# Development of Climate Smart Solar Powered Irrigation System for Improved Livelihoods in Garissa, Kenya

**J. O. Odhiambo[1], B. O. Odhiambo[2]**

*[1]Principal Technologist, Department of Environmental and Biosystems Engineering, University of Nairobi, P.O. Box 30197-00100 Nairobi, Kenya*

*[2]PhD Graduate Student, Department of Environmental and Biosystems Engineering, University of Nairobi, Nairobi, Kenya, P.O. Box 30197-00100 Nairobi*

---

**Abstract -** *The development of a Climate-smart, solar powered, water pumping, surface irrigated banana production systems is demonstrated as a sustainable means of transforming and re-organising a rain-fed, food aid dependent pastoral community into a commercially oriented financially independent, food secure agro-pastoral livelihood system. Irrigation using solar energy is progressive and currently benefits from affordable high efficiency photovoltaic modules. The system designed and developed in Garissa Kenya generates 23kW of electrical power from a 57-255W polycrystalline Photo Voltaic modules and a sun tracker system. The Photo Voltaic modules tap the available 6 kWh/m² solar insolation in the area to drive a 80 m³/hour; 52 m rated pump to draw Tana river water and deliver it through a 200mm transmission pipe system for final in field application through furrows in a 25 ha banana plantation supporting some 25 households. The system is easy to operate and maintain and generates a gross income of Kenya shilling 40 million per year transitioning households from food aid dependency into secure middle income status. The system demonstrates a scalable model of a climate smart financially and technically sustainable livelihood transitioning system applied to scale.*

***Key Words*: Climate-smart agriculture, solar, irrigation, resilience, Garissa, Kenya**

## 1. INTRODUCTION

Food security is a worldwide concern. Better part of sub-Saharan Africa is categorised as food insecure when both household level consumption indicators as well as individual indicators of the status of nutrition are measured [1,2]. Due to Africa`s rapidly growing population, meeting her food needs will require adopting technologies which are capable of significantly improving the rural livelihoods without adversely affecting the environment. Most communities in the rural areas are food insecure and they rely mainly on rain-fed agriculture for food production with Garissa, Kenya receiving an annual effective rainfall of 274.2 mm. Smallholder food production in the rural is normally characterized by low returns as a result of erratic rainfall and poor yields which are both projected to worsen because of climate change [3]. The effect of drought is evident in Garissa County in terms of reduced and unpredictable rainfall, unpredictable flooding and prolonged drought. These will lead to low productivity in livestock and total crop failure as a result of water logging and heat stress [4].

The part played by irrigation in food security has widely been investigated; with smallholder irrigation pinpointed to be key in improving food security and for climate adaptation [5]. According to FAO [6] irrigation is one of the strategies will improve yields and decrease the vulnerability to the unpredictable patterns of rainfall. It helps to ensure food security, provides job, generate income and has driven rural development. Kenya has an irrigation potential estimated at 1.2 million hectares based on water resources, land suitability, cropping patterns and the irrigation technologies used. By 2017, about 200,000 ha have been developed for irrigated agriculture through financial investments from the government, development partners, farmers and private firms. Productivity in most developed schemes is not competitive, and water use efficiencies are low. Use of inappropriate irrigation technologies, inefficient irrigation systems, and inadequate extension, inadequate financial and marketing support services are some of the reasons advanced for poor performance of public irrigation schemes.

Smallholder farms are normally about 1 hectare on average and mainly in the rural areas [7]. The farmers here cannot afford initial high investment costs of the system inputs such as purchase of pumps and generators. Also, the ever increasing fuel prices as well as maintenance costs are out of reach for the poor farmers [8]. Due to these factors coupled with environmental concerns, there is the need to put more emphasis on technologies that promote renewable energy as well as innovative financing models. Photovoltaic is a proven technology with a network of industries all over the world.

Solar-powered irrigation is becoming of interest around the world. This is evident from the increasing frequency of requests for financing, training and installation especially from the agricultural institutions in developing countries [9]. PV water pumping systems have greatly advanced from its first installation in the late 1970s with this advancement starting with centrifugal pumps which were powered by motors with direct current or motors with alternating current of variable frequency through to the introduction of positive displacement pumps [10]. Currently, solar pumping technologies have advanced to more intelligent electronic software which has enabled the systems to have increased performance, power output and overall efficiency. Electronic controllers have been incorporated into the new solar pumping technologies where they adapt the power available from the PV generators to the solar-powered pump. It has also introduced real-time observation and monitoring the parameters of source and sink levels of water [9].

