Leonardo Electronic Journal of Practices and Technologies
ISSN 1583-1078
Issue 30, January-June 2017
p. 287-298

Engineering, Environment

Hydro power potentials of water distribution networks in public universities: A case study

Olufemi Adebola KOYA[1], Temidayo Lekan OLADOSU*[1,2],

[1] *Obafemi Awolowo University, Ile-Ife, Nigeria*
[2] *Prototype Engineering Development Institute (NASENI), Ilesa, Nigeria*
E-mail(s): [1]afemikoya@yahoo.com, femikoya@oauife.edu.ng;
[2]temidayooladosu@gmail.com.
[*] Corresponding author, phone: +2347033549970.

Received: February 03, 2017 / Accepted: June 14, 2017 / Published: June 30, 2017

Abstract

Public Universities in Southwestern Nigeria are densely populated student-resident campuses, so that provision of regular potable water and electricity are important, but power supply is not optimally available for all the necessary activities. This study assesses the hydropower potential of the water distribution networks in the Universities, with the view to augmenting the inadequate power supplies. The institutions with water distribution configuration capable of accommodating in-pipe turbine are identified; the hydropower parameters, such as the flow characteristics and the pipe geometry are determined to estimate the water power. Global positioning device is used in estimating the elevations of the distribution reservoirs and the nodal points. The hydropower potential of each location is computed incorporating Lucid® Lift-based spherical turbine in the pipeline. From the analysis, the lean and the peak water power are between 1.92 – 3.30 kW and 3.95 – 7.24 kW, respectively, for reservoir-fed distribution networks; while, a minimum of 0.72 kW is got for pipelines associated with borehole-fed overhead tanks. Possible applications of electricity generation from the water distribution networks of the public universities are recommended.

Keywords

Renewable; Energy; Hydropower; Turbine; Lift-based; Nigerian Universities; Distribution line

Introduction

Hydropower is the energy generated from the kinetic energy of the falling mass of water, due to pressure gradient which is converted into electrical energy by electro-mechanical and hydraulic equipment. At the communal level, large-scale hydroelectric plants currently supply 16.3% of the world's electricity [1] but such projects often require tremendous amounts of land impoundment, dams and flood control, with the associated environmental impacts [2].

Environmental concerns have also driven changes in the design, construction, operation, and optimization of hydroelectric plants [3]. Therefore, miniaturized scales of hydropower plants have gained relevance, mainly in the developing countries. However, on the basis that supply of potable water and energy sustenance are major concern in human settlements, efforts have been made to harness the kinetic energy of the flowing water to simultaneously drive turbines, to generate electricity [4]. Although, university campuses in Nigeria may be treated as a type of human settlements with the potentials of similar benefits, they are usually supplied with processed water from public water treatment plants, or equipped with on-campus water treatment plants of the school water board. The processed water is then pumped into storage tanks at high elevations for distribution to the end users. Therefore, the promise of extracting energy will be feasible from the water distribution networks.

Water distribution system is a directed hydrologic and hydraulic system that ensures supply of water to the intended regions without affecting the quality and the optimum pressure. Excessive pressure heads in the pipelines is one of the major problems in water distribution lines that instigate static and dynamic hydraulic stresses in the water supply and distribution networks of several systems [5]. However, hydraulic devices such as pressure relief valves, water towers (surge tank) and hydro pneumatic devices (water arrestor) have been adopted to regulate hydraulic pressure, which in turn prevent pipes rupture in water distribution networks [6]. Literatures revealed that: extracting energy from such system appears practicable where water line’s pressure regulating device is replaced with turbine [5]. Pump as Turbine (PATs) in water line seems effective [7]. Other related works in this direction include a study of, hydropower potential from the drinking water systems of the Piemonte region (Italy) [8], water supply lines as a source of small hydropower in Turkey: A case study in Edremit [9]. Hydropower generation from service tanks, though modest in magnitude, have been reported in literature by Chen [10], and it was suggested that such configurations may be employed in powering on-line monitoring sensors. It also has the advantage that power extraction may be as much as the number and the capacity of distribution tanks. Lucid in-pipe energy by lucid technology analysed hydropower in water distribution lines where a lift based spherical turbine was considered instead of drag features of the conventional turbines [11]. In some of these applications, in-pipe turbines of various configurations were used or suggested, with the specifications depending on the flow characteristics and distribution-mains dimensions; albeit, there are very few reports on in-pipe water turbine [12]. The patented Lift based spherical turbine of lucid technology was considered suitable for hydraulic line optimization via energy recovery in gravity, pumped, combine gravity and pump water distribution configurations with established efficiency between 46 and 67% [13]. Therefore, energy recovery in water distribution lines is extended beyond replacement of pressure regulating devices in the hydraulic line alone but to the level of using lift-based in pipe turbines.

