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MICRO-HYDROKINETIC EXPLORATION OF A SELECTED UNREGULATED RIVER (RIVER DINDIMA), NORTH EAST NIGERIA FOR ITS ENERGY POTENTIAL

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ABSTRACT

Micro-hydrokinetic river (MHR) system is one of the promising technologies to be used for remote rural electrification. It simply requires the flow of water instead of elevation or head, leading to expensive civil works. It also demonstrates an economic benefit offered by a MHR system when compared to the commonly used systems such as solar, wind and diesel generator (DG) at the selected study site. A novel technique of estimating the daily average water velocity data in unregulated rivers is proposed. The modelling of regression equation for water velocity estimation was performed and a regression model equation was developed to estimate the water velocity on-site and proven to be valid. The daily average water level from river Dindima River was measured concurrently for two months (94 samples) as training data. Both datasets were analysed using the regression analysis method. Eight regression models were selected and analysed. As a result, the regression model Cubic curve (76%) exemplified the highest R-square value, followed by Quadratic curve model (75%), Exponential and Compound curve model (59%), Linear curve model (57%), Power curve mode (38%), Logarithmic curve model (37%), Inverse curve model (21%). The quadratic model equation was chosen due to its significant of correlation (P) less than 0.01 as well as collinearity. Based on the result (strong correlation of 81% and significant P-value of 0), there exist a strong relationship between the water level and water velocity on-site. Therefore it can be interpreted that the increment in water level can significantly hike the water velocity on-site. The regression model equation can be used to estimate long-term time series water velocity data for unregulated river in such remote areas as a very good fit between the estimated and actual velocities was obtained moreover correlation analysis carried out gave a correlation coefficient of 0.99 thus validating our results and confirming the model.

Keywords: Hydrokinetic; Energy assessment; Water velocity; Regression Analysis; Modelling.

INTRODUCTION

A solution to remote rural electrification is made possible by means of approaches/techniques such as grid-extension, diesel generator (DG) or a small-scale off-grid hydro or solar renewable energy system. Harnessing hydrokinetic energy is similar to converting wind energy into electrical energy. It generates electricity by making use of underwater wind turbines to extract the kinetic energy of flowing water instead of the potential energy of falling water. Hence, no construction of dams or diversions is necessary; it therefore creates a minimal environmental footprint (Mosallat, 2012, Van *et al.*, 2011). When considering rural electrification, one of the basic questions to be addressed is affordability. Most rural residents are low-income earners, with low living standards, limited education and little access to information. To improve the living conditions of poor rural households, it is important to provide the affordable and reliable electricity. Small remote rural communities often require electricity for small loads such as lighting, refrigeration, entertainment, etc. (Anyi*et al.*, 2007). Micro-hydrokinetic system is one of the most official and cost-effective approach as a solution for remote electrification, especially in small villages located at hilly terrains.

The aim of the research is to estimate the water velocity of an unregulated River for micro-hydrokinetic potentials for rural residents not served by the grid and are close to proximity to flowing water.

STUDY AREA

Dindima is a village in Duguri district of Alkaleri local government area, Bauchi state. The study area is enclosed in geographical coordinates of $10^0\ 3^0\ 13''$ North and $10^0\ 17^0\ 27''$ East. Rainfall starts around April/May with its peak in August and ends by October while flood occurs during the raining season (July to September). The settlement is found very close to the river, also it is primarily used for irrigation, fishing, etc. The basic occupation in Dindima is farming.

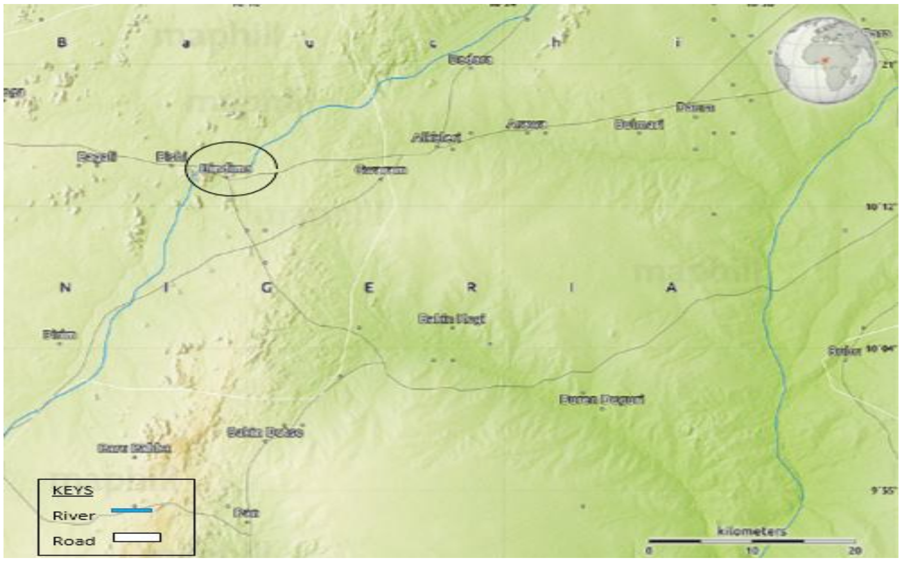

Figure 1: Map of the study area (© Alkaleri Local Government Council)

