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THEORETICAL POTENTIAL OF HYDROKINETIC ENERGY IN THE UPPER OGUN AND UPPER KADUNA RIVER BASINS NIGERIA, NIGERIA

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ABSTRACT

Hydrokinetic energy is the energy of moving water. About 1.4% of Nigeria is covered by rivers yet power supply in Nigeria is inadequate. This paper considered the potential of two Nigeria's river basins for hydrokinetic power generation. The data used were obtained both theoretically and from secondary sources. Potential hydrokinetic energy were computed using a theoretical procedure, assuming a head of 0.3 meters and a constant weight of water at 9800 n/m³. In Ogun basin, hydrokinetic energy potential was highest in Osun at Aponje (8.364 mW) and lowest in Kojuoba at Olonje (1.271 mW). In the Kaduna basin, it ranges from 0.15mW in Kwassau at Zonkwa to 34.4mW at Tubo at Kaduna. All the sub basins could generate some form of hydrokinetic energy. It is recommended that this study be extended to other Nigeria's river basins.

Keywords: Hydrokinetic Power, Power Generation, Flow Rate, Energy Potential, River Basins

INTRODUCTION

Hydrokinetic energy is produced from the flow of moving water such as ocean wave, tidal energy, river in-stream, and ocean current (Ocean Energy, 2008). It is a form of small hydropower scheme, it is environmentally friendly, it is small sized compared to hydropower, it has limited impacts on evaporation, evapotranspiration, carbon dioxide, groundwater seepage, dam failure, among others.

The hydrokinetic method of extracting energy from flows converts the kinetic energy of flow to mechanical shaft power by a propeller-like device which generates electrical current by a dynamo (or generator) attached to the shaft in a manner analogous to a wind turbine.

Hydrokinetic energy is a strong alternative to hydropower because its development will not pose any environmental problem such as construction of dams to sustain flow into the turbines, preventing the lowering of water level such that the required hydraulic head which should be sustained, obstruction of regular water flow, impacting negatively on aquatics, among others. Hydrokinetics energy does not require massive infrastructure like hydropower (Hydrovolts, 2012). It is as an alternative to wind power, photovoltaic (PV) and diesel generator where adequate water resources is available (Kusakana, 2012)). It is cost effective as minimum civil work is required. Its operation discourages discharge of excess of carbon dioxide and green house gases into the atmosphere. Besides, it may be preferred above wind energy as the speed of wind can vary over time, while water velocity tends to be relatively constant even with seasonal variations. Despite the above, the level of awareness in Nigeria on the use of hydrokinetic energy in power generation is still low.

Table 1 shows that access to electricity in Nigeria is still less than 50%, unlike what obtains in sister African countries. The development of hydrokinetic energy in Nigeria is desirable in view of the following. First, Nigeria has high concentration of scattered rural communities wherein power divisibility may be problematic. Second, rural settlements are traditionally founded close to rivers or at least a water front, suggesting that sources of water are commonly available for hydrokinetic turbines. Third, unlike hydropower development where large numbers of people would need to be displaced to make way for water pondage, hydrokinetic projects can be placed in existing water sites without having to create a large reservoir on land already occupied by people. Fourth, unlike the case of hydropower where there are continuous threats of dam failure for populations who have avoided being displaced but live downstream of a hydropower dams the hydrokinetic safe. Fifth, hydrokinetic energy will avoid impacts on wildlife that are associated with conventional hydropower projects. Lastly, the operations of hydropower dams create fluctuations in water levels, reducing the flow of water downstream. Sixth, reduced water levels downstream can create inhospitable conditions for fish as a result of higher water temperatures and lower oxygen levels. All these have made HKE more preferred.
Despite these, hydrokinetic power is not getting the required attention; there is undue focus of respective governments on hydropower development at the expense of other forms of energy. Small power schemes are generally scanty in Nigeria.

First, they can be developed independently of the national grid a condition which is relevant to rural and remote electrification projects.

Nigeria have many rivers, waterfalls and streams which have high potentials for SHP (Small-Hydro Power).

Table 1: Access to electricity in Selected Countries in Africa {% of Population}

S/N.	**Country**	**HDI**	**National**	**Rural**	**Urban**
i	Algeria	0.754	99.3	98	100
ii	Angola	0.564	26.2	10.7	38
iii	Cameroun	0.523	29.4	9	45
iv	Cape Verde	0.708	70.4	44.9	87.5
v	Cote d'lvoire	0.484	47.3	18	78
vi	Egypt	0.703	99.4	99.1	100
vii	Ethiopia	0.414	15.3	2	80
viii	Ghana	0.526	54	23	85
ix	Libya	0.847	99.8	99	100
x	**Nigeria***	**0.511**	**46.8**	**26**	**69**
xi	South Africa	0.683	75	55	88
xii	Tunisia	0.769	99.5	98.5	100

Source: Adapted from UNDP/WHO Energy Access, 2009.

This paper attempts to highlight the potential of two Nigerias rivers in the Basement Complex areas of northern and southern Nigeria to a more divisible, cheaper and complimentary energy of hydrokinetic system.

The Study Area

Two river basins were selected for this study; they are Upper Ogun (Figure 2) and the Upper Kaduna river basins (Figure 1). These basins are located in two different ecological zones. They are both underlain by the northern and western Nigeria basement complex rocks respectively.