In Nigeria, public universities, particularly in the southwest enrol tens of thousands of students on a single campus, and electricity supplies are grossly inadequate, so that, fossil fuel generators are used as supplements. Meanwhile, energy requirements range from low Watts, for low-energy instruments and sensors, to tens of kilowatts for high powered machines. Fortunately, the population must be supplied with pipe borne water. It was therefore considered that, some of the energy needs may be harnessed from the water distribution networks. Consequently, the specific objectives of this work are to determine the hydropower generation parameters of water distribution systems of some selected public universities; estimate time series output of electricity for the selected universities. At present, hydropower potential investigation of water distribution networks in most of the countries municipal water networks is novel where Nigeria is not an exception. The aim of this study is to investigate the hydropower potentials of water distribution networks in some public Universities: A case study in southwestern Nigeria on the status of water distribution systems of the universities under investigation and to suggest recommendation for their reconfiguration to fully exploit established benefits.

Material and method

This study investigated the hydropower generation potentials, where appropriate operational water distribution networks were available in public universities in southwestern

Nigeria; the preliminary survey therefore identified three out of twelve public universities in the region as fitting for the study. The hydropower potential of the service reservoirs was considered as locations with possible appreciable power potential with the use of lift-based in-line spherical turbine. Consequently, the water distribution networks of the University of Ibadan, Ibadan (UI), Obafemi Awolowo University, Ile-Ife (OAU), and the Federal University of Technology, Akure (FUTA) were surveyed for data collection. The satellite images of the selected sites are shown in Figures 1, 2 and 3.

Figure 1. Service reservoirs locations at the University of Ibadan [17]

Figure 2. Service reservoirs and significant nodal point of Obafemi Awolowo University [17]

Figure 3. Service reservoirs location at the Federal University of Technology Akure (FUTA) [17]

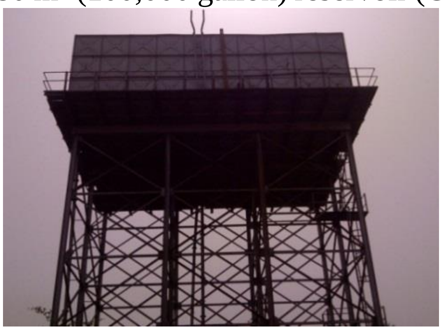
Determination of Parameters for Hydropower Generation Potential

Hydropower parameters such as, the pressure head, and the volumetric discharge for each site of interest were estimated as follow: The Global Positioning System (GPS) device (Garmin etrex® H GPS model, USA) [18] was used for effective head determination. The elevation of the nodal points of interest above the sea level was examined by placing the equipment at the nodal points, while the GPS was left at the point for satellite acquisition, until elevation error received from correction signal was nearly zero, then, the readings were taken. The measurements were replicated twice for each point to certify the accuracy of the readings. Having obtained the geo-reference data of every strategic nodal point in the water distribution networks of each site, the effective head was computed by estimating the differences in the elevation between the source nodes and destination nodes along the energy line to ensure water getting to its destination.

The volumetric discharge rates in cubic meters were taken in an hourly interval, using Kent volumetric water meters [19] (Elster Kent H4000 model, England) inserted along the energy lines. The internal diameters of samples of the pipes in the networks were measured to the nearest millimetres, using venier calliper (Mitutoyo 505 series dial calliper model, Japan). Figure 4 shows the plates of some of the service reservoirs and their locations.

(a) 380 m^3 (100,000 gallon) reservoir (OAU)

(b) Amina Way Elevated Reservoir at the UI



(c) Braithwaite tank at Stadium, UI

(d) NDDC tank at FUTA

Figure 4. Service reservoirs and their corresponding locations

The available effective pressure head and the discharge rate obtained for each site were used to compute the estimated hydropower potential of the site. Based on established conversion efficiency of in-pipe turbines, in converting available energy into electricity, lying within the range of 46 – 67 %, the minimum water to wire efficiency of 46 % was used for the computations. This was to avoid over-estimating the obtainable hydropower potential. The power potential was calculated using equation 1 below and the ancillary equations. The lean and the peak distribution discharges were used for the computation of the power potentials.