THEORY

The regression analysis method has been used to determine the relationship of water levels the study site and a reference site (Dadin-Kowa dam) by using the mathematical model equation shown in equation 1. The regression analysis incorporates five types of regression, such as Linear, Logarithmic, Quadratic, Cubic and Exponential curve type.

The regression model equation for this study had been selected based on two criteria outlined by Klunne, (2013), which are the highest value of coefficient of determination (R^2) and the significant coefficient of correlation (p) less than 0.01, in regression simulation results represented as (Sig. < 0.01). The regression model is considered as the best fit model if the value of the coefficient of determination (R^2) value exceeds 70% (Liu *et al*., 2003).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(yi - \hat{y}i)2}{\sum_{i=}^{N}(yi - \bar{y})2} \quad (1)$$

where N is the number of observations in the model, y is the dependent variable, y-bar is the mean of the y values and y-hat is the value predicted by the model.

The kinetic energy of a flowing fluid can be determined from the density of the fluid, the velocity at which the fluid travels and the cross sectional area at which the energy will be extracted.

$$P_k = \frac{\rho}{2} AV^3 \quad (2)$$

Where P_K is the available kinetic power; ρ is the fluid density; A is the cross sectional area of extraction and; V is the flow velocity. Hydrokinetic power is often reported as a power density which is the power normalized to a unit area (Klunne, 2013).

$$P_k/A = \frac{\rho}{2} V^3 \quad (3)$$

When considering flows in rivers, one can make the reasonable assumption that the density remains essentially constant, even with changes in temperature. The velocity and area remain the only variables required to determine the kinetic power. Consequently, the determination of the velocity in a river, specifically the time averaged velocity frequency distribution, is the essential and the primary factor in assessing the available kinetic energy available in a river.

The calculation of the kinetic power depends of the cross section area which is either the river cross-sectional area for an assessment of the total energy in the river, or the area of the device that will be used to extract the kinetic energy.

MATERIALS AND METHODS

The following materials were used:

Driftwood (250g): This is used for estimating the velocity of the river.

Digital weighing balance: This is used for measuring the mass used on-site.

Field notebook: It is used for recording data on-site.

Tape: It is used for taking measurement from point A to point B.

Stop watch: It is used for taking time (duration) in seconds.

Meter stick: It is used for measuring the depth of the river.

The methods are according to Figure 2. Stage one compare the daily average water level data on-site and the actual water level data accumulated from Upper Benue River Basin from Dadinkowa Area Office to establish any correlation. Stage two estimates daily average water velocity data on-site throughout the year by using the actual water level data from the site itself.

The regression analysis method was used to identify the relationship between water velocity and water level on-site, thus providing the regression model equation by adhering to the flowchart illustrated in Figure 2. Finally if validated, the long-term time series of the daily average water velocity data on-site can been estimated throughout the year by using the daily average water level data.