The photovoltaic systems are considered cost effective in terms of electricity provision to remote and rural farms, livestock and wildlife ranches as well as other systems of agriculture within the enterprises [11]. Water pumping systems that are solar-powered can either be battery-coupled; when power storage is required since electricity current is mainly produced from the photovoltaic modules at day time when there is sun and stored for use during night. Alternatively, it can be a directly-coupled system in which the electricity produced is conducted to the pump from the PV modules, that then pumps the water to the point of use through a pipe or canal system [12]. For Africa, solar energy should be of interest as the continent receives over 2000 kWh of annual global solar radiation [13].With this high potential solar energy, this project design exploited this resource to provide photovoltaic water pumping for surface irrigation for banana production in Garissa, Kenya.

Garissa County is an arid area and it is one of the areas in Kenya that have been hard-hit by the droughts; for example in the late 2009 through 2010, over 10 million people were at the risk of hunger after crops failed as a result of drought in the country [14]. This drought was described as the worst drought in 60 years in the Horn of Africa. This situation was devastating that it drew attention of the entire Kenyan nation leading to formation of *Kenyans for Kenya Initiative* with Kenya Red Cross Society at its lead which was aimed at mobilizing corporates and members of the public to raise Kshs.500 million within one month towards relief for over 3 million Kenyans faced with starvation in the Northern part of Kenya, Garissa county included.

High climatic variability is a key characteristic of arid and semi-arid areas of Kenya. This is normally manifested by the unpredictable and erratic rainfall in terms of the distribution and even its onset as well as quantity [15]. The intensities of climatic occurrences like floods and droughts are expected to accelerate in the sub Saharan Africa region [16]. Kenya has suffered from the impacts of droughts which have occurred in circles with the recent circles being those in 1983-4, 1991-2, 1992-3, and 1995-6, 1999-2000, 2005-2006 and 2008-2010. The droughts are usually associated with loss of lives;-both human and animal, loss of crops and displacement of populations. These recurring droughts worsen the situation leading to food insecurity. Over 80% of Kenya in terms of land mass is categorised to be ASALs characterised by unreliable and erratic occurrence of precipitation. ASAL environment is very fragile and the continued intensity and frequency of climate risks of droughts are envisaged to be higher in the years to come as a result of climatic changes and variability, this makes life in ASALs very unbearable [15]. Climatic variability directly affects production of agricultural produce with a direct ripple effect on food production and security since majority of Kenyans live and derives their livelihoods in the rural part of Kenya. They also largely rely on natural rains for agriculture to boost their livelihood [17].

Therefore, to sustainably adapt and mitigate the challenges associated with changes in climate such as effects of these long and harsh droughts, there is need to transition communities that are food-aid-dependent into more resilient food secure and income earning households using climate smart agriculture such as solar powered irrigation systems to support high value crop production such as the pilot project of solar driven irrigation system for banana production in Garissa, Kenya.

## 2. Methodology

The study area is located within coordinates N 0° 10′ to N 0° 15′ and E 39° 28′ to E 39° 45′ as shown in Figure 1. The scheme area extended to about 200 hectares all of which is suitable for irrigation. However, the area developed was 50 hectares from which about 25 hectares was converted into solar-pump surface irrigated banana plantation. The communities in the surrounding areas were agro-pastoralists practicing flood recession and riverbank farming around the Tana using diesel-powered pump. Nomadism is a common land use activity in the area.

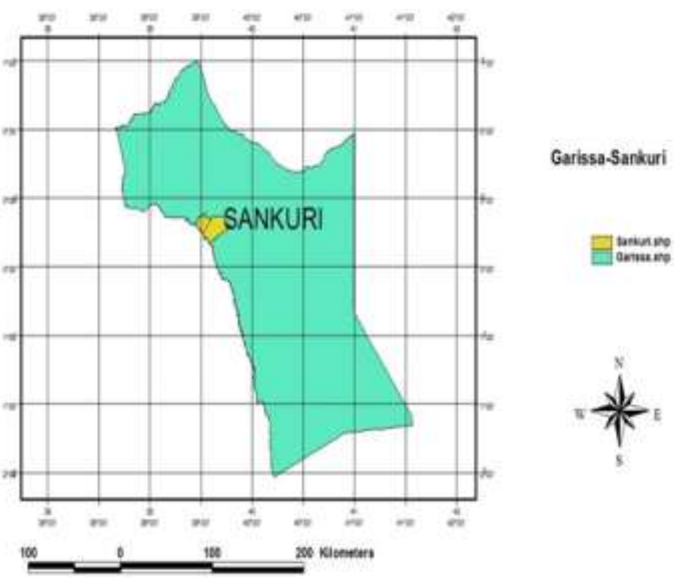



**Figure -1:** Study site location

A review on drought and climate circles for the ASALs and particularly the study area was conducted. An in-depth review of available water, solar irradiation and general climatology of the project area with relevant literature was cited. These were followed by development of a concept for household resilience including climate smart agriculture value chain suited for an ASAL environment. A survey was conducted that targeted 24 households with 9 members that were affected by the 2009-10 drought and became food-aid depended. A detailed design of solar system suitable for the project area was then conducted. A detailed engineering design was undertaken that generated topographical maps of the project area, scheme layout, water requirements and irrigation scheduling. During the design procedure, the key parameters considered included dynamic and static head, friction losses over mains to size the pump. Matching the solar modules to harness existing energy and deliver required water was using LORENTZ COMPASS 3.1.0.131; a tool for designing, planning and specifying solar pump systems. It was used to determine the appropriate pump for the system and the number of photovoltaic modules to meet the irrigation requirements. The cost-benefit analysis of the project was also done to determine the economic viability and feasibility of the proposed project.