Computation of Hydropower Parameters

Empirical equations which are important in the derivation of hydropower parameters are well established in the literatures.

Basic parameters include the power derivable from the turbine, flow velocity, and the available pressure head.

Hydropower is computed [14] from equation (1) as:

$$P_t = \rho * g * H_n * Q * \eta_t \quad (1)$$

Where: P_t - the power generated in the turbine shaft (watt); ρ, water density (1000 kg/m^3); H_n - net head (m); Q, the water flow rate (m^3/s), g, gravity acceleration constant (9.8m/s^2), and $\eta_{t,}$ turbine efficiency.

The velocity of flow (V), in a close channel, is estimated using Hazen William's Formula [15], Eq. (2):

$$V = 0.85 * C_H * R^{0.63} * S^{0.54} \quad (2)$$

Where: C_H - coefficient of hydraulic capacity; R - hydraulic mean depth of pipe (m) $=\frac{area\ of\ the\ pipe}{wetted\ perimeter} = (^{d}/_{4})$; C_H = 100, for cast iron pipe with age above 20 years; S – hydraulic gradient or frictional slope of the energy line (H_L/L); d in m - the inner diameter of the pipe; H_L - head loss, and L in m, is the length of the pipe.

The modified Hazen William's formula is derived from Darcy-Weisbach and Colebrook –White equations, which obviates limitations of other formula for estimating head loss [15]; so, that Eq. (3),

$$V = \frac{3.83C_R\left[d^{0.6575}(g.S)^{0.5525}\right]}{v^{0.105}} \quad (3)$$

Where: C_R - dimensionless coefficient of roughness; d - pipe diameter; g - acceleration due to gravity; S - friction slope; which equals H_L/L; v - viscosity of water and, for water at 20^{0}C equals 10^{-6} m^2/s.

Therefore, Equation (3) reduces to, Eq. (4):

$$V = 143.534C_R.R^{0.6575}.S^{0.5525} \quad (4)$$

And, Head loss (H_L) is written as, Eq. (5)

$$H_L = \frac{L.\left(^{Q}/_{C_R}\right)^{1.81}}{994.62.d^{4.81}} \quad (5)$$

Energy in running water is stored in terms of pressure energy, velocity energy and elevation energy. As reported by Kucukali [9], Bernoulli energy equation between two sections

1 and 2, if a velocity head correction factor of 1 is employed [16], the hydraulic head loss may be found from Eq. (6):

$$U_1/_{2g} + p_1/_{\gamma} + z_1 = U_2/_{2g} + p_2/_{\gamma} + z_2 + \Delta H \quad (6)$$

Where: U - the average velocity, p - the pressure, z - the elevation above an arbitrary datum, g - the acceleration of gravity.

The pressure head is therefore given as, Eq. (7):

$$\Delta H = (P_1 - P_2)/_{\gamma} + (z_1 - z_2) \quad (7)$$

Results and discussion

The study identified two main service reservoirs with 250 mm feeder pipe, situated at different elevated positions in Obafemi Awolowo University. The designed capacities of the reservoirs are 757 and 379 m^3 (as shown in Table 1), but the latter was not connected to distribution mains. The capacity of these reservoirs appeared enough for some reasonable hydropower potential for the campus. The elevations and geo-referenced coordinates of the nearest nodal points to distribution reservoir taken as following: The highest point on the roof of school of sciences is N07^{0}31’16.9″, E004^{0}31’19.2”, 306 m; Linguistic and African Studies N07^{0}31’18.4”, E004^{0}31’16.7”, 314 m, Tetfund Building Roof N07^{o}31’20.3”, E004^{o}31’11.4”, 315 m described as Old Bukar. Therefore, the effective head is computed to be 16 m, since 315 m is the next highest nodal point to the source node. The main water distribution reservoirs of the University of Ibadan were located at Amina way, Stadium, Lander, and Kurumi. However, Kurumi service reservoirs were not in use at the time of the study, while service reservoirs at Lander station were not gravity-drawn systems. The diameter of the main distribution pipes is 250mm. The capacity of reservoirs at UI found to be higher than what obtains in OAU; and with appreciable pressure heads, higher hydropower generation may be feasible.