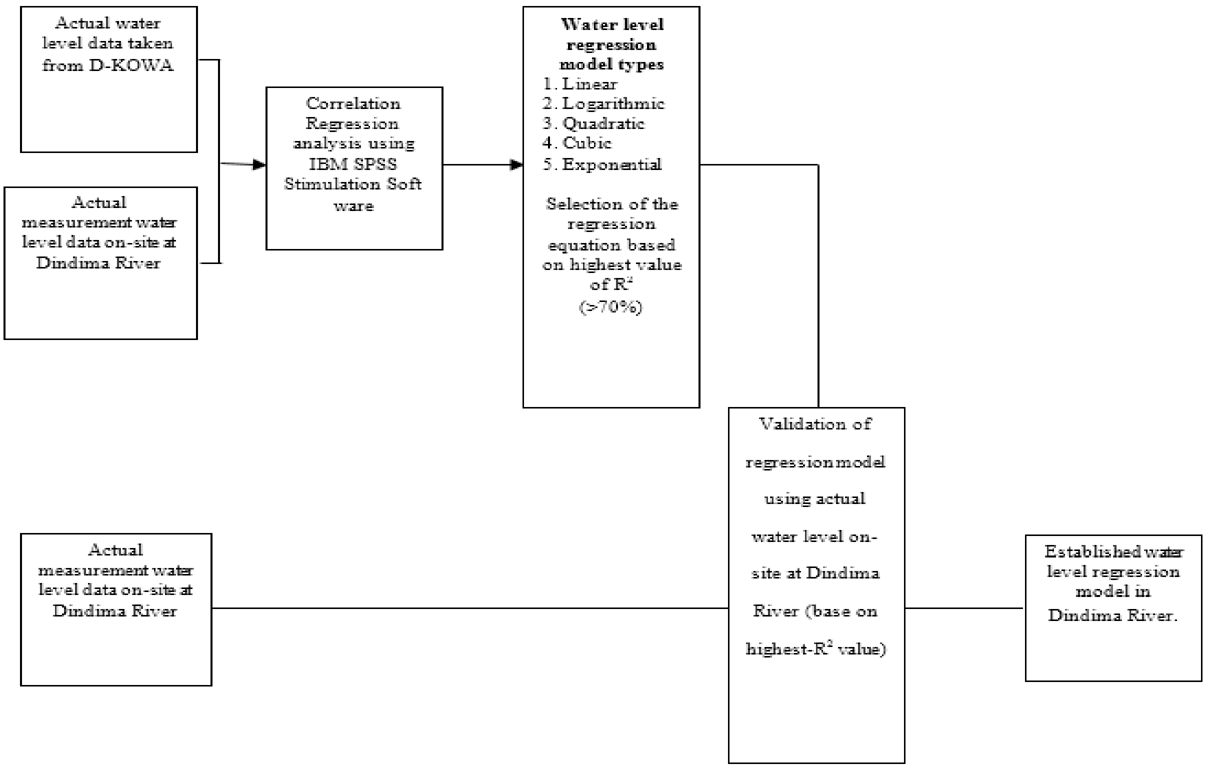

Figure 2: Flowcharts to estimate water level and velocity at Dindima River (on-site)

The daily average water level data were measured on-site by measuring the depth on daily basis for two months (47 days). The water level data had been taken twice a day at 7:00 a.m. and 5:00 p.m. daily average water level data was obtained.

The accuracy of water velocity measurement in unregulated river demands special equipment that can only be operated by experts such as Acoustic Doppler Current Profile (ADCP). However, due to the absence of such instrument the Surface Floating Method (SFM), was used to measure water velocity data on-site as it is the most economical way for collecting data, which can be handled by workers without specific skill and the data could also be collected throughout the year, even during flood season (Kunaifi, 2009).

A driftwood of 250g was placed at a point A and allowed to drift with the flow direction to point B which is 2 meters apart from point A (Figure 3). From the time interval, the velocity was then be computed.

RESULTS AND DISCUSSION

CORRELATION ANALYSIS

Based on the result (Table 1), water level data on-site showed poor relationship with the reference site for the period of study hence regression analysis process was dropped for those set of variables. Conversely, there exist a strong correlation of 81% and significant P-value of 0 which suggests strong relationship between the water level and water velocity on-site. Therefore, it can be interpreted that the increment in water level can significantly hike the water velocity on-site. Since the parameters showed strong relationship between each other, they were retained for the next process that involved regression analysis modeling.

Table 1: Correlation results among variables

		Water level at Dindima river
Water level at Dadin-Kowa dam	Pearson Correlation	0.33
	(Sig.) $P < 0.01$	0.001
	N	39
Water velocity at Dindima river	Correlation Coefficient	0.81
	(Sig.) $P < 0.01$	0.000
	N	47

ESTIMATION OF WATER VELOCITY USING REGRESSION ANALYSIS METHOD

The regression analysis was performed and involved eight types of regression models, as illustrated in Figure 3 and Table 2. The dependent variable is the velocity (v) while the independent variable is the water level (WL). The regression model of linear (57%), logarithmic (37%), inverse (21%), compound (59%), power (38%) and exponential (59%) showed the lowest R square values. That of quadratic (75%) and cubic (76%) exhibited the highest R square values however the quadratic model equation was chosen due to its significant coefficient of correlation (p) less than 0.01 as well as its collinearity.

The developed quadratic model equation is:

$$v = 5.9 - 3.19WL + 0.45(WL)^2 \qquad (4)$$

VALIDATION OF WATER VELOCITY REGRESSION MODEL

By applying the model we obtained in equation (4), the estimated water velocity data on-site recorded from September, 2019 had been generated. At the time of measurement of actual water velocity data on-site, the validation of the regression model was carried out concurrently, as illustrated in Figure 3.