## 3. Results

### 3.1 Site characteristics

*Soils:* The scheme area lies in the middle Tana catchment with deep well-structured soils ranging from sandstones, nutrient-rich clay soils and fertile alluvial soils along the River Basin. The fertile alluvial soils are suitable for crop production with the low rainfall amounts being the most limiting factor.

*Hydrology:* Discharge of Tana ranges between 60 $m^3$/sec and 750 $m^3$/sec. The maximum discharges in the river were recorded as 750 $m^3$/sec and 350 $m^3$/sec during the Southeast and Northeast monsoons respectively. The peak discharges in the river occurs in May and November. The flows are higher in May and less variable when compared to the flows in November. The peak discharge that has been recorded at Garissa is 3568 $m^3$/sec which occurred on 21 November 1961 (Figure 2). The sediment loading of River Tana was found to vary from 2796 tonnes per day in dry seasons to 24,322 tonnes per day in rainy season with a total annual sediment load of $6.8 \times 10^6$ tonnes per year.

The floods occur twice annually due to rainy periods which are both long and short experienced in the upper river basin`s catchment area. The long rains are experienced between April and May while the short rain season is experienced between October and November. The lowest flows in the river are experienced between the months of February and March as well as between the months of September and October as shown in Figure 3.

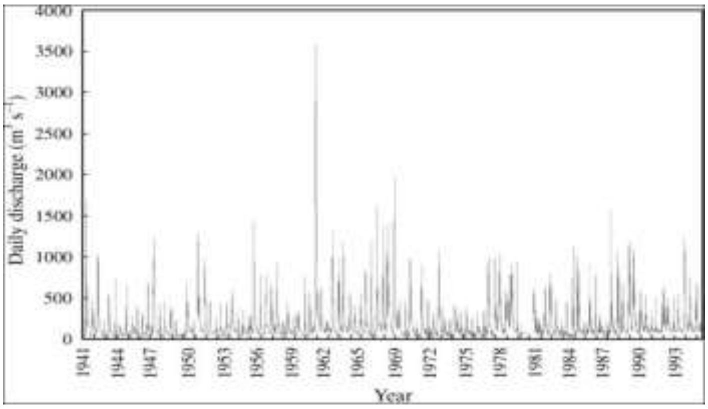
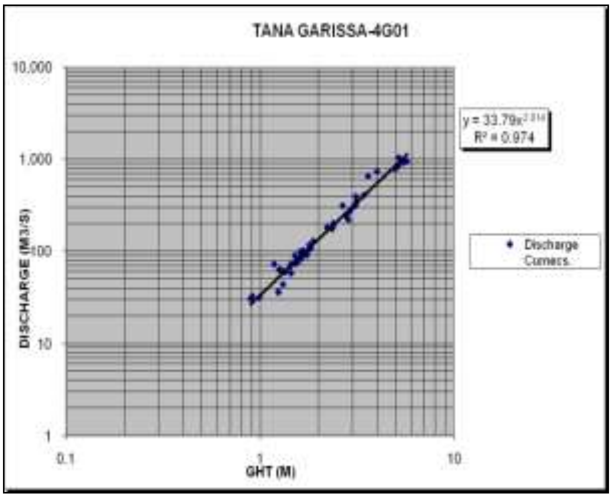



**Figure -2:** River Tana discharge as observed in the year 1941-1996 at a gauging station in Garissa

*Topography:* The area is generally flat at less than 1% slope with the points towards the river being higher (at 163 m) than the areas next to the road (162.5m) with a vertical height difference of 1.75 m.

*Vegetation:* The vegetation along River Tana bank between Mbalambala to Kipini delta is mainly riverine forest. The forest extends for about 500 m to about 3,000 m on both sides of River Tana. A deciduous bush land mainly composed of thorn-shrubs scattered with grasses extensively covers the areas that are far from the floodplain. The forest along the river is rich in biodiversity which is not common in arid environments, making it a unique ecosystem. Part of this forest had to be destroyed and replaced with a cropped system.



