

**DESIGN AND RETROFIT IRRIGATION PUMPING SYSTEM FOR
THE MIDDLE OGUN IRRIGATION PROJECT USING
HYDROKINETIC TECHNOLOGY**

ABSTRACT

High cost of irrigation pumping by use of petroleum diesel fuel has negatively impacted irrigation efficiency on the Middle Ogun Irrigation scheme. Efficient irrigation pumping would improve agricultural productivity and food production on the irrigation scheme. The research has sought for an alternative energy source for powering irrigation pumping. This study aimed at the design and retrofitting of the irrigation water pumping system on the scheme using hydrokinetic technology. Hydrological modelling of the catchment was carried out using MapWindow Soil and Water Assessment Tool to determine annual gross and recoverable hydrokinetic potential of the water resource from the river. A rating equation and the Flow Duration curve was developed and the reliabilities of streamflow discharge for different percentiles were determined. A Savonius hydrokinetic turbine system was developed and tested and the mean voltage output at selected streamflow depths were determined. Number of pumping and hydrokinetic turbine units were obtained from the pump catalogue table and the power curve respectively. Results showed that retrofitting the irrigation pumping system with an array of twenty units (20) of selected submersible irrigation pumps powered by twenty-two (22) units of an array of Savonius hydrokinetic turbines would satisfactorily deliver irrigation water into night storage and irrigate the pilot field of 100 ha of farmland on plot 2 and 5 on the scheme.

Keywords: Hydrokinetic, Savonius, Irrigation, Pump, Retrofit

1.0 INTRODUCTION

Irrigation may be defined as a process of supplying water to crops by artificial means (Modi, 2014). High cost of irrigation water supply to irrigated farms has been a major problem on many irrigation schemes in the country. High cost of fossil fuel (diesel and petrol) and its use for irrigation pumping has led to inefficient irrigation in many schemes. Middle Ogun Irrigation project is a large irrigation scheme located in the southwestern part of Nigeria in Iseyin town in Oyo state. This project is under the Ogun Oshun River Basin Development Authority (O-ORBDA). The project was originally conceived as a 12000 hectare irrigation projects covering parts of the northern and southern areas in Oyo state. However, only 3000 hectares designated as phase 1 has been developed. Located at the upstream of middle Ogun irrigation channel is the Ikere Gorge Dam with a dam reservoir capacity of about 565 Mm³ located North East of Iseyin in Oyo state. It is to provide irrigation water releases from the dam to MOIP and to supply water to Iseyin town and environs (O-ORBDA Brochure, 2017).

The irrigation project is saddled with agricultural food production and all year farming using irrigation methods. The project was faced with problem of high cost of operating the large irrigation pumping facilities on the scheme due to use of petroleum diesel fuel. This problem of powering and pumping irrigation water has consequently led to irrigation inefficiency on the scheme. Therefore, there is need to seek alternative ways of getting energy for effective irrigation pumping on the scheme.

Hydrokinetic energy conversion technology involves the conversion of kinetic energy from stream flows in rivers, oceans and tidal currents to generate electricity. This type of energy conversion system would abstract energy of streamflow, moving water, river or ocean current and converts it to rotational energy using a turbine rotor. Rotational energy produced from the rotor is converted to electrical energy using generator. This form of power generation possesses less danger to the environment because it does not require building of dams or head works. It is a renewable energy source (Botto *et. al.*, 2010). Hydrokinetic technology is able to generate electrical energy to supply households from middle to high discharge rivers (Tan *et.al.* 2017). Bancant and Wosnik (2011) also developed specialized hydrokinetic turbine which are used to power ocean instruments in Korea. Wamalwa *et al.* (2017) also studied how to retrofit a conventional hydropower plant with pump back system using hydrokinetic technology and was able to get energy yield in the resultant system by 39 to 41.48 %.

The use of this type of technology on the Middle Ogun irrigation river for irrigation pumping and retrofitting the irrigation system would alleviate the problem of power dearth presently being experienced on the irrigation scheme and improve the irrigation efficiency of the scheme. Therefore, this study is aimed at the design of a hydrokinetic energy conversion system and retrofit for more efficient irrigation water pumping system on the scheme.

2.0 MATERIALS AND METHODS

2.1 Study Area

This project is located at about fifteen kilometers from Iseyin town towards Oyo town in Oyo State of Nigeria. It lies between coordinates 875232.89 N, 578464.09 E and 871820.67 N, 576912.95 E. The Ogun River borders the north east area of the project downstream of Ikere Gorge Dam. Located on the river is a concrete weir and pump house constructed for irrigation purposes. Figure 1 shows inset of location of project area on Nigeria map. The entire layout consists of four (4) parts. Area part one (1): which is along Olokemeji has 1386 ha suitable for irrigation farming; Area part two (2): is around Eleyele axis of the project area, it covers about 12000 ha; Area part three (3): is situated around Odo Ogun where the study is focused, it is about 1200 ha and area part four (4): was originally planned has 1200 ha of farmland and recommended for development. It is located near Ikere Gorge Dam. Figure 2 shows the layout of the project and the four areas. This study focused mainly on area part 3

presently developed for irrigation activities. Figure 3 (a) and (b) presents the layout for the plots 2 and 5. Plots 2 covers 600 ha while plot 5 covers 320 ha. A layout of 100 ha was selected as the pilot scheme out of the plots 2 and 5 as shown in Figure 4. The Ogun river borders the North East area of the Project downstream Ikere Gorge dam. The irrigation distribution system for plot 2 and 5 is pipe network. The main features of irrigation facilities were shown in Table 1.