The Kaduna river basin is located between Latitude 9^0 and 11^0 03^IN and Longitude 6^0 00` and $8^0$ 00`E. It covers the whole of Kaduna State and the south western part of Plateau State around Assob (Fig 1).

The UKC has a dominant tropical climate (A_w Koppen Classification) with wet and dry season. Length of rainy days is about 150days in its extreme north, while in the southeast, it is around 180days. Rainfall amount decreases from about 1600mm on the Kogun basin in the south to about 980mm on the Kahugu basin in the northeast. All these account for the pattern of runoff experienced along the catchment. The vegetation consists of guinea savannah to the south of latitude 10^0N and Sudan Savannah to the north of 10^0N, while the Jos Plateau segment of the catchment is covered by grassland, 3 relief patterns are discernable; the south-eastern segment is dominated by hilly landscape while in the immediate north central and north western topography is undulating plain. The soil is largely ferruginous comprising the Zaria group with clayey B horizon to the north and Kagoro black soil to the south of latitude 10^0N respectively. The pattern of vegetation, nature of relief and soil types of the Upper Kaduna control runoff generation in the catchment.

The Upper Ogun River basin (Figure 2) is located between latitude 6º 26´ N and 9º 10´ N and longitude 2º 28´E and4º 8´E the Ikere river is a tributary of river Ogun. The Ogun River takes its sources from the Igaran hills with elevation of about 530 m above sea level and flows directly southwards over a distance of about 480 km before it discharge into the Lagos lagoon. Its main tributaries are the Ofiki and Opeki Rivers. Two seasons are distinguishable in the river basin, a dry season from November to March and a wet season between April and October. Mean annual rainfall ranges from 900 mm in the north to 2,000 mm towards the south. The total annual potential evapotranspiration is estimated at between 1,600 and 1,900 mm (Bhattacharya et al., 2012). Ufoegbure, et. al. (2011) reported that the mean annual temperature is about 27ºC and relative humidity is approximately 83% at 10 am. The Ogun River Basin at Ikere Gorge dam was planned to generate 3750mW of electricity and to supply water to Local communities. It was planned to supply Iju water work in Lagos and irrigate 12,000 hectares of land. Table 2 shows the land use and land cover types.

Table 2: Information on Landuse of the study Area

S/N	SWAT Code	Description	Area (Ha)	% of watershed
1	URMD	Urban and Built-Up Land	12,346,78.44	0.19
2	CRDY	Dry land Cropland and Pasture	16,253.97	1.61
3	CRGR	Cropland/Grassland Mosaic	584.07	0.06
4	CRWO	Cropland/Woodland Mosaic	128,055.89	12.66
5	GRAS	Grassland	344,444.5	0.00
6	SHRB	Shrub land	7,777.4	0.00
7	SAVA	Savannah	857,133.88	0.00
8	FOEB	Evergreen Broadleaf Forest	7,515.37	0.74
9	WATB	Water bodies	4,444.4	84.74
10	BSVG	Barren or Sparsely Vegetated	4,267.9	0.00

Source: Author's computation, 2015.

The geology of the study area is characterized by Precambrian Basement (Jones and Hockey, 1964). It consists of quartzites and biotites schist, hornblende-biotite, granite and gneisses. (Adeosun et al., 2011). The two major vegetation types dominant in the study area are: the high forest vegetation in the north and central parts (Jones et al., 1964). The 2006 population census put the population of Iseyin local government at 256,926.