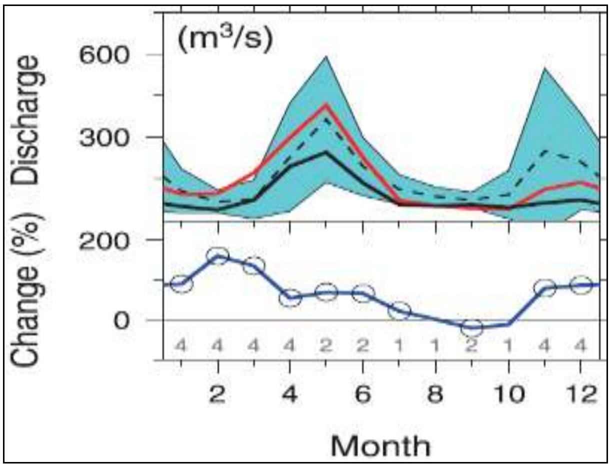



**Figure -3:** River Tana rating curve at Garissa point

**Table -1:** Monthly climatological condition for Garissa

| Period | Temperature Min. °C | Max. °C | Humidity % | Wind Km /day | Sun hours | Rad MJ/m³ /day | ET₀ Mm /day |
|---|---|---|---|---|---|---|---|
| Jan | 23.3 | 35.2 | 54 | 156 | 7 | 19.7 | 5.41 |
| Feb | 23.7 | 36.6 | 58 | 140 | 8 | 21.8 | 5.68 |
| Mar | 24.9 | 37.2 | 54 | 216 | 8 | 22.1 | 6.66 |
| Apr | 24.7 | 35.9 | 56 | 176 | 8 | 21.4 | 5.98 |
| May | 24.6 | 34.4 | 61 | 276 | 10 | 23.1 | 6.50 |
| Jun | 22.1 | 33.2 | 69 | 232 | 9 | 20.9 | 5.31 |
| Jul | 21.1 | 32.4 | 60 | 268 | 7 | 18.4 | 5.46 |
| Aug | 21.6 | 32.7 | 54 | 208 | 7 | 19.3 | 5.51 |
| Sept | 21.9 | 33.7 | 60 | 340 | 9 | 23.2 | 6.77 |
| Oct | 23.3 | 35 | 68 | 300 | 9 | 23.3 | 6.34 |
| Nov | 23.8 | 34.2 | 78 | 350 | 8 | 21.2 | 5.48 |
| Dec | 23.5 | 33.7 | 76 | 360 | 8 | 20.8 | 5.48 |
| **Average** | **23.2** | **34.5** | **62** | **252** | **8.2** | **21.3** | **5.88** |

*Climatology:* Garissa is an arid area with no rainfall all year. The climate of Garissa is classified as BWh by the Koppen–Geiger system. It has an average temperature of about 29.3°C and an annual precipitation of about 362 mm. More climatic information is shown in Table 1.

### 3.2 Drought Circles

**Table -2:** Drought periods in Kenya, its impacts and worst affected group

| *Period* | *Impacts* | *Most Affected* |
|---|---|---|
| 1983-1984 | Loss of livestock and crops, drying up of water reservoirs | Communities in the ASAL areas |
| 1996 | Reduced levels of water in reservoirs, loss of livestock and crops | Communities in ASAL areas |
| 1999-2000 | Loss of livestock and crops, reduced water levels in reservoirs | Communities in ASAL areas |
| 2005-2006 | Reduction in levels of water in the reservoirs, loss of crops and livestock | Communities in ASAL areas |
| 2008-2010 | Loss of crops and livestock; loss of human life as a result of hunger and starvation | Communities in the ASAL areas |

From the reviewed literature, it was concluded that in the case of drought occurrence in Kenya, the most affected group is the ASAL community.

### 3.3 Survey

**Table -3:** Impacts of the project on target community

| **Results indicator** | | **Baseline value** | **Target value** |
|---|---|---|---|
| Number of men benefiting from IFSAP assistance | | 0 | **36** |
| Number of women benefiting from IFSAP assistance | | 0 | **39** |
| Number of youth benefiting from IFSAP assistance | | 0 | **24** |
| **Intermediate outcome level** | | | |
| ***Outcome 1: Increased food production and productivity*** | | | |
| **Baseline value** | | | **Target value** |
| Number of farmers to whom technologies are transferred | | 0 | 75 |
| Technologies transferred and type | | 0 | 10 |
| Increase in production | Bananas (ton) | - | 960 |
| | Pasture (bales) | - | 34080 |
| | Poultry | - | 168 |
| Increase in productivity | Bananas (ton/acre) | 10 | 16 |
| | Pasture (bales/acre) | 700 | 852 |
| | Poultry (No. month) | 5 | 500 |
| Increase in turn over (Kshs) | Bananas | - | 19,200,000 |
| | Pasture | - | 6,816,000 |
| | Poultry | - | 2,400,000 |
| ***Outcome2: Improved post-harvest management*** | | | |
| Reduction in post-harvest losses | Bananas (%) | 35 | 10 |
| | Pasture (%) | 35 | 9 |
| | Poultry (%) | 35 | 10 |
| Number of farmers using improved storage and conservation technologies | Bananas | 0 | 75 |
| | Pasture | 0 | 75 |
| | Poultry (No.) | 0 | 75 |
| ***Outcome 3: Improved market access*** | | | |
| Increase in volumes marketed by the Value Chain Groups | Bananas (tons) | 0 | 960 |
| | Pasture (bales) | 0 | 34080 |
| | Poultry (No) | 0 | 168 |
| ***Outcome 4: Improved access to agricultural inputs and services*** | | | |
| Number of farmers using farm inputs | Bananas | 400 | 475 |
| | Pasture | 20 | 75 |
| | Poultry (numbers) | 3 | 75 |