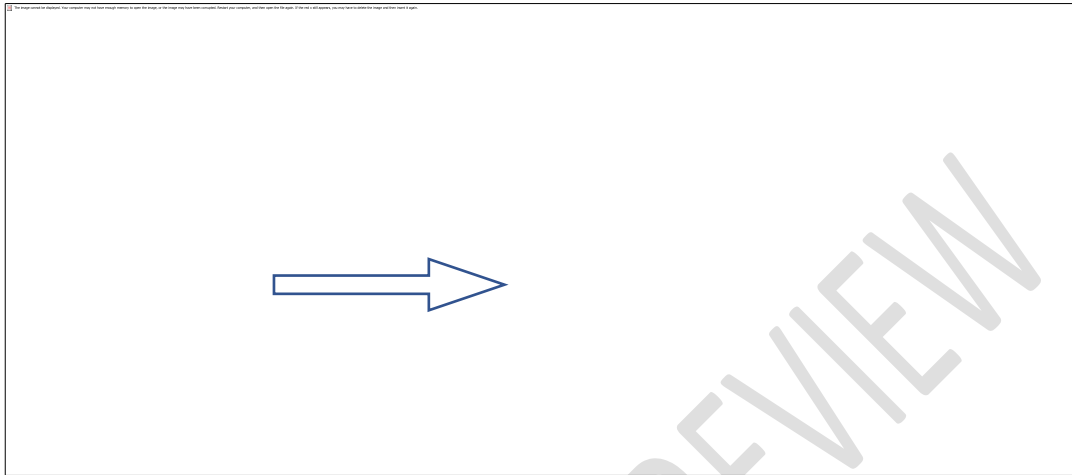


Figure 1: Location of study area. Source: Federal survey Abuja (1995)



Figure 2: Layout Map of Middle Ogun Irrigation Project.
Source:Konsadem Associates, (2021)

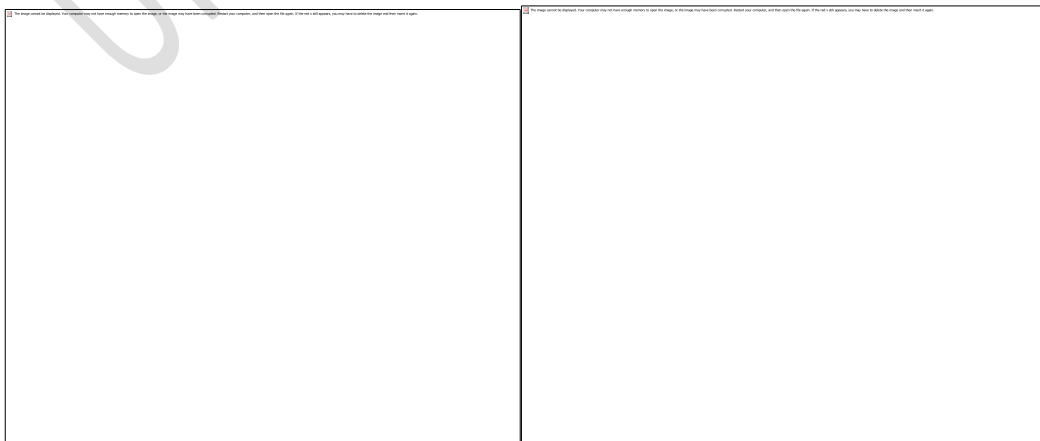


Figure 3: Layout of Pilot 100 ha of farmland located at Plot 2 and 5.

Source:Konsadem Associates, (2021)



Figure 4: Layout of Plot 2 and 5. Source:Konsadem Associates, (2021)

Table 1: Main features of irrigation facilities

Description	Capacity
Headwork	70 m concrete ogee spillway,
Generator house with 5nos generator	1500 KVA each generator
Vertical pump Installations with total	8 nos, 900 Hp vertical pump
Ductile Iron Rising Mains diameter	14 km of 900/800/700 mm
Downstream release from Ikere Gorge	60 Mm ³
Sprinkler Irrigation Distribution System	3000 ha planned irrigation area
Service, Secondary and farm roads	152 km
Reinforce concrete bridge deck	70 m

Source: Ogun Oshun River Basin Development Authority (OORBDA, 2008)

2.2 Determination of irrigation water requirement

A pilot irrigation field of about 100 ha was selected at plot 2 and 5 of the scheme. Irrigation water requirement of crops was determined by deducting the effective rainfall from the crop water requirement. This parameters can be evaluated using the CROPWAT 8.0. CROPWAT 8.0 is a decision support tool for determining the crop water requirements and the irrigation requirements of crops developed by the United Nations Food and Agriculture organization (UNFAO). The model gave the Crop Evapotranspiration (ET_c) Effective rainfall (Eff_{rain}) and Irrigation Requirements (IRR) of these crops. Crops grown on the scheme includes Maize, Tomatoe, Soyabeans and

Cabbage. These were evaluated in order to determine seasonal crop water requirement and irrigation water supply for the scheme. Input parameters to be determined included the average monthly weather record, effective rainfall, soil bulk density, soil moisture content, soil texture, soil infiltration rate of the irrigation field. These parameters were determined on the irrigation scheme (Modi, 2014).

2.3 Topographical survey of study area

Topographical survey of study area was taken to evaluate the volumetric capacity of night storage (V_{NS}) and delivery head of the submersible pumps (H) from the Pumping Point (PP) to Night Storage (NS). Survey was carried out using the total station (Nikon, NTS - 365). The survey equipment was set up and carried out by positioning the instruments at the proposed turbine point. Data recorded were taken using a datum of Universal Transverse Mercator (U.T.M Zone 31) with a scale of 1: 120000. Figure 5 showed contour map with profile of the Night Storage (NS) and Turbine Point (TP) representing the pumping station. Map showed Temporary Benchmarks (TBM) 01 and 02 located on the coordinates 579573.13 E, 873884.46 N and 579600.44 E, 873830.96 N respectively. Corresponding height at TBM 01 and 02 were 200.623 m and 201.54 m Mean Sea Level (MSL). Turbine point (TP) or Pumping Point (PP) and Night Storage (NS) were located at 579576.666 E, 874039.088 N and 577083.14 E, 871759.59 N with surveyed height of 198.014 and 242.63 m respectively. The corresponding data point for the salient features were recorded and presented as Eastings (E), Northings (N), Height (m) above the Mean Sea Level (MSL) as the datum.