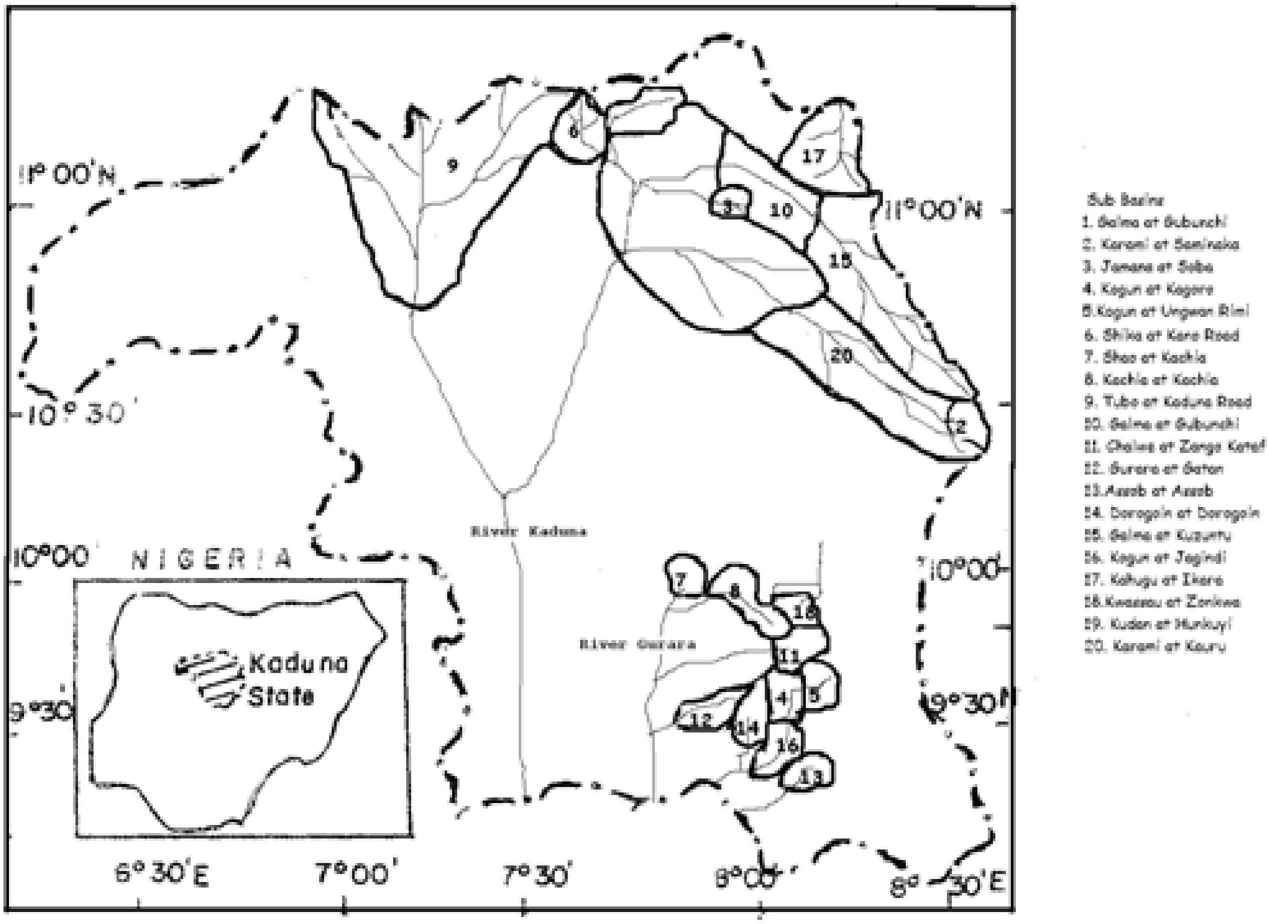

Figure 1: Upper Kaduna Basin

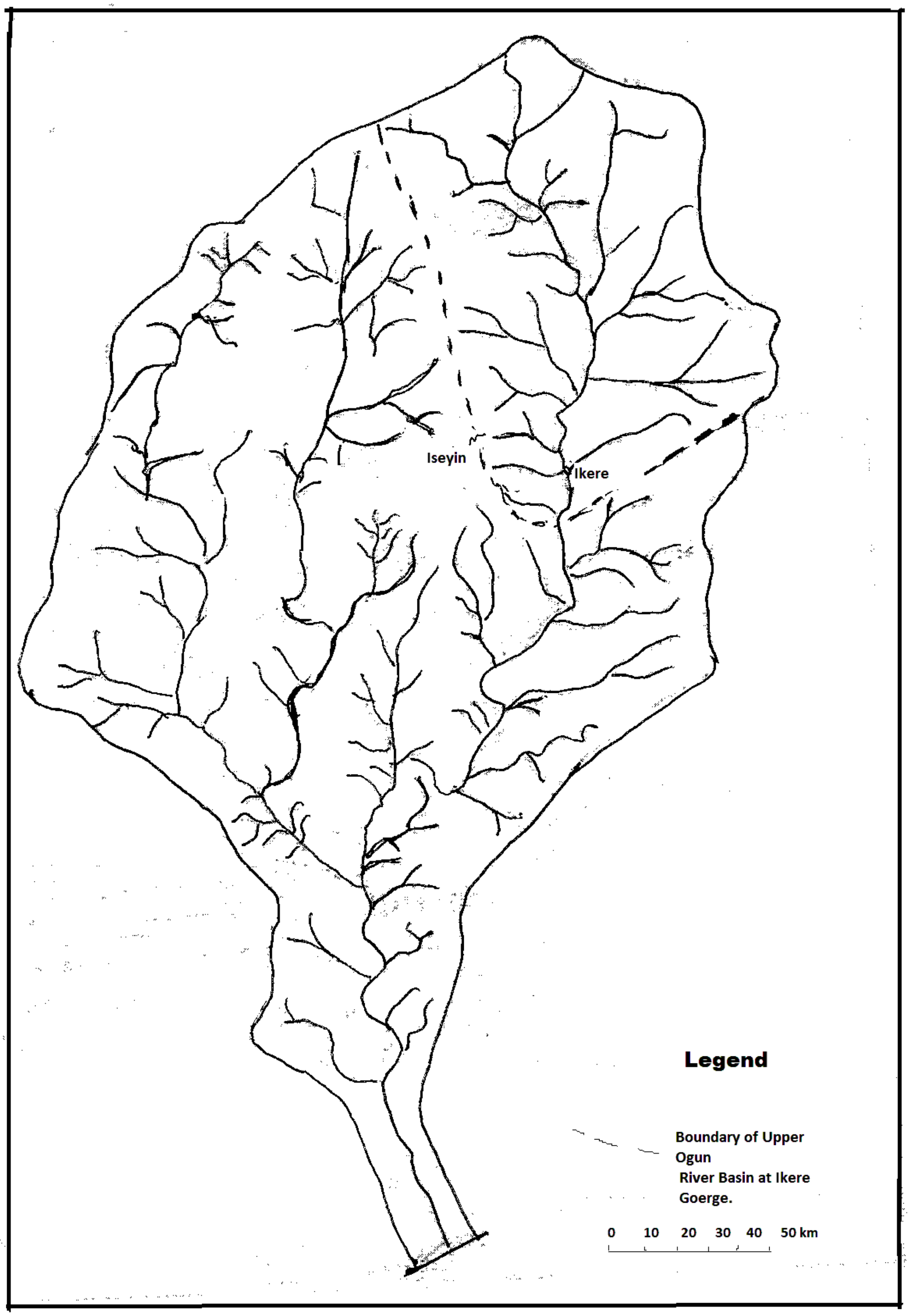

Figure 2 : Map of Ogun River Basin Showing Upper Ogun at Ikere Gorge

METHODS OF STUDY

The data required in this study were mainly, hydrologic, morphometric and power potential data of the two river basins. Secondary data were used. In view of the low gauge network in Nigeria, the Upper Ogun basin is largely ungauged, hence a synthetic approach via SWAT was used to generate runoff data for the basin with the exception of some basic climatic data which were sourced from the Ogun Oshun River basin. In the Kaduna basin, runoff data were obtained from the Hydrological Department of the Kaduna State Water Board. The information on gradient were extracted from 1: 50,000 topographical map covering the study. This map was sourced from Federal Surveys, Office of the Surveyor General of the Federation, Lagos Nigeria.

Method of Data Preparation and Analysis for SWAT Modelling

The data used in the Upper Ogun basin were generated using the Soil-Water Assessment Tool (SWAT) model. SWAT is a watershed scale and continuous-time model that is capable of simulating long-time yield for determining the effects of land management practices (Arnold and Allen, 1999). The Coordinate points were derived with the use of GPS. This data were downloaded and converted to shape files