Solar Water Pump System
Tsavo East National Park
Kenya

Feasibility Study Report

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Table of contents

List of Figures

1. Introduction

Presented below is an analysis describing a feasible solution to curb the persistent threat to the elephant population in the Tsavo East National Park in Kenya. Motivation towards the solution's design came from the witnessing of tens of elephants amongst other animals giving up on life due to the lack of water in mid-2010. Besides a way around these misfortunate occurrences, the report also outlines a strategy intended in the reduction in human-elephant conflicts around the park.

A team of Electrical Engineering students from Imperial College London has suggested installing four solar water pumping systems in strategically chosen locations within the park. Four pumps are the initial proposition for a pilot study and upon further evaluation up to fifteen pumps could be installed in various points of the park. The aim is to provide additional supply of water, drawn from beneath the ground's surface. This simultaneously reduces the wandering of elephants out of the parks perimeters in search of water, a threat to human settlements and animals likewise. This paper aims to present the results from a feasibility study and to review the possible solutions using solar water pumping systems and the extent to which the issue could be resolved.

The report is structured in six sections with the introduction to the analysis being the first. The subsequent section describes the area under study, characterises the problem and justifies the choice of locations for the pumps, while the next concentrates on choosing appropriate components (types, sizes, models). This is followed by introducing additional technical solutions that would improve the performance and facilitate system maintenance in the fourth chapter. The penultimate section summarizes the economics of the equipment and attempts to foresee the benefits and possible problems arising from the implementation of pumps. Finally, the report concludes with a set of recommendations.

2. Outline of the Problem

2.1. The Area Under Study

Tsavo East National Park, one of the largest game parks in Africa, covers a surface area of 11,747km^2 and is located in the South Eastern parts of Kenya (2). It is home to many species of animal including the iconic African elephant (*Loxodonta Africana)*. Recent studies show that as at 2008 there were 11,700 elephants in the Park(3). Despite being an increase from previous years, it is as a result of tighter security measures against poachers. 2010, however, saw 38 elephants and 26 hippopotamuses among animals die due to drought. Various other species in the park are also threatened by drought: lion, zebra, buffalo and leopard to name a few.

The human population around the Tsavo ecosystem (an area of approximately 43 000 km^2 in the south of Kenya) had increased from 100 000 in 1948 to 400 000 in 1997(4), and this trend seems to have remained to date. Based on a sample of 312 people living in this area, research by S. Kasiki(5) found that almost 4 out of 5 work in agriculture, while the rest have paid jobs.

The park's climate is mostly dry with rainy periods from November to December and from March to May (4). The annual rainfall averages between 200-600mm, with an average of 95mm in the April-May period. The temperature variations are not so significant, the average low and high monthly temperatures being 24°C and 35°C respectively with February and March falling amongst the considerably warmer months(6).

Water sources in the park are limited (4). Natural sources include the Athi and Galana rivers and various other seasonal springs. Although these tend to generally have large volumes of water flowing through them, they are considerable distances from certain regions of the park. Small volumes of water were previously supplied by a wind-powered pump located in the Aruba region of the park.

2.2.The Human-Elephant Conflict

There are several reasons which account for the human-elephant conflict in some areas of Tsavo East. A recent study by R. Smith and S .Kasiki explains these (4). According to the authors, this conflict occurs mainly on the border between elephants' range and agricultural areas. When water or food is scarce, animals wander to areas outside the park.(5) Undoubtedly, this often means invasion of human settlements including damage of crops, loss of lives and destruction of feed for livestock.(4). The average number of elephants in a group is generally over 5(4), increasing the probability of harming people, livestock and destroying of crops.

The response from the local communities is varied, but the majority of people use repercussive measures to discourage the elephants from entering their farms. Fire, noise and spotlights are generally the defences used. However, animals may be shot at or poisoned too (4). Kasiki(5) claims that in some cases protecting crops with fences for example, exceeds the annual income of the household therefore deterring locals from such measures. Kenya Wildlife Service (KWS) also has a special unit to help with the problem, but their actions have proven to have an insignificant effect on the number of incidences (4).

According to the study, the average number of conflicts varies from season to season, the driest periods generally having the peak numbers (4). This further supports the deployment of solar water pumping systems in being a relief to the problem.