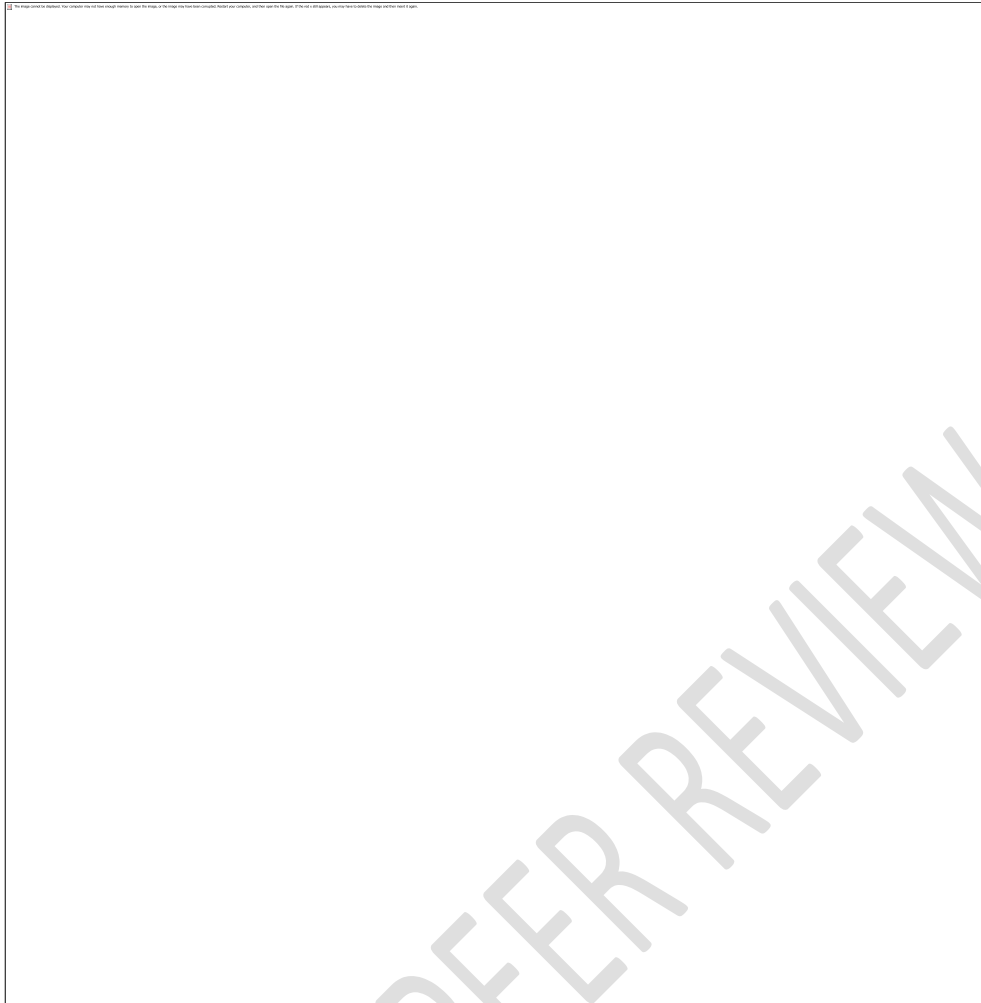


Figure 5: Contour map showing elevation Night Storage and Turbine Point

2.4 Determination of Delivery Head (H)

Figure 5 showed topographic and contour map of reservoir Night Storage (NS) and the reservoir. Data were taken between four cardinal points were represented as RES 1 577083.142 E and 871759.59 N, RES 2 577142.235 E and 871782.789, RES 3 577051.301 E, 871853.712 N, RES 4 577051.301 and 871835 N with heights of 242.396 m, 242.26 m, 242.63 m and 242.736 m respectively. The dimensions of the NS including width, length and height were 75.01 m, 90.105 m, and 5.002 m respectively. The Night Storage was located at the highest point on the field at surveyed height of 240 m. This would enhance sufficient head for effective and efficient delivery of irrigation water supply to the commandable areas of the irrigation field. Figure 6 showed head of NS from TP. Delivery head was estimated as 44.616 m at a distance of 300 m from each other.

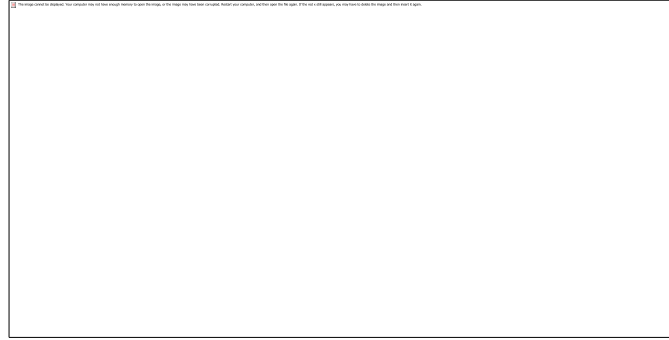


Figure 6: Evaluation of delivery head from Turbine Point and Night storage

2.5 Selection of pumps

The selection of submersible pumps was carried out using the Lowara Xylem brand pump catalogue chart. Selection from the brand was mainly due to pump efficiency and cost effectiveness as shown in Figure 7. The delivery head was evaluated using contour map in Figure 5. Flow rates of the pump was evaluated using equation 1 (Michael, 2009) respectively. Selection of submersible pumps was carried out using 2GS Lowara Xylem pump catalogue (2024) shown in the Figure 6.

$$Q = \frac{Ay}{RT} \times \frac{1000}{36} \quad (1)$$

$$Q = 27.78 \frac{Ay}{RT}$$

where: Q is discharge of pump (m^3/s); A is area of land under crop (hectares); y is depth of irrigation (cm); R is rotation period (days); T is duration of pumping (hour/days) (Michael, 2009).