using MWSWAT Software. This was done to get the exact location of the study area in the satellite imagery. Spatial data such as Latitude, Longitude and Elevation were processed using the flow rate, slope, depth and Digital Elevation Model (Figure 3). MAPWINDOW was used to process watershed, sub basin and stream delineation. While, weather time series and soil map data served as input into the SWAT model. Weather parameters such as minimum and maximum temperature, rainfall, relative humidity within the river basin for the period of 10 years were used. The parameters of the Catchment such as: sub-basin order, straight-length, slope, and hydraulic head (ΔH) were derived to get mean annual discharge along each sub basin of the catchment. The data acquired from Ogun Osun River Basin Development Authority and world global weather database of World Meteorological Agency were used. The data generated from hydrokinetic power resource assessment was used in SWAT model simulation analyses. Digital Elevation Model (DEM) of the terrain features were generated in the simulation processes. Also, the delineation of the watershed was carried out with the use of MAPWINDOW spatial tool. The Arc SWAT model was used to generate all the files needed through input from digitized map.

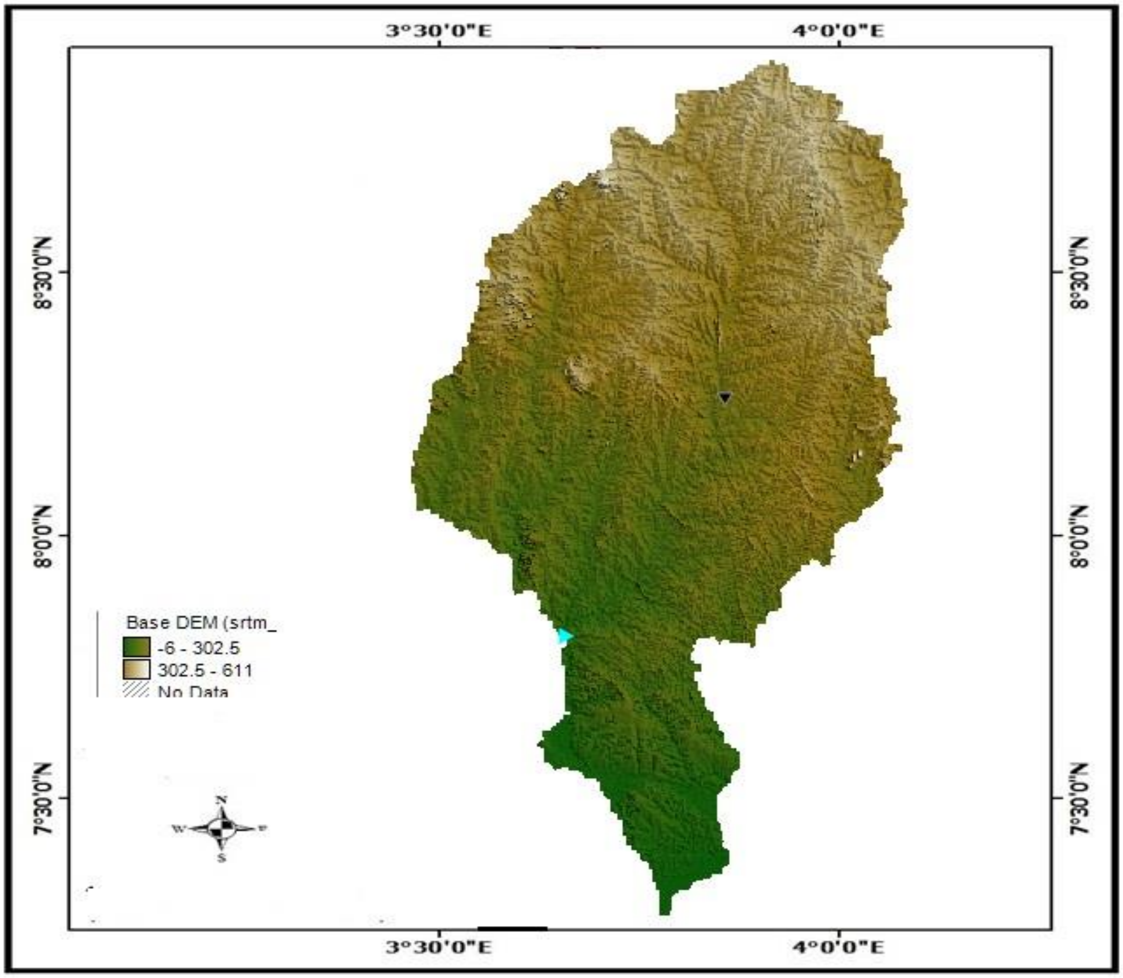

Figure 3: Digital Elevation Model (DEM) of Ogun River Catchment.