2.3.Finding the Appropriate Locations for Implementation

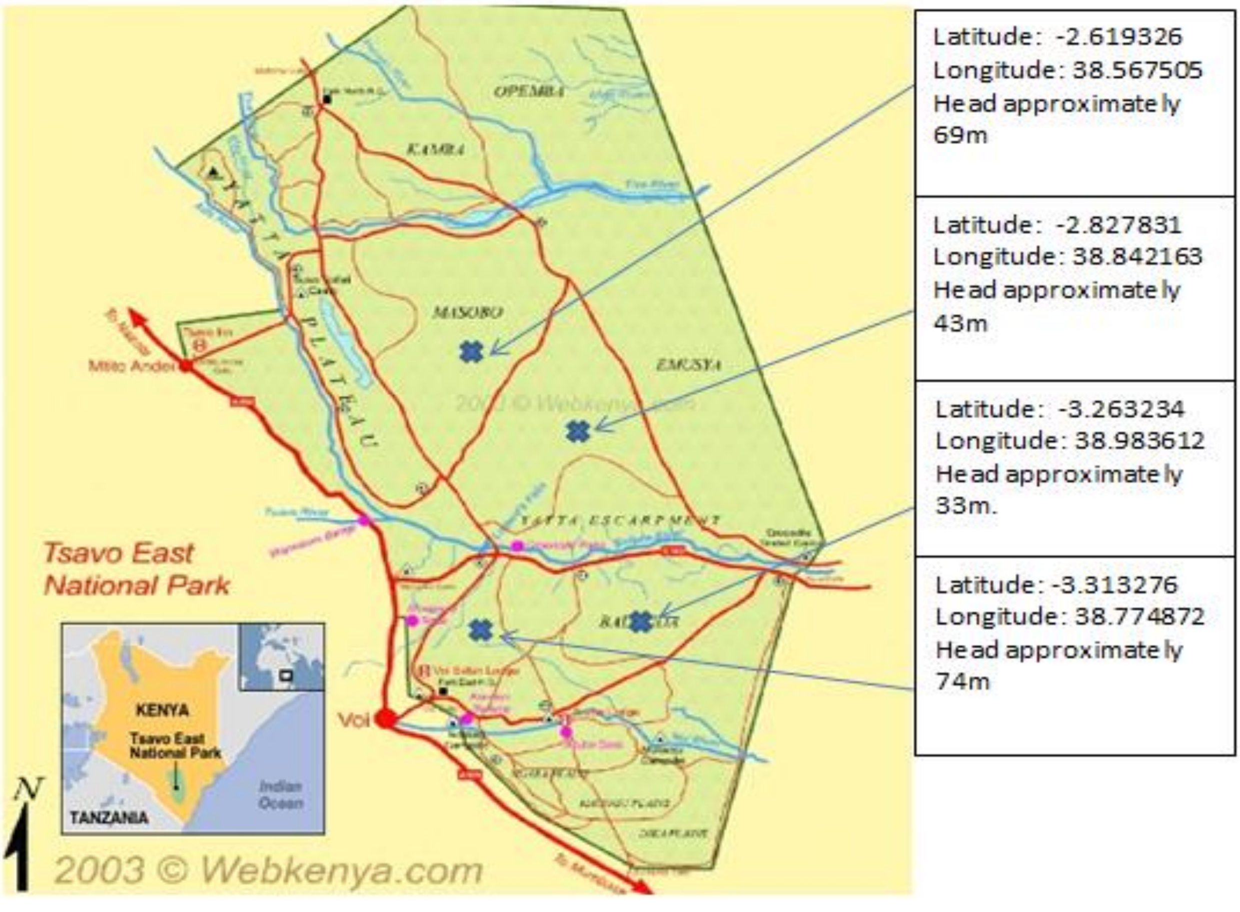


Fig 1. The location of the Tsavo East National Park in Kenya and the planned locations of solar-powered water pumping units.

The locations have been meticulously chosen in order to spread the availability of water over the park. They are also placed far from the borders to discourage animals from leaving park. It can be noted that the East-most points are at lower altitudes than the West, another characteristic in the pump and panel determinations. The data in this figure is what is later utilized in the determination of pump and panel sizes for each unit.

3. Design of the Solar Water Pumping System

3.1.The description of the system

The design of the system can be outlined as being in various major parts: an energy source, the pump and a borehole from which water attained flows into an artificially created reservoir of around $250m^2$. Specifics include solar panels that provide power to the pump alongside a water detection system that facilitates the maintenance process besides allowing remote control over the system and finally, a submersible pump placed in a borehole.

3.2. Energy Source

Choices behind the energy sources for pumping are limited having considered the circumstances for implementation. Greater reliability and lower running and maintenance costs (fuel supply and general breakdowns) are the main reason as to the choice of solar panels for this application. Another major benefit is the fact that the system is environmentally friendly, both in terms of noise and gas emissions. Wind power was also considered an option due its 24 hour pumping capabilities, but with the wind speeds noted (7), wind turbines are not economically feasible in comparison to solar panel arrays.

3.3. Pumps

Two basic pump types were considered: centrifugal and helical. These pumps are submersible, and are to be placed in a 6 inch borehole. Centrifugal pumps are generally considered for the boreholes with low static heads (8). This type offers high flow rates, whereas helical pumps are more efficient with low flow rates and high static heads and are also preferred when pumping greasy or dirty water(8). Our final choice relies on the helical pumps, due to the fact that the water will not be filtered before being fed into the pump.

Calculations are based on 20,000 litres per water point per day, which is considered enough for about the maximum daily consumption for 100 elephants. The average of 8.2 peak sunshine hours each day, so if we only consider the peak hours then an average flow rate of $2.4m^3$ /hour must be attained per water point.

Solar water pumps are currently produced by various manufacturers around the world. Having noted the pumping requirements, and the reliability factor we are wishing to attain, pump suppliers are limited to two: Lorentz and Grundfos. They were compared on the basis of performance and price.

The two pumps models bearing similar characteristics are Lorentz PS1200 (9) and Grundfos SQ-5A7(10). The Lorentz model has slightly better performances and is economically appealing. It is noted that Lorentz pumps have integrated maximum power point tracking (MPPT) controllers, thereby increasing overall efficiency.

3.4.Choosing the suitable pump model

Lorentz offers a range of solar water pumps that might be suitable for the purpose of our project. These are PS600(11), PS1200(9) and PS1800(12) whose characteristics are presented in the table below. To choose the most appropriate model for each of the sites, the power required to pump out water at a given rate was established.