The delivery head of submersible pumps was evaluated considering the elevation of Night Storage and the turbine point location. Topographic map in Figure 12 and Figure 13 gave the elevation of these points. Delivery head was evaluated as 44.616 m using the Topographic maps. Selection of pumps was carried out using the pump catalogue chart and considering the pumping delivery Head (H) of 44.616 m and pumping discharge (Q) of $21 \text{ m}^3/\text{s}$.

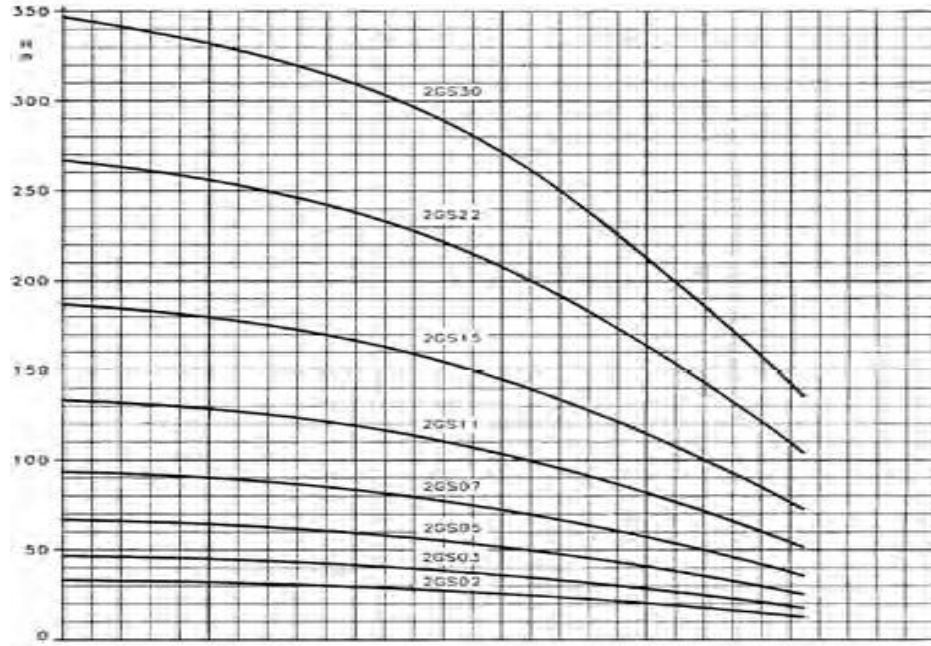


Figure 7: Lowara Xylem 2GS (2024) Pump Catalogue Chart

2.6 Evaluation of volumetric capacity of night storage

Table 8 showed the Seasonal Irrigation Requirements as 428.460 mm or 428460 m³ for the 100 ha of farmland. Number of the pumping cycle to satisfy seasonal irrigation requirements.

Width of Night storage is 75.701 m

Length of Night storage is 90.105 m

Height of Night storage is 5.0 m

Volumetric Capacity of Night Storage (m³) = 75.701 × 90.105 × 5.0 m³ = 34,105.19 m³

2.7 Number of pumping cycles and Turbine Required to satisfy the Irrigation Requirements

Number of pumping cycles to satisfy the irrigation requirements

$$\text{No of pumping cycles} = \frac{\text{Field Seasonal Irrigation Requirements}}{\text{Volumetric capacity of Night Storage}} \quad (2)$$

Pumping hours per cycle to fill Night Storage

Number of pumping hour per cycle to fill night storage is given as

$$\text{Pumping hour per cycle} = \frac{\text{volumetric capacity of the night storage (m}^3\text{)}}{\text{total capacity of pumps (m}^3\text{/hr)}} \quad (3)$$

Number of Hydrokinetic Turbine (HKT) per pumping cycle

$$\text{Number of Hydrokinetic Turbine} = \frac{\text{power output of 20 units of pumps kW}}{\text{Power output per unit HKT}} \quad (4)$$

2.8 Hydrological modelling using MWSWAT

Mapwindow Soil Water Assessment Tool (MWSWAT) is an interface merging both the Soil and Water Assessment Tool (SWAT) with MapWindow Geographic Information System (MWGIS). It was used to model the catchment and to evaluate the annual yield, the gross and recoverably hydrokinetic power resource potential of the middle Ogun river. Digital representation of shape files for land use of the catchment area and digital soil data for the study area were extracted from harmonized digital soil map of the world (HSD v 1.1) produced by food and Agriculture Organization (FAO) of the United Nations obtainable from MapWindow GIS (MWGIS). Digital Elevation Model (DEM) of the catchment was extracted from Shuttle Radar Topographic Mission (SRTM). Simulation of catchment was carried by discretizing the catchment areas into subbasins using the land use and cover types of the catchment area which are characterized by Global Land Cover Characterization (GLCC) data base. Subbasins were further delineated by subdividing subbasins to Hydrological Response Unit's (HRU'S) using the digital Elevation Model (DEM) of the catchment. This was extracted from Shuttle Radar Topographic Mission (SRTM). Thirty five (35) years rainfall data were sourced from WMO and used to estimate the runoff from the catchment. Table 2 showed the input data for the MWSWAT simulations (Neitsch *et al.*, 2009).

Table 2: Input data for MWSWAT modelling

S/N	Description	Resolution	Remark
1	Digital Elevation Model	90 × 90	Shuttle Radar Topographical Mission
2	Land use Classification	1km	Global Land Cover Classification Satellite Raster
3	Soil Types and Texture	10km	Digital Soil Map
4	Daily precipitation, max & min temp, Rel Humidity, Wind and Solar		Thirty-four years (Jan 1979- Dec 2013) weather record from WMO

Source: Neitsch *et al.* (2009)

2.9 Equations for the surface runoff from the catchment

SWAT evaluated the surface runoff from catchment using input weather data which included daily precipitation of the study area. Equations such as the SCS curve number, Green and Ampt infiltration method where used to evaluate the overland flow, lateral flow and underground flows from the catchment as shown in the equations 5-7 respectively.