Manual editing of the necessary data were carried out and the weather data of the basins were processed accordingly to get the average daily discharge in order to calculate potential capacity of each river.

Energy potential was estimated by relating the theoretical hydraulic power (P*th*, watts) to discharge (Q, m^3/s) and hydraulic head or change in elevation ΔH (m) over the length of the segment. A computation of discharge values with the measured elevation and constant mass density gives the segment specific theoretical hydrokinetic power properties of each basin. The theoretical hydraulic power potential were be calculated using equation 1,

$$P_{th} = \gamma \, Q \, \Delta H. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [1]$$

Where:

P*th* (watts) = theoretical hydraulic power,
γ= Specific weight of water (9800 n/m^3),
ΔH (m) = Change in Hydraulic head between the beginning and end of the river segment or change in elevation over the length of the segment,
Q= Flow rate (m^3/s).

This method was used by the Electric Power Research Institute (EPRI) in determining the theoretical river hydrokinetic resource for USA using assumed river slope of 0.3m and a constant weight of water of 9,800 n/m³. (EPRI, 2012; Ladokun, et. al., 2013).

RESULTS AND DISCUSSION

Hydrokinetic Potentials in the Upper Kaduna River Basin.

The result presented in the Tables 3 and Figure 4 show that the higher the discharge the higher the potential energy generated. Table 3 shows a number of large basins. Energy potential was lowest in five basins ranging between 0.15mW in Kwassau to 0.90 at Kahugu basin. Many rural and semi urban settlements are in the Kaduna basin. Energy potential displayed four patterns.

Low Energy Generation

These basins have the least potential energy in the UKC (0.15 - 0.90mW). Prominent urban centers are: Zonkwa, Zango Kataf, Hunkuyi and Ikara. There are growing power need that could require the development of hydrokinetic power system in order to assist these growing urban and semi urban settlements to meet their power need. Meanwhile, the relatively low potential of HKE in the five basins could augment existing hydroelectricity capacities in the basin (see: Figure 4).

Table 3 : Pattern of Discharge and Hydrokinetic Energy in the Upper Kaduna Catchment.

S/N	River basin		Discharge	Hydrokinetic Potential (mW)	Group
1.	i	Kwassau at Zonkwa	51	0.15	Low Energy Generation
2.	ii	Chalwe at Zango Kataf	141	0.41	
3.	iii	Kudan at Hunkuyi	138	0.41	
4.	iv	Dorogoin at Kwoi	146	0.43	
5.	v	Kahugu at Ikara	307	0.90	
6.	i	Jamana at Soba	421	1.24	Moderately Low generation
7.	ii	Shika at Zaria	1443	4.24	
8.	iii	Kogun at Kagoro	1509	4.44	
9.	i	Shaho at Kachia	1721	5.06	Moderate Generation
10.	ii	Kachia at Kachia	2355	6.92	
11.	iii	Galma at Kuzuntu	2509	7.38	
12.	iv	Karami at Saminaka	2722	8.00	
13.	v	Kogun at Ugwan Rimi	2970	8.73	
14.	vi	Kogun at Jagindi	2986	8.78	
15.	vii	Gurara at Gatan	3056	8.98	
16.	i	Assob at Assob	3424	10.0	High Generation
17.	ii	Galma at Gubunchi	4196	12.3	
18.	iii	Karami at Kauru	6830	20.0	
19.	iv	Galma at Ribako	9140	27.0	
20.	v	Tubo at Kaduna Road	11,698	34.4	

Moderately Low Generation

There are three sub basins in this category (Jamana (1.24mw); Shika (4.24mw) and Kogun (4.44mw)). Shika is the largest settlement out of these basins; it is gradually fusing into Zaria. Zaria is the second largest settlement in the Kaduna basin and houses many higher institutions and one of the largest universities in West Africa (Ahmadu Bello University); of which one of its campuses is located in Shika. The power need is relatively huge. The development of the 4.24mw will assist in augmenting the city's energy supply. There is an increasing energy demand in Kagoro; one of the largest cities in southern Kaduna sub basins. It has a fairly large population. The development of the hydrokinetic in conjunction with the available hydropower will resolve the epileptic power supply in this area.

Moderate Energy Generation.

There are seven sub basins in this category, they are: Shaho at Kachia, Galma at Kuzuntu, Karami at Saminaka, Kogun at Ugwan Rimi, Kogun at Jagindi and Gurara at Gatan. The energy potential ranges from 5.0mw in Shaho to 10mw in Gurara at Gatan. These basins can generate between 5 mw to 9 mw suggesting that they could sufficiently generate their energy need. Saminaka is the largest city in this category; it is a local government headquarter and cosmopolitan in nature. Saminaka is a large commercial center and in view of its location in a road junction, it is home to many traders. The basins in this area could generate their power need without any need for augmentation when the hydrokinetic resources are developed.