The predicted sites for the devices have heads of approximately 33, 43, 69 and 74m. Only the latter two models can operate on the last two sites. In the calculations three different depths are used: 30, 40 and 70m.

Pump Model	PS 600	PS1200	PS1800
Max. Head lift	240m	240m	250m
Max. flow rate (m^3/hour)	2.7	2.7	4.0
Operating Voltage (VDC)	24-48	72-96	72-96
Min power required (for 30m head) (W)	840	840	720
Min power required (for 40m head) (W)	-	1200	1000
Min power required (for 70m head) (W)	-	-	1100

Fig 2. The characteristics of various Lorentz pump models with the power requirements found in the appendix A.

Based on a 20,000 litre ($20m^3$) per day volume, water for approximately 100 elephants can be supplied. This is assuming all the water is consumed on a daily basis, which is not routine for the elephants. The performance of the pumps (flow rate at given power input for a given head) is obtained from the product datasheets(9,11,12). Graphs in the Appendix A provide the minimum power input for the pumps, at which they meet the pumping requirement. The results of these estimations are given in the table. It is also noted that not all pumps can supply the required amount of water for some heads, rendering it impossible to find power demand.

It can be seen that the PS1800 requires the least amount of power, however is not taken into consideration as it is the more expensive option of the three.

Factors we considered during determination of the pump sizes include water evaporation rates from the water body and its seepage through the ground. The effects is not very significant, in the worst case scenario, using the Penman equations(13), it is revealed that for a water body of around $250m^2$ around 10% of the water pumped daily is lost to the atmosphere. Seepage through the ground is insignificant to the amount of water in the body.

3.5.Choosing an optimal tilt angle to receive maximum radiation

Efficiency is one of the most important factors that should be considered in the systems design. Lower efficiency signifies lower levels of water pumped therefore a reduction in overall performance. A good way to improve it is adjusting the tilt angle of the solar panel to maximize the power output and thus the amount of water pumped every day.

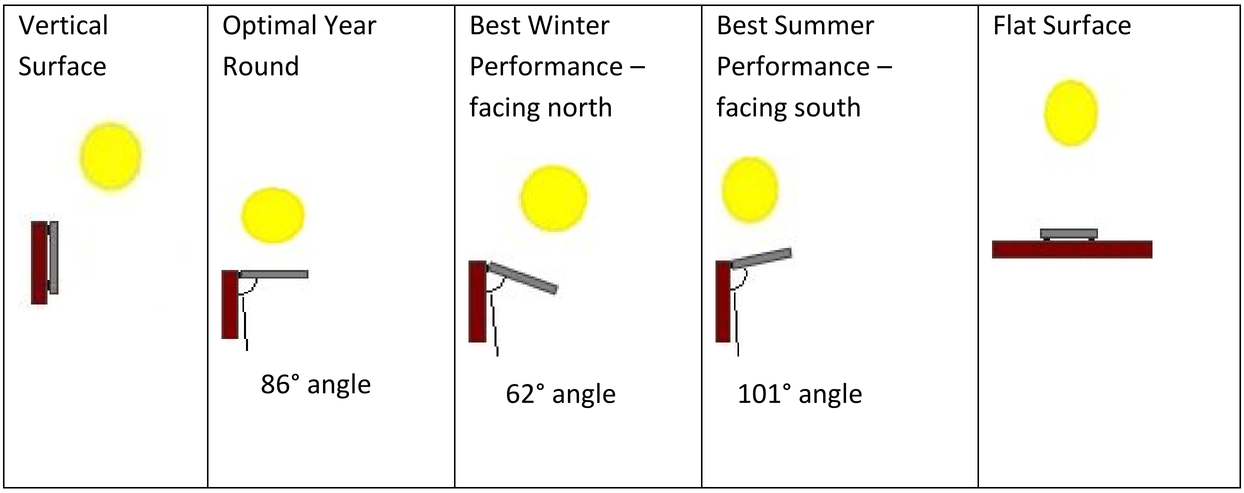


Fig. 3. The various positions of a panel with respect to the vertical surface that were considered.

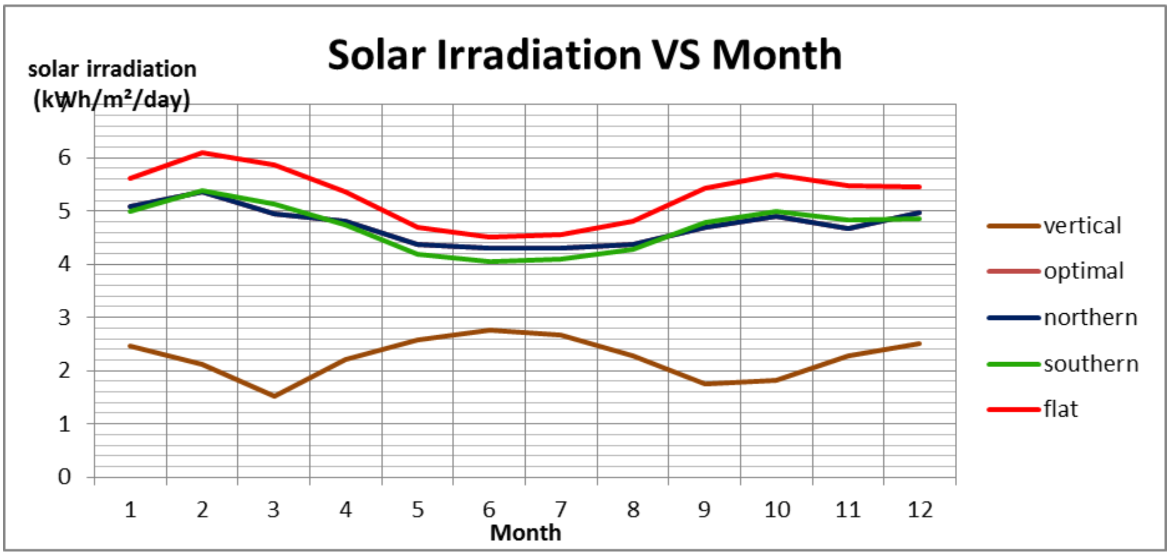


Fig. 4. The diagram of solar irradiation per square meter per day for different positions (from figure 3) of the solar panels.