$$Q_{Surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (5)$$

Where: Q_{Surf} is Runoff (mm); R_{day} is Rainfall depth/day (mm); S is retention (mm)

$$q_{lat} = \frac{0.024 (2SSC \sin \alpha)}{\theta_d L} \quad (6)$$

Where: q_{lat} is Lateral flow (mm/day); S is drainable volume of soil water per unit area (mm/day); SC is hydraulic conductivity (mm/hr); L is flow length (m); α is slope of land and θ_d is drainage porosity

$$Q_{gwj} = Q_{gwj-1} \cdot e^{(-\alpha_{gw} \cdot \Delta t)} + W_{rchr g} \cdot (1 - e^{(-\alpha_{gw} \cdot \Delta t)}) \quad (7)$$

Where: Q_{gwj} is Groundwater flow on day j; α_{gw} is base flow recession constant and Δt is time step

2.10 Gross and recoverable hydrokinetic potential of Middle Ogun River

Gross theoretical hydrokinetic power resource is the segment specific gross naturally available hydrokinetic resource. The theoretically available or gross power P_{th} available from a stream or moving body of water is as shown in equation 8. Also, technically recoverable hydrokinetic power can be generated from kinetic energy of a flowing body of water, stream, river or marine water. It is the power extracted by turbine of a given swept area as shown in equation 9. Power density is defined as the power available per square meter area of flow. It is also a function of kinetic energy of the moving water.

$$P_{th} = \gamma Q \Delta H \quad (8)$$

Where: P_{th} is theoretically available hydrokinetic power (watts)

Q is the discharge (m^3/s)

ΔH is hydraulic head (m)

γ is the specific weight of water (N/m^3)

$$P_{rec} = \frac{1}{2} \rho A_s V^3 \quad (9)$$

Where: P_{rec} is recoverable hydrokinetic power (watts)

ρ is density of water (kg/m^3)

A_s is swept area (m^2)

V is velocity of flow (m/s)

2.11 Hydrokinetic Turbines

Hydrokinetic turbine are devices that converts kinetic energy in streamflow into mechanical rotating energy. Turbine can be in the form of wheel, rotor, propellers and so on. It can be arranged in manner that streamflow can impacts energy to it to be converted to mechanical energy. Hardesty (2009) described the mechanical energy as energy being transferred through a drive shaft to operate a machine, compressor, electric generator or propeller. Hydrokinetic turbines are classified as vertical or horizontal axis turbines. The water possesses a large amount of hydraulic energy, when it strikes the blade, it does work on the runner and causes it to rotate. The

mechanical energy generated is transferred to generator connected to the turbine to produce electricity (Howard, 2013).

2.12 Savonius Hydrokinetic Turbines

Savonius turbines are one of the commonly used turbines in hydrokinetic energy conversion technology (Golecha *et al.*, 2011). The rotor was developed by Finnish Engineer Savonius in 1925. The Savonius rotor comprises two identical hollow semicircular cylinders fixed to a vertical axis. The two half cylinders faced each other to have an S-shaped cross section. The Savonius turbine comprises basically of Savonius blades, the rotor, rotor shaft, and endplates. Due to differences in pressure between the two sides of the turbine rotation takes place. Savonius operates mainly by drag forces which acts in parallel direction to the fluid flow. It requires less torque to operate unlike the Darrius turbine. It is environmentally friendly and does not need external input to self-start.

2.13 Design and fabrication of Savonius turbine

The design of Savonius turbine for power extraction considered the firm yield of the irrigation channel of 0.6 m with streamflow of 1.2 m/s to attain sufficient swept area (A_s) and Aspect Ratio (AR) on the turbine.

Design Parameters

Rotor height and Aspect Ratio is given in equation 10 and 11

$$H = 2D \quad 10$$

$$A_s = H \times D \quad 11$$

where: H is height of rotor (m); D is diameter of rotor (m); A_s is swept area of rotor (m^2)

End plate diameter

End plate diameter is given as in equation 12. It is designed for optimal rotational speed and tip speed ratio of the turbine (Miller *et al.*, 2015).

$$D_o = 1.25 \times D \quad 12$$

where: D_o is end plate diameter (m); $D_o = 1.25 \times 0.3$ m; $D_o = 0.375$ m

Stage height

Rotor stage height in double stage turbine will be evaluated using equation 13

$$h = \frac{H - 3t}{2} \quad 13$$

where: t is thickness of end plates (m); h is stage height of rotor (m); thickness of endplates is 0.002m

Aspect Ratio

The ratio of height of rotor to its diameter is known as Aspect Ratio (AR). The Aspect Ratio and stage Aspect Ratio was evaluated according to equations 14 and 15 respectively. Performance of the turbine increases with increase in Aspect Ratio of the rotor (Kothari *et.al.*, 2012).

$$AR = \frac{H}{D} \quad 14$$

$$AR_{stage} = \frac{h}{D} \quad 15$$

where: AR is aspect ratio (dimensionless); AR_{stage} is stage aspect ratio (dimensionless)

Maximum thrust on turbine

Maximum thrust on Savonius turbine is calculated using equation. Average velocity of flow from flow duration curve is 1.7. Thrust coefficient for Savonius turbine due to the dense medium of water is 0.9 (Kothari *et al.*, 2012).

$$f = \frac{1}{2} \rho A_T v^2 \quad 16$$

where: ρ is density of water (kg/m^3); f is maximum thrust (N); A_T is velocity of flow (m/s); V is velocity of water flow (m/s)

Torque on Savonius rotor

Maximum torque on a turbine rotor occurs when maximum thrust can be applied at the blade tip farthest from the axis. Equations 17-20 shows the relationships of maximum torque, maximum thrust on the turbine and velocity of flow (Kothari, *et al.*, 2012). Table 3 shows summary of the design.

$$T_{max} = f_{max} * R \quad 17$$

$$f_{max} = \frac{1}{2} \rho A v^2 \quad 18$$

$$T_{max} = \frac{1}{2} \rho A v^2 R \quad 19$$

$$T = C_t T_{max} \quad 20$$

where: ρ is density of water (kg/m^3); A_s is swept area of rotor (m^2); V is velocity of water flow (m/s); R is blade radius (m); C_t is coefficient of thrust (dimensionless); f_{max} is maximum thrust on turbine (N); T_{max} is maximum torque on rotor (Nm); T is torque on rotor (Nm)