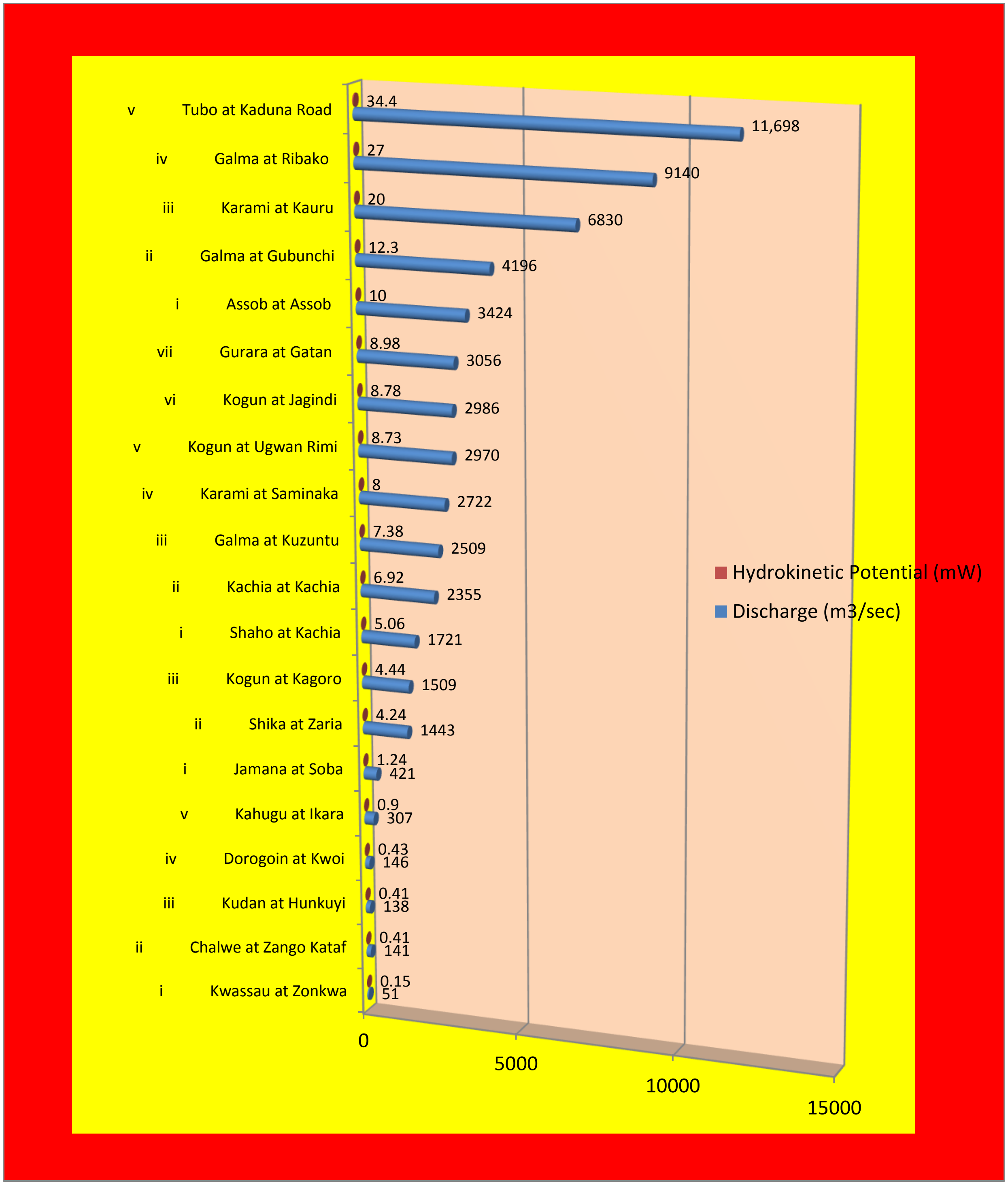

Figure 4: Stream Discharge and Potential Hydrokinetic Energy in the Upper Kaduna Basin.

High Potential

The five sub basins with the highest discharge belong to this group. They are: Assob at Assob, Galma at Kauru, Galma at Ribako and Tubo at Kaduna. The potential energy capacities of these basins are quite high. HKE ranges from 10mw in Assob to as much as 34.4mw at Tubo basin in Kaduna. The potential energy at Tubo basin could be developed to assist Kaduna city, the state capital city and one of the largest cities in Nigeria. It is a major industrial city in Nigeria. Some of the settlements in this zone would generate excess energy than what they needed. These excess could be exported to other areas where potential are weak. These basins have enormous potentials in terms of the power endowment.

ii. **Hydrokinetic Potentials in the Upper Ogun Basin.**

Hydrokinetic energy potential is higher at Apoje in river Osun (8.364mW) followed by Onikankan at river Oshe (4.404 mW;). The lowest hydrokinetic potential is recoded at Olonje on river Kojuoba (1.271 mW) (Figure 5). It can be concluded that river Osun holds the highest potential for Hydrokinetic energy in that region. Unlike what obtains in the northern Nigerian basin, the Ogun basin has smaller sub basins where runoff is generally low. Hence, the potential energy generated reflects this pattern. Two patterns were discernable (Table 4 and Figure 5).

