,000=
Buildings	74,500=
Fencing	32,800=
Total Costs	865,300=
	=========

(d) Operational and maintenance problems.

This solar pump is relatively new, and no failures have been experienced. The surface floating pump occassionally is cleaned when the strainer is blocked by floating material and debris.

(e) Social and instituional aspects

This surface water solar pumping unit operates under the supervision of the staff at the nursery. Therefore, day to day operation is well supervised. The unit has the advantage of ease of dismantling, when repairs on the pump are to be undertaken.

This solar unit has proved to be economical to the management of the project. The overhead and running costs are minimal. The labourers who get their supply of domestic water are benefiting greatly and the spouses can now spend their time working at the tree nurseries rather than spend long hours fetching water from the river.

There are plans to install another unit to increase the output at a future date. This indicates the confidence the management has on the pumping system.

1.7 Ilpatmaro solar pump

This solar pump is located in Ilpatmaro Ranch in Kajiado District about 25 km from Namanga Town on the Tanzania border. Ilpatmaro is a very dry area with hardly any streams and a lot of water is required by the local maasai for their livestock. The Solar model is the Arco Solar panel and invertor. The water is pumped from the 55 m deep borehole into a 90 m^3 masonary ground storage tank. The water is then fed into cattle troughs.

The operator explained that there has been electric problems with the inverstor, which has caused the local residents to use hand dug wells constructed in the dry river beds. This system is administered by the District Water Engineers Office, therefore maintainence funds are not readily available.

1.8 Matiga Agricultural Nursery Solar pump

This solar pump is installed on an agricultural tree nursery near Kibwezi. The water is pumped from a small dam near the nursery and used for irrigating the nursery. The pump is of a submersible type and the array output is 0.75 KW. The system is administered by the management of the Matiga Agricultural Nursery. Since it was commissioned in early 1985 there are no failures which have been experienced. However, during the long dry season the water level in the dam drops considerably causing the foot valve to clog frequently.

1.9 Bumala solar pump

This pump is located in Bumala Health Centre in Marachi location of Busia District. It was installed to pump borehole water to the health centre and is currently under the Ministry of Health. The system has not experienced any failures since commissioning and the Health Officer incharge expressed satisfaction with the performance of the unit, particularly the low operational cost required by the system.

1.10 Turkana solar pumps

Turkana is located in the arid area of Northern Kenya adjacent Lake Turkana. The area is extremely hot and the mean annual rainfall is 200 mm, which is too low for any meaningful agricultural farming. The inhabitants of the area are generally nomadic and their main occupation is livestock rearing and fishing in the lake.

An Italian Missionary Organization has been undertaking minor projects in the area to uplift the living conditions of the people of this region. The projects have included schools, dispensaries and water projects.

There are three water projects which utilize photovoltaic pumping. These are:

(a) Turkana Girls School

This photovoltaic pumping system supplies borehole water to the school. The pumps were commissioned in 1986 and the borehole pump delivers water to a ground level tank on a hill side approximately 1 kilometer away. From there the water gravitates down to the school and the adjoining village. The total system head is 25m and the maximum output is $5.5m^3$/hr. No major breakdowns have been experienced and the unit is good working condition.

(b) Loarengak village

This photovoltaic pumping system supplies borehole water to the nearby village. The pumps were commissioned in 1986 and the borehole pump delivers water to an elevated concrete tank. From there the water gravitates 9 km to an elevated steel tank at Loarengak. The supply is then conveyed to a health centre, a school and surrounding villages. The total system head is 20m and the maximum output is $5.0m^3$/hr. No breakdowns or failures have been reported and the system is in good working condition.

(c) Katilu Secondary School.

This photovoltaic pumping system supplies water to Katilu Secondary School. The system was commissioned in 1984 and the borehole pump delivers water to a 3 m^3 elevated steel tank from where the water gravitates into the distribution system of the school.

This solar pumping system has experienced several major failures with the pump motor, not starting on five different occassions. Each time the local supplier in Nairobi has been requested to undertake the repair work. The system was finally replaced with a new system after two years of operation. There was no technical explanation for the replacement but it appears that the system could have been faulty before it was installed.