Water use at the Federal University of Technology was solely from ground water sources via numerous boreholes. At full operating capacity, the combined installed output was 1152 m^3/day, but with combined operational capacity of 806 $m^{3/}$s. Large number of service tanks are installed at various locations on the campus but the three main service reservoirs with appreciable capacities are located at NDDC, Hill Top and Jibowu distribution stations. The three reservoirs therefore formed the basis of the estimated hydropower potentials for the campus. Table 12 summarized the peak and the lean power potential of the university considered.

Table 1. Hydropower parameters of the service reservoirs in the selected Universities

University	Capacity	Reservoir coordinate and elevation	Effective head (m)	Mains pipe diameter (m)
OAU				
Reservoir 1	757 m^3 (200,000 gallons)	N07^0 31’ 26.2”, E004^{0}31’16.6” and 331 m	16	0.25
Reservoir 2	379 m^3 (100,000 gallon)	N07^{0}31’30.7”, E004^{0}31’11.0” and 371 m	28	0.25
UI Ibadan				
Amina Way	1200 m^3	N07^{0}26' 44.46"N E003^{0}54'18.42"E and 246 m	17.9	0.25
(Stadium)	690 m^3	N07^{0}26’05.06”, E003^{0}53’26.29 and 241.2 m	13.7	0.25
FUTA				
NDDC	126 m^3	N07^{0}18’24.3”, E005^{0}08’16.0” and 406 m	7.5	0.10
Jibowu	150 m^3	N07^{0}18’12.53”, E005^{0}08’28.32” and 398.5 m	8	0.10
Hill Top	147 m^3	N07^{0}18’20.5”, E005^{0}08’08.4, and 418 m,	12.3	0.10

Time Series of Electricity Output Potential of the Selected Universities

Figure 5 is the plot of volumetric discharge and the distribution periods and figure 6 gives the deducible nominal power output, estimated from hydropower data of the different stations, for the various periods of the day. However, the time series of hydropower potential estimation of FUTA is not shown, because the reservoirs were filled at irregular intervals.

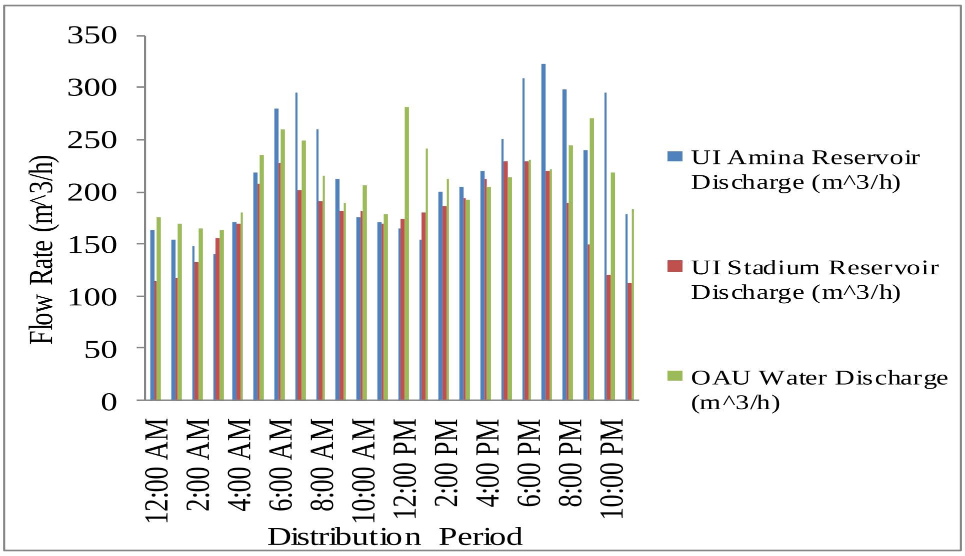


Figure 5. Time series flow rate and hydropower for the different distribution period