### 3.4 Project design

*Crop water requirement (CWR)*

Usually for dry areas, the amount of water required by bananas in its whole production period is about 1200-2000 mm (CROPWAT 8.0). In this project, an average crop factor of 0.9 was adopted for banana crops and a rate of 2 mm/day was obtained. The daily water requirement therefore for the 25 hectares was 750 m³/day when an irrigation efficiency of 67% is assumed. The crop water requirements were determined using Eq.1.

$$ET_c = K_c * ET_o \quad (1)$$

Where; $K_c$ is factor of crop and $ET_o$ the reference crop Evapo-transpiration (mm/day), the $K_c$-values were obtained from FAO: Irrigation Water Needs. $K_c$ and $ET_o$-values and the resultant monthly crop water requirements for banana ($ET_c$) are presented in Table 2.

**Table -2:** Irrigation requirement per growth stage for Banana

| Month | Decade | Stage | $K_c$ | $ET_c$ | $ET_c$ | Effective rain | Irrigation requirement |
|---|---|---|---|---|---|---|---|
| | | | coefficient | mm/d | mm/d | mm/dec | mm/dec |
| January | 3 | Initial | 0.4 | 2.20 | 8.8 | 0.6 | 8.8 |
| February | 1 | Initial | 0.4 | 2.24 | 22.4 | 1.3 | 21.1 |
| February | 2 | Initial | 0.4 | 2.27 | 22.7 | 0.3 | 22.5 |
| February | 3 | Development | 0.46 | 2.79 | 22.3 | 3.5 | 18.8 |
| March | 1 | Development | 0.63 | 4.07 | 40.7 | 7.2 | 33.5 |
| March | 2 | Development | 0.81 | 5.58 | 55.8 | 10 | 45.8 |
| March | 3 | Development | 1.01 | 6.6 | 72.6 | 13.2 | 59.4 |
| April | 1 | Mid | 1.13 | 6.95 | 69.5 | 18.8 | 50.7 |
| April | 2 | Mid | 1.13 | 6.66 | 66.6 | 23.1 | 43.5 |
| April | 3 | Mid | 1.13 | 6.9 | 69 | 17 | 52 |
| May | 1 | Mid | 1.13 | 7.32 | 73.2 | 8.7 | 64.5 |
| May | 2 | Late | 1.12 | 7.52 | 75.2 | 3.3 | 71.9 |
| May | 3 | Late | 0.96 | 5.98 | 65.7 | 2.7 | 63 |
| June | 1 | Late | 0.75 | 4.25 | 42.5 | 2.5 | 40 |
| June | 2 | Late | 0.6 | 3.11 | 18.7 | 0.8 | 18 |
| | | | | | **725.8** | **113.2** | **613.3** |

*Net irrigation requirement*

The net irrigation requirement was determined as in Eq.2.

$$NIR = ET_c - P_e \quad (2)$$

Where; $NIR$ is the Net Irrigation Water Requirements (mm/day); $ET_C$ is Crop Water Requirement (mm/day); and $P_e$ is effective rainfall (mm/day).

*Gross irrigation requirement*

The Gross Irrigation Requirements was determined as in Eq.3.

$$GIR = \frac{NIR}{Efficiency} \quad (3)$$

Where; $Efficiency = E_c \; x \; E_d \; x \; E_a$; and $E_c$ is conveyance efficiency; $E_d$ is distribution efficiency and $E_a$ is application efficiency;

*Irrigation duration*

This was limited to eight hours/day from 9 am - 5 pm based on the fact that the pumping system is solar powered and upon consideration of the available irradiation per day (Figure 4).