Low Potential.

Twelve out of the 13 basins in the Ogun basin are on small basins with very low potential ranging from 1.271 in Onikanakan 4.4 mw at Aponje.. The Ogun basin consist many of rural settlements with many farming communities can be found here. In view of the high numbers of farming communities, the power need in these places are generally low. The available potential will support these farming communities and a few cottage agro allied industries in the area.

Moderate Potential.

River Osun at Aponje is the only basin in this category. It has a potential of 8.00mw it probably has higher potential than what it actually required being a remote village. The advantage of the potential could be maximized as it could serve to attract cottage industrialize.

Table 4: Hydrokinetic potential of some rivers in South-western Nigeria (Assuming a head of 0.3 m)

Location			Rivers	Average Discharge (m^3/s)	Hydrokinetic Potential (MW)	
1.	i	Olonje	Kojuoba	432.2	1.271	
2.	ii	Gborun	Awo	438.2	1.288	Low potential
3.	iii	Adewuyi	Onko	459.6	1.351	
4.	iv	Babasango	Owi	533.4	1.568	
5.	v	Ajura	Ogun	55.36	1.628	
6.	vi	Woro	Woro	580.8	1.708	
7.	vii	Opo	Opo	634.6	1.866	
8.	viii	Sepeteri	Tewu	658.3	1.935	
9.	ix	Ifon	Osse	80.00	2.352	
10.	x	Ogbooro	Konsun	697.1	2.843	
11.	xi	Elere	Igba	147.9	4.348	
12.	xii	Onikankan	Oshe	149.8	4.404	
13.	i.	Aponje	Osun	284.5	8.364	Moderate Potential

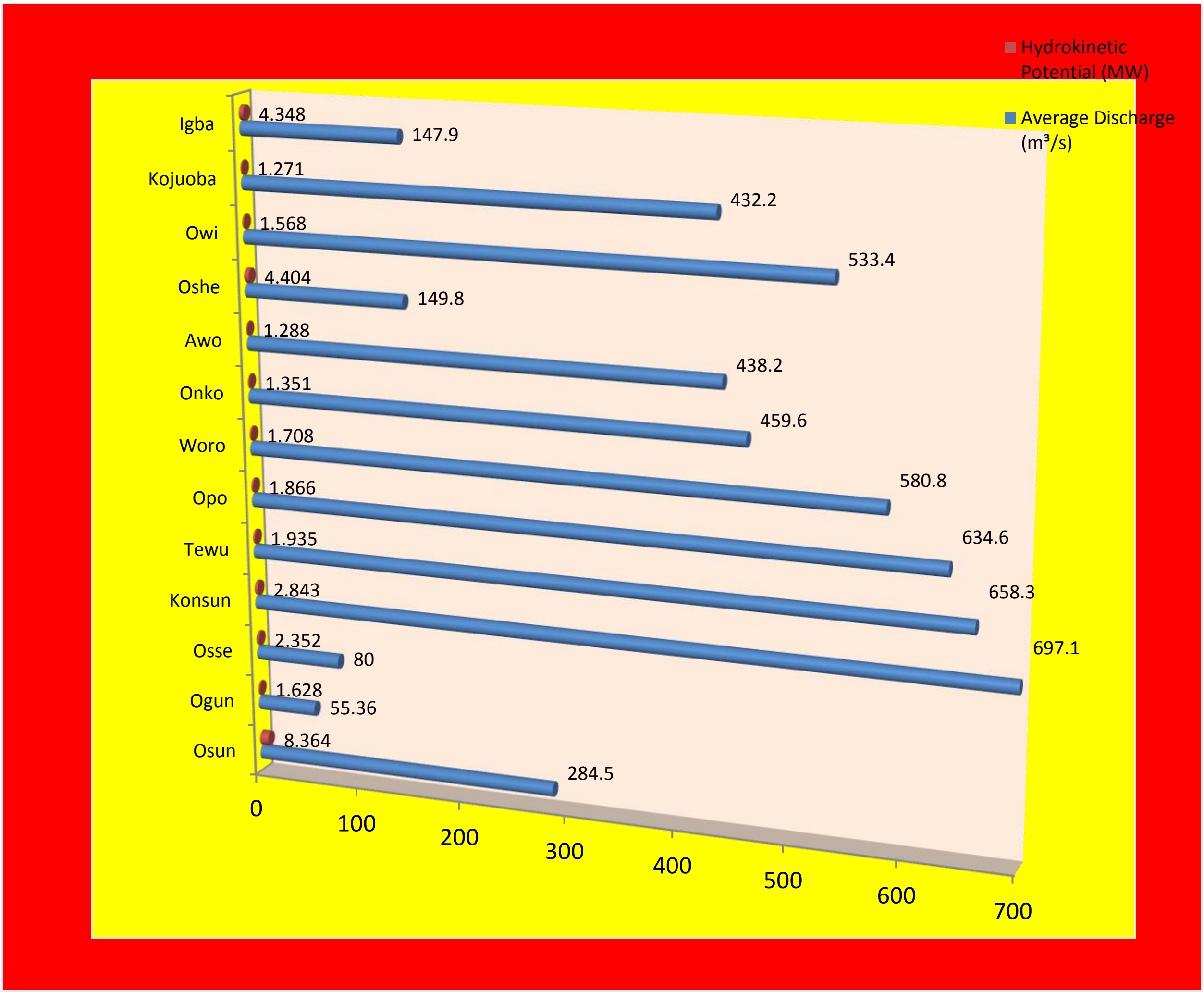

Figure 5: Average Discharge and Hydrokinetic Potential of Selected Basin in the Upper Ogun Basin Nigeria

SUMMARY AND CONCLUSION

The Development of the HKE is still at infancy in Nigeria but there is no doubt, its potential ; it is an alternative way of preventing constant power outages in Nigeria. Hydrokinetic power generation is a clean energy source with little or no side effects. Its potential is available in virtually all parts of the study area. This is because of the potential of flowing rivers. The available hydrokinetic potential differs from one area to the other depending on the discharge and the slope.