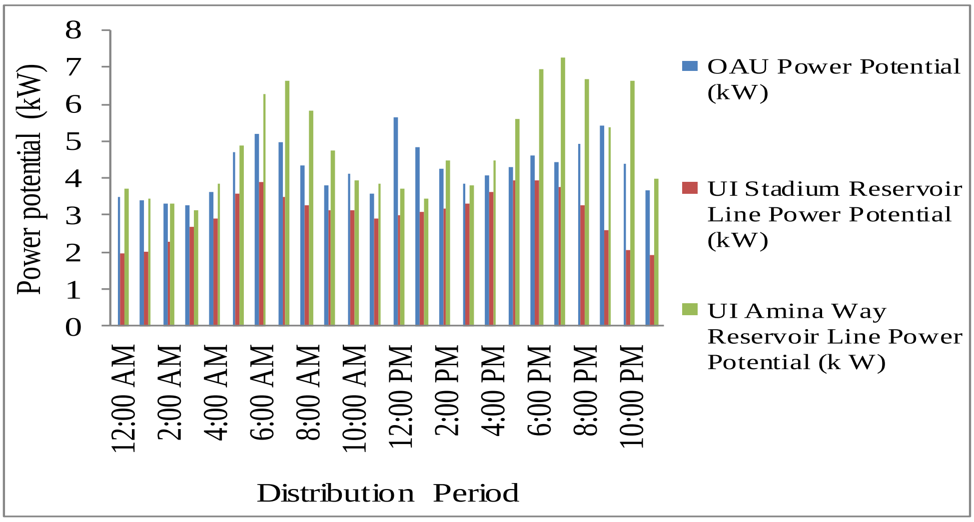


Figure 6. Distribution period and hydropower potential

This study reveals that the water consumption of OAU and UI follows similar patterns, with the peak at about 7.00 am and 6.00 – 8.00 pm as shown in the table 2.

Table 2. Summary of peak and lean estimated hydropower potential presents in water distributions networks of selected public universities

Site Studied Reservoirs	Service Pipe Diameter (m)	Hydropower Potential			
		Peak		Lean	
		Flow rate (m^3/h)	Power (kW)	Flow rate (m^3/h)	Power (kW)
OAU					
UI	0.25	281	5.63	163	3.27
Amina Way Stadium	0.25	323	7.24	140	3.14
	0.25	230	3.95	112	1.92
FUTA					

Jibowu	0.1	288	2.89	72	0.72
Hill Top			4.44		1.11
NDDC			2.71		0.68

The lean water consumption periods were in the dead of the night (about 1.00 am) and in the afternoon. Therefore, the demand for water at these periods is low. The relevance of water consumption rate to this study stance on the fact that: water distribution flow rate depends on the consumption rate and flow rate is a critical parameter in hydropower computation. The study considered the design peak and lean flow rates of Federal University of Technology Akure water distribution networks due to irregularities in the period of water distributions and unavailability of online monitoring flow meters.

Based on the estimated flow characteristics in this study, and using the lucid turbine performance [11], the Lift-based Spherical Turbine (LST) with NACA 0020 foil cross-section was found suitable for extraction of electrical energy in the water distribution pipelines [20]. The derived electrical energy may be exploited in driving appropriate device(s) suitable for the available hydropower. The modest wattage attainable in the sites investigated can be used off-grid in augmenting power supply. The simplest may be in on-condition monitoring of the water distribution equipment and the ancillary facilities, or as input for small laboratory equipment, or in lighting low energy bulbs. Sombat suggested that, 0.644 kW rate of hydropower derived from a farming village in upstream watershed in Thailand, was suitable for off grid applications (indoors appliances) [21]. Furthermore, optimization of the turbine, using appropriate numerical tools, may also enhance its efficiency, and therefore, improve the derivable power output.

Conclusions

The study evaluated the hydropower generation potentials of three public universities in south western Nigeria. The hydropower potentials of the selected universities were characterised by minimum water distribution flow rates of 112 – 163 m^3/h at lean periods, 230 – 323 m^3/h at peak periods, in reservoir-fed 250 mm diameter pipe networks, yielding 1.92 – 3.30 kW and 3.95 – 7.24 kW power respectively. Borehole-fed overhead tanks in one of the universities yielded a minimum of 0.72 kW. The Lift-based Spherical Turbine (LST) with NACA 0020 foil cross-section was found suitable for extraction of electrical energy in the water distribution pipelines. It is recommended that future work may model and numerically compute the electric power potential of in-pipe turbine, to optimize its design features. The head loss due to insertion of in-pipe turbine and effect of pipe diameter on the magnitude of the potential power may also be considered.