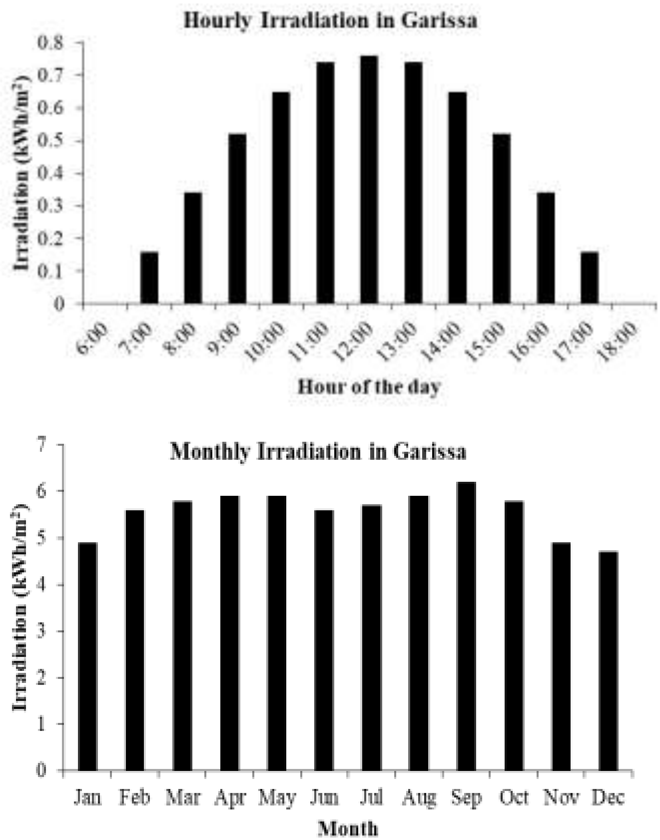



**Figure -4:** a) Hourly and b) monthly irradiation in Garissa County

*Irrigation application*

The total irrigation applications required over the total growth period is described as in Eq.4.

$$IA = \frac{IWR}{NID} \quad (4)$$

Where $IA$ is irrigation application; $IWR$ is irrigation water need; $NID$ is net irrigation depth per application.

In this project, water conveyance from the pump point was through mains of 200 mm PVC pipe covering 1 km long with saddle clamps and gate valves that opened into furrows. Furrow irrigation was applied since it prevents flooding of the whole field surface through directing water along the main direction of the contours using creases. In this system, water moves through wetted perimeter spreading both horizontally and vertically refilling the reservoir of the soil. What sets furrow irrigation unique from other systems is the fact that flow in each furrow controlled and set independently compared to furrowed basins which have their flow controlled and set border by border basis. The smaller the wetted area, the lesser the evaporation losses experienced. The irrigator has more opportunity of managing the system of irrigation when furrows are used to attain good efficiencies with changing field conditions within the season. The furrow layout is shown in Figure 5.

**Figure -5:** The furrow layout as shown on contour map of the site

**Table 3:** Irrigation requirement year round for Bananas

| Month | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Precipitation deficit** | | | | | | | | | | | | |
| Banana | 11 | 75 | 72 | 32 | 100 | 106 | 133 | 155 | 204 | 200 | 126 | 95 |
| **Net irrigation requirement.** | | | | | | | | | | | | |
| mm/d | 0.7 | 2.4 | 3.1 | 2.5 | 4.4 | 2.7 | 2.6 | 3 | 4 | 3.8 | 2.4 | 1.9 |
| mm/m | 22. | 69. | 97 | 76 | 136 | 82. | 79 | 94 | 121 | 117. | 73. | 59 |
| l/s/ha | 0.08 | 0.28 | 0.36 | 0.29 | 0.51 | 0.32 | 0.3 | 0.35 | 0.47 | 0.44 | 0.28 | 0.22 |
| Irrigated area as a % of total area) | | | | | | | | | | | | |
| | 100 | 100 | 100 | 100 | 100 | 100 | 60 | 60 | 60 | 60 | 60 | 60 |
| **Irrigation requirement for the actual area** (l/s/ha) | | | | | | | | | | | | |
| | 0.08 | 0.28 | 0.36 | 0.29 | 0.51 | 0.32 | 0.49 | 0.58 | 0.78 | 0.73 | 0.47 | 0.37 |
| | | | | Daily | | | | | | | | |
| | | | 0.78 l/s/ha | | 0.0624 Cusec | | | | | | | |
| | | | | | **224.64 m³/hr.** | | | | | | | |

*Maximum irrigation interval*

The total growing season for bananas is 12 months which is equivalent to 365 days. This corresponds to one application every day.

*Pump Sizing and Selection*

The total vertical head to be overcome was 26 m with suction of 2 m, delivery head of 2 m and pipe friction losses of 22 m. The solar powered pump that met the requirements was Lorentz $P_SK9$ selected from the manufacturer based specifications as shown in the pump characteristic curve (Figure 6). A sun tracker was also incorporated to improve system efficiency.