The graph (figure 4) shows the solar energy incident per square metre of solar panel at various tilt angles per day (the details of these calculations can be obtained in Appendix B). It is visible that the most efficient position is almost flat; however, the solar panels would be placed at a 4 degree angle from the horizontal, as seen in the graphs in appendix X, the optimum position in order to receive maximum radiation at solar noon. Another reason not to install the panels exactly horizontally would be so as to not accumulate as much dirt. The 4 degree angle also allows rain to wash this away as well.

3.6.Choosing the Size and Number of the Panels

Most solar panels used for providing ~1kW power output are crystalline-silicon panel. Efficiencies range between 10 and 20 per cent for the same. The comparison of efficiency of different types of photovoltaic cells is given in the table.

Type of Photovoltaic Cell	Efficiency (%)	Costs
Silicon - Monocrystaline	18-24	High
Silicon - Polycrystaline	13-17	Moderate

Fig 5. Comparison of the most popular types of photovoltaic cells.

Based on the data given in the table, the best compromise will be to use poly-crystalline photovoltaic cells to reduce the cost of each station and provide good efficiency. From table one can see that the main requirements for the panels is to provide voltage of 72-96 V and a power of 900-1100W. A good compromise is using a number of panels connected in series to meet the power and voltage demand. Many manufacturers offer products that can produce voltage of 12V, which means that the predicted number of panels that will supply the voltage would be between 6 and 8.

A solar panel that can meet the requirements is offered by Mitsubishi Electric(14). Its power output can vary between 120 and 130 W and the voltage supplied per panel is approximately 12V. The details of how many panels are used for each site vs. their power output can be found in the cost estimation section (Chapter 5).

4. Water Level Detection System

In order to guarantee a plentiful supply of water at all times, a mechanism that can control the pumping of water and detect the level of water in both the borehole and that in the water body can be implemented (15). This will also to serve as a monitoring system for the parks wardens. Another benefit of such a technique is to avoid water overflowing.

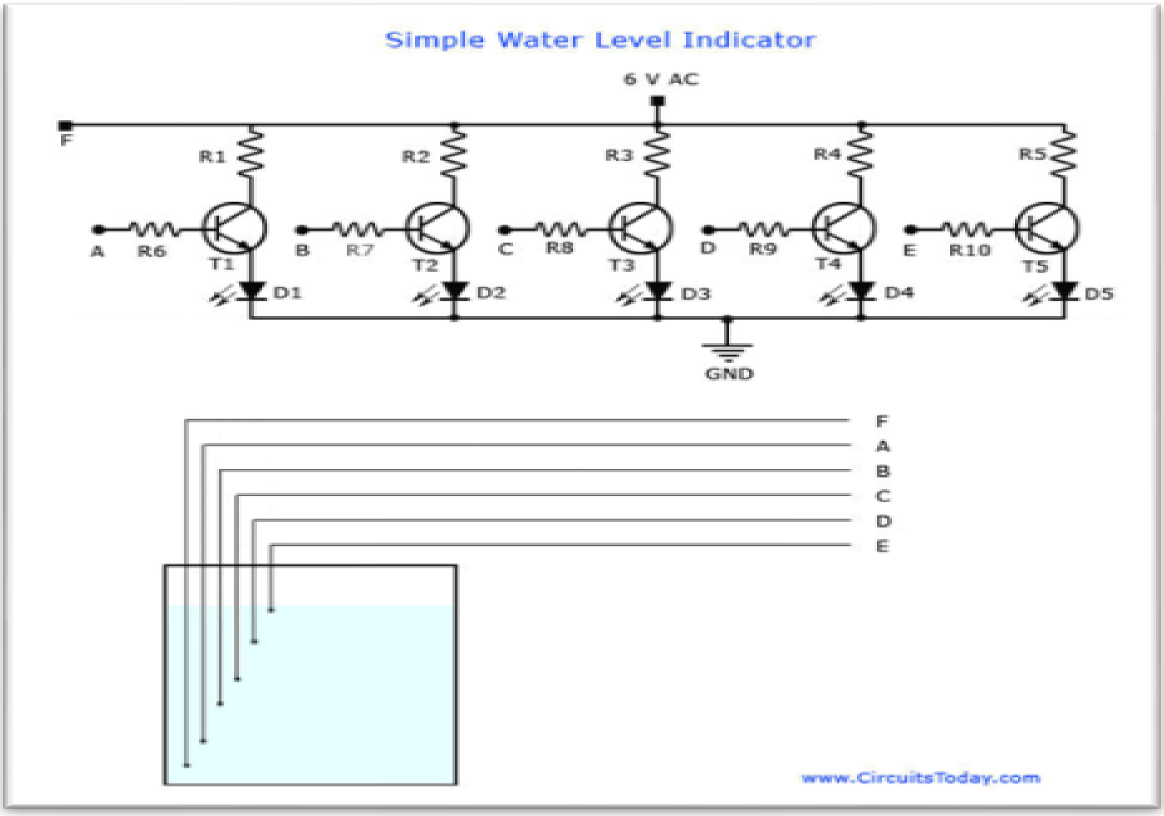


Fig 6. A schematic diagram of a water level indicator.