Acknowledgements

My profound gratitude goes to administration of the institutions visited for data gathering by using their water distribution equipment: Obafemi Awolowo University, University of Ibadan, and Federal University of Technology Akure, Nigeria. I also appreciate Prototype Engineering Development Institute, Nigeria for the opportunity (release to further) accorded to pursue my M Sc. because this paper was derived from the research objectives.

References

1. IEA, *The international energy's renewable energy essentials: hydropower*, International Energy Agency, 2010, p. 1-4.
2. Dilip S., *Micro hydro power, resource assessment handbook*, An Initiative of the Asian an d Pacific Center for Transfer of Technology of the United Nations (APCTT) Economic an d Social commission for Asia and the Pacific (ESCP), (2009), p. 02-10.
   Available at: http://www.recap.apctt.org/Docs/MicroHydro (accessed June, 2015).
3. Odeh M., *A summary of environmentally friendly turbine design concepts*, Prepared for United States Department of Energy, Idaho Operations Office, Advanced Hydropower Turbine System Program, 1999, (online) Available at: http://www.nipptransactions.com (accessed: April, 2015).
4. Hosseini S.M.H., Forouzbakhsh F., Rahimpoor M., *Determination of the optimal installati on capacity of small hydropower plants through the use of technical, economic and reliabi lity indices*, Energy Policy, 2005, 33, p. 1948-1956.
5. Fecarotta O., Arico C., Carravetta A., Martino R., and Ramos H.M., *Hydropower potential in water distribution networks: pressure control by PATs*, SpringerScience+Busi ness Media Dordrecht, 2014, p. 2.
6. Shu J., *Modelling vaporous cavitation's on fluid transients*, International Journal of pressure Vessels and Piping, 2003, 80 (3), p. 187–195.

7. Carravetta A, Del Giudice G, Fecarotta O, Ramos H.M., *Pat design strategy for energy recovery in water distribution networks by electrical regulation*, Energies, 2013a 6(1), p. 411–424.
8. Soffia C., Miotto F., Poggi D., and Claps P., *Hydropower potential from the drinking water systems of the Piemonte region (Italy), SEEP 2010* Conference Proceedings, June 29th – July 2nd, Bari, ITALY, 2010, p. 1-12.
9. Kucukali S., *Water supply lines as a source of small hydropower in Turkey: A Case study in Edremit*, World Renewable Energy Conference, Sweden, 2011.
10. Chen J., Yang H.X., Liu C.P., Lau C.H., Lo M., *A novel vertical axis water turbine for power generation from water pipelines*, Energy, 2013, 54, p.184-193.
11. Lucid Technology, Lucid Energy, available at: http://www.lucidenergy.com (accessed 4^{h} feb. 2014).
12. Antheaume S., Maitre T., Achard J.L., *Hydraulic Darrieus turbines efficiency for free flui d flow conditions versus power farms conditions*, Ren. Energy, 2008, 33(10):21, p. 86-90.
13. Schlabach R. A., Cosby M.R., Kurth E., Palley I., Smith G., *In-Pipe hydro-electric power system and turbine*, US Patent Application Publication, (Northwest Pipe and Lucid Energy), Patent (10) Patent No.: US 7,959,411 B2, 2011.
14. Khurana S., Hardeep S., *Effect of cavitation on hydraulic turbines-A review*, International Journal of Fluid Mechanics Current Engineering and Technology, 2012, (2) 1, p. 172-177.
15. Garg S. K., *Environmental Engineering*, Water Supply Eng., 1: p. 261-2, 694-5, 2005.
16. White F.M., *Fluid Mechanics*, 7th Edition, McGraw-Hill, New York, 2011, p. 169-176.
17. Google Earth, *Google Earth software*, produced by Google Incorporated, available at: www.google.com/earth, 2015.
18. GPS, *Garmin Etrex GPS receiver*, Garmin Ltd., available: http://www.garmin.com, 2015.
19. Elster Kent H4000, Elster Water Metering Limited 130 Camford Way, Sundon Park Luton, Bedfordshire, United Kingdom. 2015, available at: http://www.elstermetering.com
20. Oladosu T.L., *A study of hydropower generation from water distribution network in public university in south western Nigeria*, Unpublished M Sc. thesis: Obafemi Awolowo University Ile-Ife, Nigeria, 2016.
21. Sombat C., *Development of Pico-hydropower plant for farming village in upstream watershed*, Thailand, Prosperity and Poverty in a Globalised World-Challenges for Agricultural Research, 2006.