**Table -4:** Pump sizing parameters as from Lorentz Compass 3.1.0.131

| Location: | Kenya, Garissa (1° South; 39° East) | Water temperature: | 25°C | Altitude: | 147 m |
|---|---|---|---|---|---|
| Required daily output: | 500 m³; sizing for average month | Dirt loss | 5.0 % | Motor cable: | 10 m |
| Pipe type (Discharge side) | - | Dynamic pressure head | 26 m | Pipe length (Discharge side) | - |
| Pipe type (Suction side) | Plastic, drawn/pressed, new; 0.007 mm | Suction head | 2 m | Pipe length (Suction side) | 10 m |
| **Products** | **Quantity** | **Details** | | | |
| PSk2-9 CS | 1 pc | Surface pump system including controller with DataModule, motor and pump end | | | |
| AS-6P30-255W | 57 pc | 14,535 Wp; 19 x 3 modules; 15° tilted | | | |
| Motor cable | 10 m | 2.5 mm² 3-phase cable for power and 1-phase cable for ground | | | |
| Pipeline (suction side) | 10 m | 80 mm (inner diameter) pipeline | | | |
| Accessories | 1 set | Water sensor, float switch, surge Protector, PV Disconnect 1000-40-5, PV protect 1000-125 | | | |
| SunSwitch setting in PumpScanner | | | | Min. 150 W/m² | |

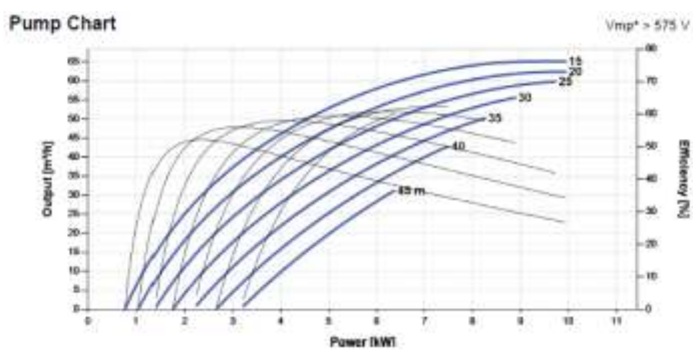



**Figure -6:** Pump characteristic curve adapted from Lorentz Compass 3.1.0.131

During heavy downpour in the Tana River catchment, there is possibility of high sedimentation and hence changes in river flows within the channel that may render the pump inoperative as water levels and flows shifts away from pump sites. This challenge was addressed by mounting the pump on a dinghy to mitigate on the flow patterns. The following expression was used to design the dinghy;

*For Buoyancy of the drums;*

$$F_b = V_s * D * g \quad (5)$$

Where $F_b$ is the force of buoyancy acting on the drums; $V_s$ is the volume of the drums submerged; $D$ is water density in river and $g$ is the gravitational acceleration.

*Finding volume of the submerged portion of the drums;*

In this project, 12 drums of 200 L were used to hoist the pump system

Total volume of the drums, $V_t = (12*(2.0*10^{-1})) = 2.4$ m³. Assuming each drum is half submerged,

$$V_s = {}^{2.4}\!/_{2} = 1.2 \text{ m}^3$$

Density of water, D assumed as 1000 kg/m³; Force of gravity, g = 9.81 N/kg

From Eq. 5, buoyancy of the drums is,

$$= 1.2*1000*9.81 = \mathbf{11.772\ kN}$$

*Checking whether the hoist will sink or float;*

Calculating buoyancy of the whole drum system

$$F_b = (2.4 \times 1000 \times 9.81) = \mathbf{23.544\ kN}$$

Calculating the force pushing downwards after mounting the pump system

G = (mass of the pump system mounted) x (gravitational pull)

= (135 kg) x (9.81 N/kg)

**= 1.324 kN**

This force is much less than the buoyancy force, so the entire system (drums and mounted pump system) will float.

Taking this system shown in Figures 7 and 8 as a benchmark; to hoist a similar pump system of mass, y kg requires 0.089y drums of 200 L capacity. Hence, 3 to 6 drums would economically suffice and still technically functional.

**Figure -7:** Pump and the pump system installed on site

**Figure -8:** Photovoltaic modules on site

### 3.5 Economic analysis

From the economic analysis, the enterprise is profitable and financially viable as indicated by the internal rate of return, IRR of 24%. With an assumption of 10% WACC, this project is considered add value. Also, assuming an incremental return at risk-free rate of 2%, this modifies the internal rate of return to 17%, signifying that the project is commercially viable.

### 3.6 Management structure

The system is operated by farm labourers with an agrarian background while management is done by beneficiary community through a committee. This is essential as the farming operations required minimal labour inputs by the largely pastoral households fitting into their livelihood work systems granting acceptability and sustainability.