A GSM-based dialer serves as the communication channel between electronic switches (which control the pump) and the parks wardens, who can remotely control the pump. In the case where the level of water falls below a certain threshold, a message in the form of an SMS is sent to the warden who remotely activates the pump. The same structure works in the opposite way: too high water levels, can call for pump deactivation. The pumps used have dry-running protection, therefore eliminating the need to detect the water levels in the borehole.

In the simple indicator circuit described above, the probe at F has to be always immersed in the water, as this connects the rest of the probes via the 6V AC.

Depending on the water level, a corresponding transistor base has a voltage flowing through lighting up the LED. In the design, the LED would be replaced with a simple connection to the GSM controller which could hereby send an SMS. The circuit could be adapted to use only three transistors to give indications of three water levels.

The Global Water WL450 transmitter model(16) is chosen together with the GD04 Universal GSM Dialer(17) developed by Quicksafe Security Systems. The device supports up to four input terminals, and could be adapted to have two for the borehole and another two for the water body. These devices could be powered using a 10Ah battery that is charged by the solar panel during the day.

5. Economic Feasibility and Project Costing

Quantity	Item	Cost Per Unit	Discount	Total Cost (KSHS)
	Location with 33m Head			
1pc	Lorentz PS600c Submersible Pump	208800	35%	135000
7pc	120W PV-UE120MF5N Mistubishi Panel	32000	25%	168000
1pc	GSM Dialer and Transmitter	62000	10%	55800
1pc	Locally Manufactured Panel Support Structure	12000		12000
35m	CUL40 Griflex Delivery Hose	800	40%	16800
10m	CS40 Heavy Duty Griflex Suction Hose	2000	55%	31500
	Total Unit Cost			**419100**
	Location with 43m Head			
1pc	Lorentz PS1200c Tracked Submersible Pump	214000	35%	139100
7pc	120W PV-UE120MF5N Mistubishi Panel	32000	25%	168000
1pc	GSM Dialer and Transmitter	62000	10%	55800
1pc	Locally Manufactured Panel Support Structure	12000		12000
44m	CUL40 Delivery Griflex Hose	800	40%	21120
10m	CS40 Heavy Duty Suction Griflex Hose	2000	55%	9000
	Total Unit Cost			**265920**
	Locations with 69m and 73m Heads			
2pc	Lorentz Ps1800c Tracked Submersible Pump	252000	35%	327600
16pc	PV-UE130MF5N Mistubishi Panel	32000	30%	358400
2pc	GSM Dialer and Transmitter	62000	10%	111600
2pc	Locally Manufactured Panel Support Structure	12000		12000
140m	CUL40 Delivery Griflex Hose	800	40%	67200
20m	CS40 Heavy Duty Suction Griflex Hose	2000	55%	18000
	Total Cost for 2 Units			**894800**
	Misc. items such as cement, electrical cabling,			
	connectors	F.O.C		
	Transport from Malindi to Tsavo Locations	F.O.C		
	Installation of Units + Testing Phase + Labour	F.O.C		
	Costs over 3 Days			
	Borehole Drilling in 4 Locations	F.O.C		

	Prices Include VAT Quoted in Kenyan Shillings for 4 Complete Units Installed & Tested			1,579,820
	Approximate Quote in £ GBP **£1 = 135 KSHS**			**£11,702**

Fig 7. The summary of costs of each site and total cost of implementation of 4 pumping stations. KSHS – Kenyan Shilling.

Transport costs are to be covered by Milano Electronics Ltd, a local Kenyan company who has kindly agreed to fully sponsor this(18). Installation and testing costs will be covered by Davis and Shirtliff, who have also agreed to fully sponsor the borehole drilling. Similarly, airline tickets will be provided by local airline company Kenya Airways who agreed to cover ticket costs excluding taxes for up to 3 students. Lodging for 3 students will also be provided at the KWS Voi Headquarters. Also to be noted, discounts mentioned are as per agreements with manufacturers and suppliers, both in UK and in Kenya and prices quoted are 16% VAT inclusive, where VAT amounts could be claimed back in the case where invoices are made in the name of the KWS.

Maintenance has been agreed with Davis and Shirtliff, for an annual fee of 15000Kshs for 4 pumps, per visit to the park + additional material costs if required.

Admittedly, our research revealed that the project is economically and practically feasible. The KWS, in a meeting held in December 2011, are of the opinion that it could be practically possible to implement the system as the above designed. Applying for funding and sponsorship in the UK revealed various unexpected responses. This is mainly due to the fact that most charities and organisations are based on caring for humans and not for animals. However, we still feel that it could be possible to set-off the project, with aid from world bodies such as the WSPA in collaboration with the KWS.