The Upper Kaduna basins have larger sub basins than the Upper Ogun Basin. In the UOB, most of the sub basins are generally smaller in size. This explains while they have weaker potential compared to the Kaduna basin (Tables 3 and 4 and Figures 4 and 5). However in some basins, hydrokinetic energy will only supplement existing hydroelectricity as available potential are generally low. Its development in Nigeria would provide a platform for building a virile economy and usher in massive rural and regional transformation particularly in poor countries in the world.

REFERENCES:

Alaska Center for Energy and Power (ACEP) (2011): *Hydrokinetic energy* (In-River, Tidal and Ocean Current), Retrieved from http://energy-alaska.wikidot.com/ on April 20th, 2014

Aquastat - *FAO's Information System on Water and Agriculture* http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/aquastat/countries/nigeria/index.stm

Botto, A., Chaps, P. Ganora, D., and Laio, F. (2010). Regional-Scale Assessment of Energy Potential from Hydro Kinetic Turbines used in Irrigation Channels. *SEEP 2010* ***Conference Proceedings,*** **Bari, Italy.**

Bureau of Public enterprises (2012). *Nigeria Power Sector investment Forum*- Lagos, Dubai, London, New York and Johannesburg.

Community Research and Development Centre (2009). *Energy Efficiency Survey in Nigeria, a guide for developing policy and legislation*, Benin, Edo State.

Bertsch, J.D. (2008). *Hydrokinetic energy: Trying to navigate the energy and water law frame Work to Develop New Renewable Energy Technolog*y; Juris Doctoral candidate, The University of South Dakota School of Law, 2011; B.S. Criminal Justice and Psychology, The University of South Dakota, 2008.

Electric power research institute, (EPRI) (2012). Assessment and mapping of the riverine hydrokinetic energy resource in the continental United States, *Technical Report,* EPRI Palo Alto, USA, pp. 1-2.

Energy Information Administration (2014). Retrieved on Dec. 20th, 2014 from www.eia.gov/electricity

Etiosa, U. (2009). Energy Efficiency Survey in Nigeria, *Community Research and Development Centre,* Benin, Edo State, Nigeria.

FAO (Food and Agricultural Organization) of the United Nations: *Hydrology and Inland Water Resources of Nigeria* retrieved from http://www.fao.gov.ng on 7th March, 2016.

Federal Ministry of Power and Steel (2004). Retrieved on June 20th, 2014 from www.power.gov.org/

Hydrovolt (2012). *Hydrokinetic power*. Retrieved on November 15th, 2014 from www.hydrovolts.com

International Energy Agency (2009). Retrieved on 20th June, 2014 from www.iea.org.

Kusakana, K., and Vermaak, H. J. (2013). Hydrokinetic Power Generation for Rural Electricity Supply: Case of South Africa. *Renewable Energy, 1*(55), 467-73.

Ladokun, L.L., Ajao, K.R., and Sule, B. F. (2013). Hydrokinetic Energy Conversion System: Prospects and Challenges in Nigerian Hydrological setting, *Nigerian Journal of Technology 3*(32), 538.

Musiliu, O.O. (2013). *Power Outages and the costs of unsupplied Electricity: Evidence from Backup Generation among Firms in Africa*, Judges Business School, University of Cambridge, UK.

Nigeria Direct - The Official Information Gateway of the Federal Republic of Nigeria http://www.nigeria.gov.ng/fed_min_water_resources.aspx.

Ocean Energy (2008). *Ocean Energy*. Retrieved on December 20th, 2014 from http: //ocsenergy.anl.gov/guide/wave/index.cfm.

Olusola, A. (2001*). Moving Nigeria forward: the development planning approach*, Ibadan University Press, Ibadan, Nigeria.

Oshodi, K.S. (2006). *Hydrological Study of Nigeria- A GIS Projec*t, GIS Hydro 2006, Centre for Research in Water Resources, University of Texas, USA.

Policy and Legal Advocacy Center P.L.A.C., River Basins Development Authorities Act, 1987, Retrieved from www.placng.org/new

Sambo, A.S. (2009). Strategic developments in renewable energy in Nigeria; *International Association for Energy Economics*, Third Quarter, 15-19.

Sandra, L.O. (2010). *Hydrokinetic power review: Civil and environmental engineering*, Mississippi State University, USA.

Temilade, S. (2008). *Status of renewable energy policy and implementation in Nigeria*, University of Nottingham, United Kingdom.

Verdant Power Canada, ULC (2006).*Technology Evaluation of Existing and Emerging Technologies-Water Current Turbines for River Applications, USA.*

Zarma I.H (2006). *Hydropower Resources in Nigeria*. 2nd Hydropower for today Conference of the International Center for small Hydropower (ICSHP), China. Canada

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