Power abstracted by the turbine is given in equation 21

$$P_{rec} = \frac{1}{2} \rho A_s V^2 \quad 21$$

Where A_s is rotor swept area (m^2); V is velocity of water (m/s); ρ is density of water (kg/m^3); Diameter of the turbine is given in equation 22

$$d_{shaft} = \left(\frac{32n_s}{\pi \sigma_y} \sqrt{M_b^2 + T^2} \right)^{1/3} \quad 22$$

Where d_{shaft} is diameter of shaft (m); n_s is factor of safety (dimensionless); σ_y is yield strength of material (MPa); M_b is bending moment on shaft (Nm); T is torque transmitted by shaft (Nm); Tip Speed Ratio (TSR) of turbine is the ratio of velocity of rotor blade to the linear velocity of streamflow given by equation 23

$$\text{TSR} = \frac{w \times D}{V} \quad 23$$

Where TSR is Tip speed ratio of turbine (dimensionless); w is angular velocity of rotor (rad/sec); D is diameter of circular blade of rotor (m); V is velocity of water (m/s); Torque transmitted by the solid shaft is given as equation 24

$$T = \frac{2\pi N}{60} \quad 24$$

Where T is Torque on turbine rotor (Nm); N is angular speed of shaft (rpm)

Table 3: Summary for design of developed Savonius turbine

Parameter	Value
Rotor Diameter (D_{sav})	0.3 m
Rotor Height	0.6 m
Swept Area (A_s)	0.18 m ²
Diameter of End Plates (D_o)	0.38 m
Stage Height (h)	0.3 m
Stage Aspect Ratio (AR_{stage})	0.99
Thrust on shaft (T_{shaft})	260.1 N
Drag force on Shaft (M)	104 Nm
Hydrokinetic Power ($P_{\text{hydrokinetic}}$)	442.17 W
Torque transmitted by Shaft	19.56 Nm
Diameter of Shaft	0.02 m
Overlap Ratio	0.2
Shaft speed (RPM)	216.55 rpm
Tip Speed Ratio (TSR)	2
Blade Arc angle	124°

2.14 Fabrication of turbine

Materials for fabrication of developed Savonius turbine was carried out from material selection consideration of desired physical and mechanical properties of various members of the developed turbine. Materials were sourced locally for the fabrication. Fabrication was carried out at the Mechanical metal workshop of Lower Niger River Basin Development Authority, Ilorin. The developed Savonius turbine was tested on the Middle Ogun irrigation river.. Orthographic views of turbine, exploded view and isomeric views were shown in Figure 7-10 respectively.



Figure 7: Orthographic diagram with front view of turbine



Figure 8: Orthographic diagram with side view of turbine



Figure 9: plan view turbine

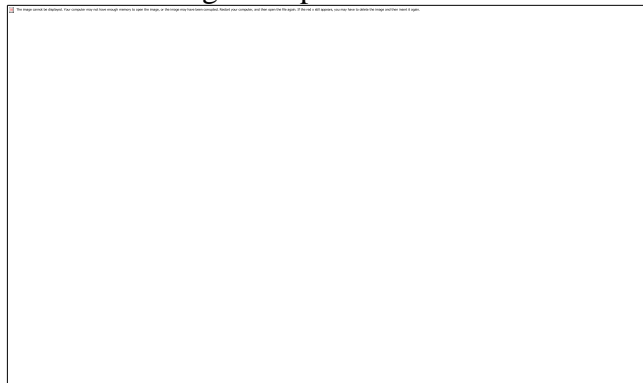


Figure 10: Exploded View of turbine

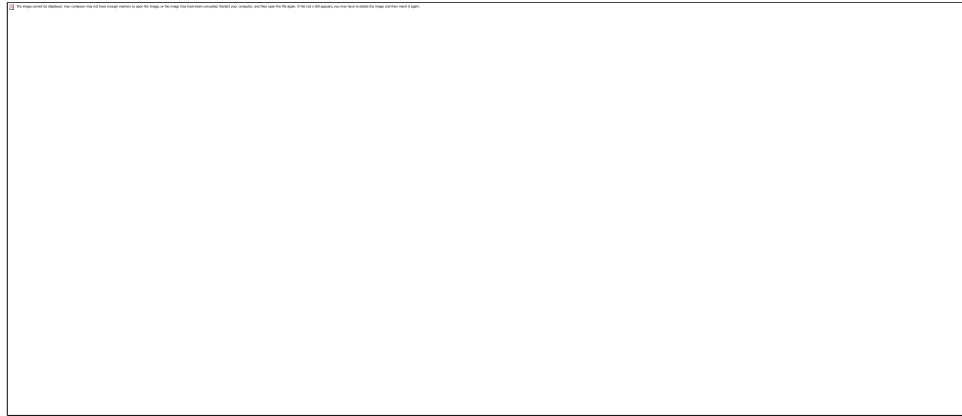


Figure 11: Isomeric view of Savonius turbine

2.15 Power curve

The power curve showed power output (watts) versus the various streamflow velocity (m/s). Readings for power generated from various streamflow on the river were taken to develop the turbine power curve

Results and Discussions

Table 4–8 showed the Crop Evapotranspiration (ET_c) and Irrigation Requirements (IRR) for crops grown on the pilot irrigation field of plot 2 and 5 using CROPWAT 8.0. Considering about 100 ha of the pilot irrigation field for this study. ET_c of the major crops grown including Maize, Soyabeans, Tomato and Cabbage were determined using CROPWAT 8.0. ET_c varied between 9.0 – 49.50 mm/decade, 5.0 – 5.7 mm/decade, 9.30 – 58.60 mm/decade and 27.50 – 54.90 mm/decade for cultivated Maize, Tomato, Soya beans and Cabbage respectively. IRR for each crops varied between 0.0 – 46.50 mm/decade, 0.0 – 59.70 mm/decade, 0.0 – 49.30 mm/decade and 0.0–54.60 mm/decade for Maize, Soyabeans, Tomato and Cabbage respectively depending on the effective rainfall during the planting season.