That aside, the system designed could also be slightly modified for use in various other applications, where the pump-panel arrangements could be used. For example, in the Dadaab region of Northern Kenya(19), which currently hosts the world’s largest refugee camp, with around 500,000 refugees struggling to live due to inadequate water supplies. Another place could greatly benefit from the design is the Footprints Orphanage in Shimba Hills, Kenya. This is the home to 20 orphans aged 1-5 who attract various sicknesses due to the lack of supply of clean water(20).

Minor modifications to the system’s design would be needed to adapt to the other locations. Various companies contacted are happily willing to help with the project if humans or children are to benefit from the implementations.

6. Conclusions

Numerous ideas initially sprang into action when a co-author of this report eye-witnessed an animal-as immense as the African Elephant-writhe on the floor, in agony in the Tsavo East National Park in mid-2010. This is the more reason why reality was taken to be one of the most influential aspects behind which research was carried out in this study. Having characterised the problem, aspects such as low noise levels, high efficiency and maximum reliability took control over the entire design process. Admittedly, this is why solar power and submersible helical pumps remain as the final choices.

The project analysed above concludes to be of substantial feasibility both physically and economically. Initially, various senior scientists and park wardens in the KWS were approached; whose promising feedback enhanced the remaining parts of the study. Solar panels, though currently rather expensive, are indeed the best way forward for an implementation of this nature. Pump choice, one of the most rigorous and demanding parts of the project, remains with the Lorentz brand, with notable success rates in the submersible pump industry. Similarly, predicted outcomes from the implementation are indeed affirming, in regard to both elephants and the humans living around the park alike. The idea of being able to provide such volumes of water with a simple arrangement such as this supports this equally.

Water, as everyone knows, is the most fundamental resource. Its provision is a gift to some, to others it is actually a commodity to be cherished. This is the basis of our work, the reason why one should attach value to a project such as the aforementioned. The quenching of "Tsavo's Thirsty" could indeed be used as a pilot program, after which similar implementations could be carried out world-over, in any environment.

References

(1) Greenstream Publishing. *Solar Electricity Handbook.* [Online] Available from: http://solarelectricityhandbook.com/solar-irradiance.html [Accessed 18th February 2012].

(2) Kenya Wildlife Service. *Tsavo East National Park.* [Online] Available from: http://www.kws.go.ke/parks/parks_reserves/TENP.html [Accessed 22 January 2012].

(3) Korir D. *A personal conversation with R. Vagani.* Personal communication. 16th December 2011.

(4) Smith RJ, Kasiki SM. *A spatial analysis of human-elephant conflict in the Tsavo ecosystem, Kenya.* Kent, United Kingdom: University of Kent, Canterbury; 2000.

(5) Kasiki SM. *Human-elephant conflicts in areas adjacent to the Tsavo National Parks, Kenya.* PhD Thesis. University of Kent; 1998.

(6) Ngoru B. *A personal conversation with R. Vagani.* Personal communication. 19th December 2011.

(7) Harries M. Disseminating wind pumps in rural Kenya-meeting rural water needs using locally manufactured wind pumps. *Energy Policy* 2002;30(11-12): pp. 1087-94.

(8) Vick BD, Nolan Clark R. Determining the Optimum Solar Water Pumping System for Domestic Use, Livestock Watering and Irrigation. In: Campbell-Howe R. (ed.) *ASES National Solar Conference 2009, 11th-16th May 2009.* Buffalo, New York, USA: American Solar Energy Society; 2009.

(9) BERNT LORENTZ GmbH & Co. KG. *PS1200 HR/C Solar-operated Submersible Pump System.* [Online] Available from: http://solar.astra.bg/images/p_pump/lorentz_ps1200_hrc_en.pdf [Accessed 18th February 2012].

(10) Grundfos. *SQFlex - Data Booklet.* Bjerringbro, Denmark: Grundfos.

(11) BERNT LORENTZ GmbH & Co. KG. *Ps600 HR/C Solar-operated Submersible Pump System.* [Online] Available from: http://www.lorentz.de/pdf/lorentz_ps600_hrc_en.pdf [Accessed 18th February 2012].

(12) BERNT LORENTZ GmbH & Co. KG. *PS1800 Centrifugal Pumping System. General Data and Sizing Tables.* [Online] Available from: http://www.solartronic.com/download/ps1800.pdf [Accessed 18th February 2012].

(13) Cuenca R, Nicholson M. APPLICATION OF PENMAN EQUATION WIND FUNCTION. *Journal of the Irrigation and Drainage Division* 1982;108(IR1): pp. 13-23.

(14) Mitsubishi Electric. *UE4 Specification Sheet 115-130W.* [Online] Available from: https://www.mitsubishielectricsolar.com/pdfs/UE4%20Specification%20Sheet%20115-130W.pdf [Accessed 18th February 2012].

(15) Johari A. Tank Water Level Monitoring System using GSM Network. *International Journal of Computer Science and Information Technologies* 2011;2(3): pp. 1114-1115-1120.

(16) Global Water. *WL450 All Stainless Level Transmitter.* [Online] Available from: http://www.globalw.com/downloads/wl400/wl450B.pdf [Accessed 19th February 2012].

(17) Quicksafe Security Systems. *GD04 Universal GSM Dialler.* [Online] Available from: http://www.quicksafe.co.uk/gsm-dialler.htm [Accessed 19th February 2012].