### 3.7 Impacts of the Project

The project was a pioneer solar powered irrigation system not only in Kenya but in sub-Saharan Africa with comparable feats only found in Morocco and Tunisia at the time of its commissioning. The year 2009 was a critical moment for water pumping using solar. This is also the year when the world was regaining it foot financially following the worldwide financial issues in the previous years; cost of solar modules decreased drastically hence the larger solar pumping systems could be afforded in the agriculture sector [8]. The immediate economic and social impacts was the transitioning of the beneficiary communities from food aid-based livelihoods into commercial farming arena with net farm income hitting Kshs.40 million per year by the second year of commissioning. Most households have recorded annual incomes of Kshs.1 million to Kshs.2 million from bananas, water melons and tomatoes. There is minimal technical support required while the water pumping cost is minimal since the sunshine is in abundance in the area. This project has tremendously transformed the livelihoods of the target community from food aid-dependent in 2010 to income generating food secure and financially stable households (Figure 9). On average, a household with six people lives on at least $4.5/day per capita, signifying transition into middle income status within two seasons and the system has been sustained.

**Figure -9:** Banana plantation and harvested bananas ready for marketing in project site

## 4. CONCLUSION

This pilot project demonstrates application and feasibility of adopting financially and technically sustainable climate smart solar powered irrigation systems for food production at a scale that transitions food-aid-dependent households into food secure and income earning households. The Garissa pilot project on banana production using solar driven irrigation system has altered and strengthened use of land in the area as well as practices of farming and thus promoted food security.

## ACKNOWLEDGEMENT

This project was financed by the Swedish Government through the Ministry of Agriculture and Livestock Development. The Implementation was done by The University of Nairobi with significant inputs by Prof. Patts Odira and Eliakim Mwachoni. Mikael Segerros and Benjamin Ndegwa both from The Ministry of Agriculture and Livestock Development provided substantial logical and moral support during project initiation and implementation.

## REFERENCES

[1] Food and Agriculture Organization of the United Nations. The State of Food Insecurity in the World 2008: High Food Prices and Food Security-Threats and Opportunities. FAO; 2008.

[2] L.C. Smith, H. Alderman and D. Aduayom, "Food insecurity in sub-Saharan Africa: new estimates from household expenditure surveys". Intl Food Policy Res Inst; 2006.

[3] D.B Lobell, M.B Burke, C. Tebaldi, M.D Mastrandrea, W.P Falcon and R.L Naylor, "Prioritizing climate change adaptation needs for food security in 2030". Science. 2008 Feb 1;319(5863):607-10.

[4] Climate Risk Profile for Garissa County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya. MoALF. 2016.

[5] P. Polak, R. Yoder, "Creating wealth from groundwater for dollar-a-day farmers: Where the silent revolution and the four revolutions to end rural poverty meet". Hydrogeology Journal. 2006 Mar 1; 14(3):424.

[6] Food and Agriculture Organization of the United Nations. 2011. Save and Grow: A policy-maker`s guide to the sustainable intensification of smallholder crop production. FAO; 2011 www.fao.org/docrep/014/i2215e.pdf.

[7] Food and Agriculture Organization of the United Nations. 2012 Farm size.http://www.fao.org/family-farming/data-sources/dataportrait/farm-size/en.

[8] P. Pavelic, K.G Villholth, Y. Shu, L.M Rebelo and V. Smakhtin, "Smallholder groundwater irrigation in Sub-Saharan Africa: country-level estimates of development potential". Water International. 2013 Jul 1;38(4):392-407.

[9] Food and Agriculture Organization of the United Nations. 2018. The Benefits and Risks of Solar-powered Irrigation-A global overview.

[10] S.S Chandel, M.N Naik and R. Chandel, "Review of solar photovoltaic water pumping system technology for

irrigation and community drinking water supplies". Renewable and Sustainable Energy Reviews. 2015 Sep 1;49:1084-99.

[11] B. Eker, "Solar powered water pumping systems". Trakia Journal of Sciences. 2005;3(7):7-11.

[12] H.J Helikson, "Pumping water for irrigation using solar energy". University of Florida, U.S.A. 1995.

[13] D.A Quansah, M.S Adaramola and L.D Mensah, "Solar photovoltaics in sub-Saharan Africa–addressing barriers, unlocking potential". Energy Procedia. 2016 Dec 1; 106:97-110.

[14] D.E Mateche, The cycle of drought in Kenya; a looming humanitarian crisis. Environmental security programme, ISS Nairobi-institute for security studies

[15] S.N Marigi, A.K Njogu and W.N Githungo, "Trends of extreme temperature and rainfall indices for Arid and Semi-arid lands of South Eastern Kenya". Journal of Geoscience and Environment Protection. 2016; 4, 158-171.

[16] Government of Kenya (GoK). The national climate change response strategy. A Kenya strategy document, Ministry of environment and mineral resources. 2010, p 97.

[17] J. Ochieng`, L. Kirimi and M. Mathenge, "Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya". NJAS-Wageningen Journal of Life Sciences. 2016: 77, 71-78.

[18] Nations U. International Strategy for Disaster Reduction ISDR (2005)." Drought coping strategies". Available at http://www.unisdr.org