Table 4: Maize seasonal evapotranspiration and Irrigation requirement

Month	Decade	Stage	K_c Coefficient	ET_c mm/day	ET_c mm/dec	Eff _{rain} mm/dec	Irr. Req. mm/dec
Sep	3	Init	0.30	1.47	14.7	35.6	0.0
Oct	1	Deve	0.41	2.00	20.0	22.6	0.0
Oct	2	Deve	0.65	3.19	31.9	12.6	19.3
Oct	3	Deve	0.91	4.21	46.3	9.3	37.0
Nov	1	Mid	1.12	4.95	49.5	5.8	43.7
Nov	2	Mid	1.15	4.78	47.8	1.3	46.5
Nov	3	Mid	1.15	4.68	46.8	1.0	45.9
Dec	1	Mid	1.15	4.59	45.9	0.7	45.1
Dec	2	Late	1.11	4.36	43.6	0.0	43.6
Dec	3	Late	0.90	3.69	40.5	0.1	40.4
Jan	1	Late	0.66	2.84	28.4	0.3	28.1
Jan	2	Late	0.50	2.25	9.0	0.1	8.9
					437.6	130.8	358.4

Table 5: Soyabeans seasonal evapotranspiration and Irrigation requirement

Month	Decade	Stage	Kc coefficient	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	3	Init	0.50	2.45	19.6	28.5	0.0
Oct	1	Deve	0.53	2.58	25.8	22.6	3.2
Oct	2	Deve	0.87	4.25	42.5	12.6	29.9
Oct	3	Mid	1.15	5.33	58.6	9.3	49.3
Nov	1	Mid	1.15	5.07	50.7	5.8	44.9
Nov	2	Mid	1.15	4.79	47.9	1.3	46.6
Nov	3	Mid	1.15	4.69	46.9	1.0	46.0
Dec	1	Late	0.95	3.81	38.1	0.7	37.4
Dec	2	Late	0.61	2.38	14.3	0.0	14.3
					344.4	81.8	271.4

Table 6: Tomato seasonal evapotranspiration and Irrigation requirement

Month	Decade	Stage	Kc coefficient	ETc mm/day	Etc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	3	Init	0.60	2.94	23.5	28.5	0.0
Oct	1	Init	0.60	2.94	29.4	22.6	6.8
Oct	2	Init	0.60	2.94	29.4	12.6	16.7
Oct	3	Deve	0.61	2.84	31.2	9.3	21.9
Nov	1	Deve	0.71	3.14	31.4	5.8	25.6
Nov	2	Deve	0.83	3.46	34.6	1.3	33.2
Nov	3	Deve	0.95	3.87	38.7	1.0	37.7
Dec	1	Deve	1.07	4.26	42.6	0.7	41.9
Dec	2	Mid	1.13	4.42	44.2	0.0	44.2
Dec	3	Mid	1.13	4.64	51.0	0.1	50.9
Jan	1	Mid	1.13	4.85	48.5	0.3	48.2
Jan	2	Mid	1.13	5.06	50.6	0.3	50.3
Jan	3	Mid	1.13	5.37	59.1	0.3	58.8
Feb	1	Mid	1.13	5.67	56.7	0.1	56.7
Feb	2	Late	1.13	5.97	59.7	0.0	59.7
Feb	3	Late	1.07	5.95	47.6	0.8	46.8
Mar	1	Late	0.97	5.66	56.6	5.4	51.3
Mar	2	Late	0.85	5.24	52.4	7.9	44.5
Mar	3	Late	0.79	4.99	5.0	0.9	5.0
					792.3	97.8	700.3

Table 7: Cabbage seasonal evapotranspiration and Irrigation requirement

Month	Decade	Stage	Kc coefficient	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	3	Init	0.70	3.43	27.5	28.5	0.0
Oct	1	Init	0.70	3.43	34.3	22.6	11.7

Oct	2	Init	0.70	3.43	34.3	12.6	21.6
Oct	3	Init	0.70	3.26	35.8	9.3	26.5
Nov	1	Deve	0.73	3.20	32.0	5.8	26.2
Nov	2	Deve	0.78	3.27	32.7	1.3	31.4
Nov	3	Deve	0.84	3.44	34.4	1.0	33.4
Dec	1	Deve	0.90	3.60	36.0	0.7	35.3
Dec	2	Deve	0.96	3.75	37.5	0.0	37.5
Dec	3	Deve	1.02	4.19	46.0	0.1	45.9
Jan	1	Mid	1.05	4.50	45.0	0.3	44.8
Jan	2	Mid	1.05	4.70	47.0	0.3	46.7
Jan	3	Mid	1.05	4.99	54.9	0.3	54.6
Feb	1	Mid	1.05	5.27	52.7	0.1	52.7
Feb	2	Late	1.05	5.55	55.5	0.0	55.5
Feb	3	Late	1.01	5.65	45.2	0.8	44.4
Mar	1	Late	0.97	5.67	34.0	3.2	31.3
					684.9	86.8	599.6

Table 8: Seasonal Irrigation Water Requirements

Parameters	Value
Gross Irrigation Requirement (GIR)	645.90 mm
Net Irrigation Requirement (NIR)	428.46 mm
Irrigation Efficiency (IE)	69.0%

Annual gross and recoverable hydrokinetic power resource

Table 9 and Table 10 showed that hydraulic slope of the sub basin varied between 0.001894 – 0.004933 while the hydraulic head varied between 5.48647 – 26.7693 m. SWAT simulations indicated sub basin in the catchment with different land use or soils having remarkable effect on the hydrology of the catchment. The mean annual flows from the catchment varying between 98.33 – 1214 m³/s within subbasins 35 – 44. Estimated annual gross hydrokinetic power (HKP) from the water resource is 1004.60MW. Recoverable Factor (PF) for power generations was 0.0035 and annual recoverable HKP was evaluated as 4.01MW.