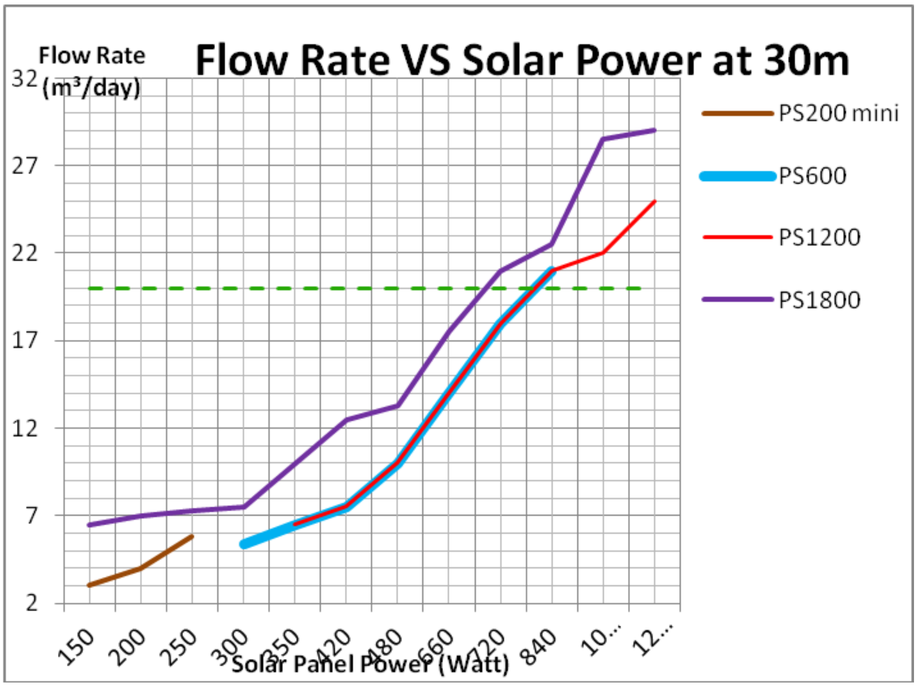
(18) Milano Electronics Ltd. Malindi, Kenya. *Personal communication with R.Vagani.* Personal communication. 21st November 2011.

(19) Humanitarian Accountability Partnership. *HAP in Dadaab (Northern Kenya).* [Online] Available from: http://www.hapinternational.org/projects/field/hap-in-dadaab.aspx [Accessed 19th February 2012].

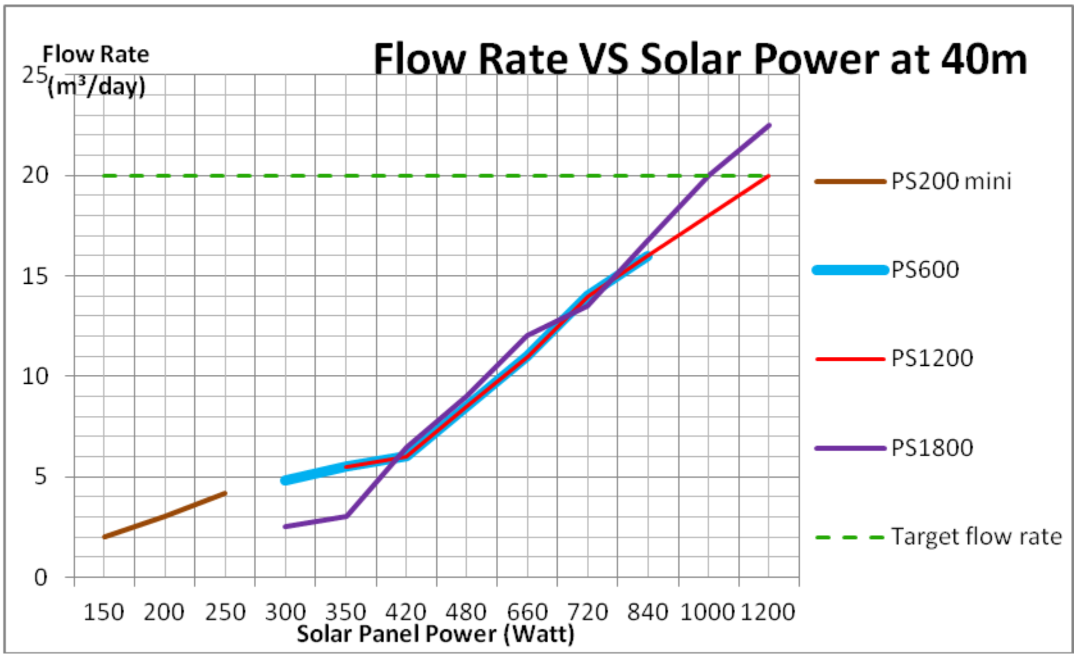
(20) Footprints Orphanage. *Our Progress.* [Online] Available from: http://www.footprintsorphanage.com/project.php [Accessed 19th February 2012].