APPENDIX II

KISERIAN SOLAR PUMP - Average monthly water pumped (m^3/d)

(Commisioned 22.5.83)

Month	Year 1983	Year 1984	Year 1985	Year 1986	Mean daily Irradiation
January		19	28	23	504
February		21	23	19	512
March		17	13	18	498
April		8	9	14	430
May		23	12	15	390
June	14	15	16	13	341
July	10	12	14	14	321
August	15	13	10	16	344
September	9	17	13	12	424
Octomber	-(N.D)	12	18	24	464
November	18	18	22	25	440
December	18	27	25	22	479

-(N.D)- No Data (System out operation)

* The mean daily irradiation in langleys (calories /cm^2) for each month corresponds to data collected by the nearest meteorological station. In this case the nearest station is The Kenya Meteorotogical Department at Dagoretti, Nairobi (Kenya meteorological Department, 1984).

APPENDIX III

KISERIAN SOLAR PUMP - Average monthly water pumped (m^3/d)

(Commisioned 22.5.83)

Month	Year 1983	Year 1984	Year 1985	Year 1986	Mean daily Irradiation*
January		19	28	23	504
February		21	23	19	512
March		17	13	18	498
April		8	9	14	430
May		23	12	15	390
June	14	15	16	13	341
July	10	12	14	14	321
August	15	13	10	16	344
September	9	17	13	12	424
Octomber	(N.D)	12	18	24	464
November	18	18	22	25	440
December	18	27	25	22	479

(N.D)- No Data (System out operation)

* The mean daily irradiation in langleys (calories /cm^2) for each month corresponds to data collected by the nearest meteorological station. In this case the nearest station is The Kenya Meteorotogical Department at Dagoretti, Nairobi (Kenya meteorological Department, 1984).

APPENDIX IV

KAHAWA SOLAR PUMP - Average monthly water pumped (m^{3}/d)

(Commisioned 16.3.81)

Month	Year 1982	Year 1983	Year 1984	Year 1985	Year 1986	Year 1987	Mean daily irradiation*
January	25	17	17	26	20	15	504
February	24	22	23	21	19	16	
March	26	18	19	23	17	14	512
April	14	23	15	14	21	12	430
May	25	17	9	11	12	9	390
June	10	(N.D)	14	6	5	5	341
July	7	(N.D)	3	4	7	2	321
August	5	(N.D)	3	11	8	4	344
September	11	(N.D)	17	17	9	8	424
October	(N.D)	18	15	16	13	12	464
November	12	21	19	14	12	14	440
December	17	20	23	18	14	18	479

(N.D)- No Data (System out operation)

* The mean daily irradiation in langleys (calories/cm^2) for each month corresponds to data collected by the nearest meteorological station. In this case the The Jomo Kenyatta Airport Station is the nearest station. (Kenya meteorological Department, 1984).

APPENDIX V

CHWELE WATER SUPPLY -Average Monthly water pumped (m^3/d)

(Commissioned 10.9.87)

Month	Year 1987	Mean daily irradiation*
January		569
February		556
March		561
April		519
May		503
June		489
July		474
August		507
September	30	562
Octomber	25	555
November	28	540
December	26	573

*The mean daily irradiation in langlesys (calories/cm^2) for each month corresponds to data collected by the nearest meteorological station. In this case the nearest station is Mumias Sugar Company Ltd. (Kenya Meteorological Department, 1984)

APPENDIX VI

KISONGO IRRIGATION SCHEME - Average Monthly water pumped (m^3/d)

(Date of Commissioned January, 1987)

Month	Year 1987	Mean daily irradiation*
January		547
February	24	567
March	20	556
April	24	512
May	22	582
June	20	428
July	18	383
August	16	390
September	20	480
Octomber	27	502
November	25	499
December	26	535

*The mean daily irradiation in langlesys (calories/cm^2) for each month corresponds to data collected by the nearest meteorological station. In this case the nearest station is Kampi ya Mawe. (Kenya Meteorological Department, 1984)