Table 9: Geometry and hydraulic head (m) of sub-basins

Sub-basin	Order	Length (m)	Slope	Adjacent Straight L (m)	Hydraulic Head ΔH (m)
35	1	2781.90	0.0021568	2543.8	5.48647
36	1	2835.50	0.002468	2330.6	5.75192
37	1	5260.30	0.003231	4610.6	14.8949
38	1	34673.30	0.0029129	26732.6	77.8694
39	1	6789.20	0.0033877	6153.2	20.8452
40	1	7720.40	0.004274	6263.3	26.7693

41	1	5108.60	0.004893	4094.4	20.0339
42	1	14483.50	0.004933	12132.6	23.4523
43	1	5266.80	0.002848	4395.6	12.5170
44	1	4221.80	0.001894	3941.1	7.4680

Table 10: Annual gross and recoverable hydrokinetic power

Sub-basin	Hydraulic Head ΔH (m)	Mean Annual Flow Q (m^3/s)	Specific Weight of Water γ (Nm^{-3})	Mean Annual Gross HKP (P_{th}) $\times 10^6$ Watts	Mean annual recoverable HKP (P_{rec}) $\times 10^6$ Watts
35	5.48647	191.564	9800	10.3	0.04
36	5.75192	510.9230	9800	28.8	0.12
37	14.8949	600.80	9800	87.7	0.35
38	77.8694	169.04	9800	129.0	0.52
39	20.8452	1214.00	9800	248.6	0.99
40	26.7693	947.7088	9800	265.7	1.06
41	20.0339	657.4232	9800	108.4	0.43
42	23.4523	98.33	9800	22.6	0.09
43	12.5170	184.2392	9800	92.3	0.37
44	7.4680	140.7368	9800	10.3	0.04
				1003.70 MW	4.01 MW

Power curve

Figure 11 showed the power curve which indicated the power output with respect to velocity of streamflow using the developed Savonius turbine. Results showed that stream velocities of between 0.32 – 0.5 m/s gave zero power output. Cut in speed of 0.564 m/s of flow was attained with power output of 0.18 W. Average streamflow speed of 1-2 m/s gave 0.3 kW. The exponential curve showed that rated speed of 4 m/s would produce power output of 1.1 kW using the turbine of 0.18 m² swept area.



Figure 11: The Savonius Hydrokinetic Power curve

This study gave mean annual gross and recoverable hydrokinetic power potential of the irrigation river as 1004 MW and 4.01 MW respectively. This is a significant to power output for irrigation pumping. Power curve gave an exponential curve gave streamflow velocities of 3 m/s as power output and turbine swept area of 9.6 kW and 1.8 m² turbine swept area. The turbine showed a satisfactory performance of evaluation for TSR and C_p as 1.00 and 19.1 % respectively. Retrofit of twenty (20) units of selected pumps powered by twenty two (22) units of Savonius hydrokinetic turbines would satisfactorily deliver irrigation water to pilot irrigation scheme and in essence improve irrigation efficiency.

Evaluation of Pumping cycles and Turbines Required

Table 8 showed the Seasonal Irrigation Requirements as 428.460 mm or 428460 m³ for the 100 ha of farmland. Figure 5 shows topographical and contour map for estimatind volumetric capacity of Night Storage. This was evaluated considering the dimensions of survey data points. Number of the pumping cycle to satisfy seasonal irrigation requirements.

$$\text{No of pumping cycles} = \frac{\text{Field Seasonal Irrigation Requirements}}{\text{Volumetric capacity of Night Stor age}}$$

$$\text{No of pumping cycles} = \frac{428,460 \text{ m}^3}{34,105.19 \text{ m}^3} = 12.56 \text{ per season}$$

Pumping hours per cycle to fill Night Storage

Delivery head (H) is 44.616 m

Discharge of selected pump is 21 m³/s

Energy requirement of selected pump is 2.20 kW

Number of units of selected pumps is 20 units

Total discharge capacity of selected pumps is 420 m³/hr

Total power requirements of selected pumps is 44 kW

Power requirements of unit Hydrokinetic Turbine (HKT) is 2.2 kW

Volumetric capacity of the night storage = 34,105.19 m³

Number of pumping hour per cycle to fill night storage is given as equation 3.44

$$\text{Pumping hour per cycle} = \frac{\text{volumetric capacity of the night storage (m}^3\text{)}}{\text{total capacity of pumps (m}^3\text{/hr)}}$$

$$\text{Pumping hour per cycle} = \frac{34105.19}{420} \text{hrs} = 81.20 \text{ hrs}$$

Number of Hydrokinetic Turbine (HKT) per pumping cycle

Number of Hydrokinetic Turbine (HKT) per pumping cycle is given equation 3.45

$$\text{Number of Hydrokinetic Turbine} = \frac{\text{power output of 20 units of pumps kW}}{\text{Power output per unit HKT}}$$

$$\text{Number of Hydrokinetic Turbine} = \frac{44 \text{ kW}}{2.2 \text{ kW}} = 22 \text{ units}$$

Conclusion

This study had revealed that mean annual gross hydrokinetic power potential obtained was 1004 MW and mean annual recoverable hydrokinetic power resource was 4.01 MW. This is sufficient to power the selected pumps for irrigation water delivery. Also, seasonal net irrigation requirement for selected crops was 428,460 m³. This can be satisfied from the water resource available on the Middle Ogun irrigation channel. This can be efficiently delivered through the retrofitted pumping units. Retrofit of twenty (20) units of selected irrigation pumps can likewise be powered by twenty two (22) units of Savonius hydrokinetic turbines. This would satisfactorily deliver irrigation water to the pilot scheme. It would also provide a viable alternative to the diesel powered water delivery pumping system presently used at the pumping station. Further works may look into a hybrid system involving solar energy resource. Water releases from the upstream Ikere Gorge Dam shall also ensure continuous reservoir inflow for dry season farming.

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