APPENDIX A – The Graphs of Flow Rates of Various Models of Pumps versus Power Input from the Solar Panels

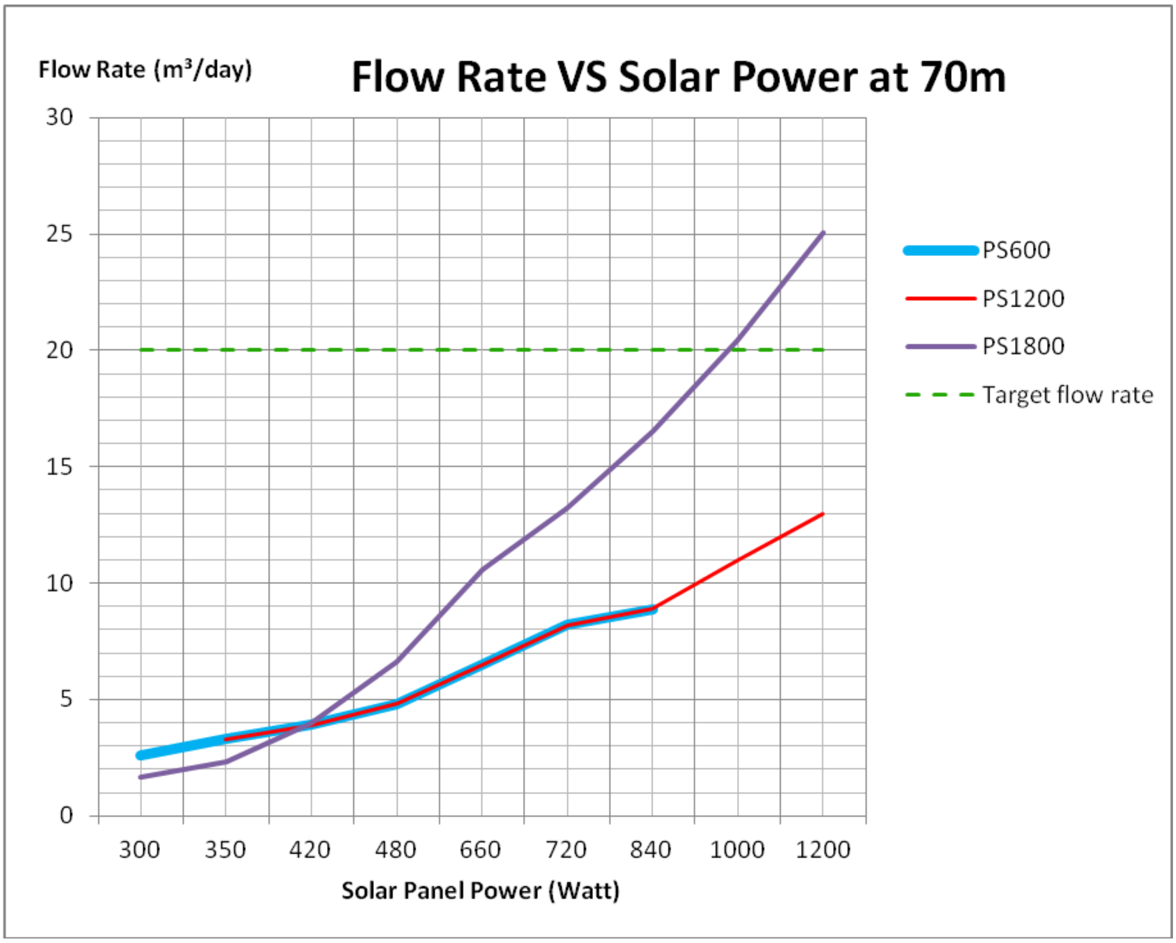
In order to find which model of Lorentz pump is the most suitable for each site the data from the sizing tables for given models were taken and plotted against the power input from the solar panel. It was compared with the daily demand of 20m^3 per day to see which pump is the most efficient.



Flow rate of different models of Lorentz pumps for a head depth of 30m.



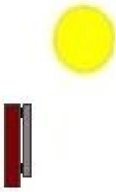
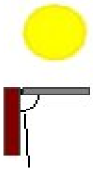
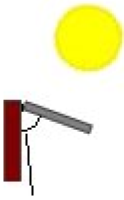
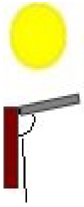
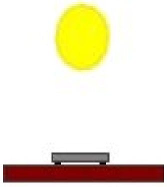
Flow rate of different models of Lorentz pumps for a head depth of 40m.



Flow rate of different models of Lorentz pumps for a head depth of 70m.

APPENDIX B – Solar Irradiation Data

These are the data of average solar power in Kenya, Mombasa measured in $kWh/m^2/day$

MONTH	POSITION OF SOLAR PANEL					
	Vertical Surface 	Optimal Year Round  86° angle	Best Winter Performance  62° angle	Best Summer Performance  101°	Flat Surface 	Optimum Tilt of Solar Panel by month
	Irradiation $kWh/m^2/day$	Irradiation $kWh/m^2/day$	Irradiation $kWh/m^2/day$	Irradiation $kWh/m^2/day$	Irradiation $kWh/m^2/day$	
JANUARY	2.46	5.08	5.08	4.99	5.62	70°
FEBRUARY	2.11	5.36	5.36	5.39	6.11	78°
MARCH	1.51	4.95	4.95	5.13	5.87	86°
APRIL	2.22	4.8	4.8	4.74	5.36	94°
MAY	2.57	4.38	4.38	4.19	4.7	102°
JUNE	2.76	4.31	4.31	4.05	4.51	110°
JULY	2.66	4.31	4.31	4.09	4.56	102°
AUGUST	2.28	4.38	4.38	4.27	4.81	94°
SEPTEMBER	1.76	4.69	4.69	4.78	5.44	86°
OCTOBER	1.83	4.91	4.91	4.99	5.68	78°
NOVEMBER	2.28	4.68	4.68	4.84	5.47	70°
DECEMBER	2.52	4.96	4.96	4.85	5.45	62°

Data obtained from http://solarelectricityhandbook.com/solar-irradiance.html