The plots according to Figure 4 showed a very good fit between the estimated and actual velocities moreover correlation analysis carried out gave a correlation coefficient of 0.99 thus validating our results and confirming the model.

Table 2: Model summary and parameter estimates

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.057	1.277	1	21	.271	.106	.054		
Logarithmic	.037	.803	1	21	.380	.105	.153		
Inverse	.021	.450	1	21	.509	.419	-.409		
Quadratic	.749	29.845	2	20	.000	5.904	-3.191	.450	
Cubic	.758	31.380	2	20	.007	2.128	.000	-.441	.082
Compound	.059	1.322	1	21	.263	.159	1.188		
Power	.038	.840	1	21	.370	.158	.496		
Exponential	.059	1.322	1	21	.263	.159	.172		

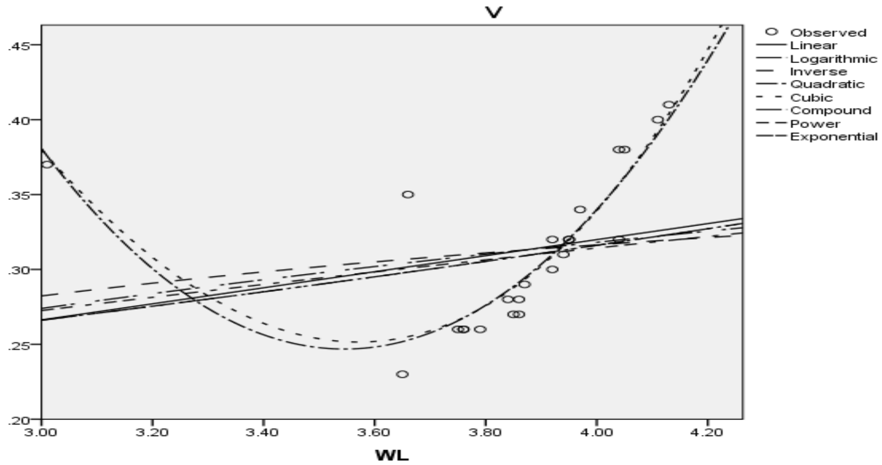

Figure 3: Analysis result of eight types water velocity regression models

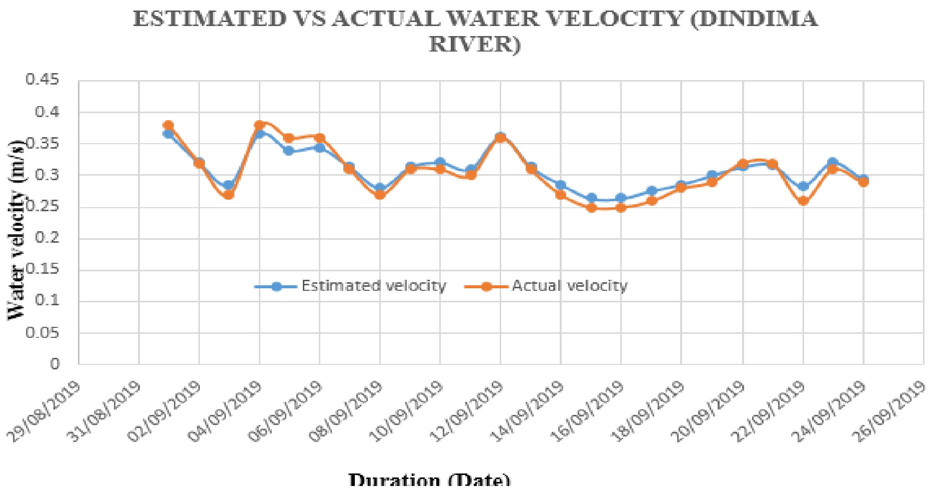

Figure 4: Variance between estimated and actual water velocities on-site

CONCLUSIONS

The Dindima River showed that its rising water level has no relationship with the Dadin-kowa River. Nevertheless, the relationship between water level and water velocity at the study site is proven to be non-linear when a quadratic curve was applied. The standard of procedure proposed is proven to be adequate and reliable for predicting the daily average water velocity data throughout the year for unregulated rivers especially in the remote area of Akko Local government and environs.

The ability to estimate such water velocity data offers opportunities and encouragement to other researchers to continue studies pertaining to hydrokinetic power generation systems, particularly for remote area electrification in Dindinma village and surrounding villages. This procedure is also highly recommended to be extended to other remote area rivers around the country especially for sites with limited water discharge and rainfall data. Furthermore, this method is much cheaper, safer and does not require the specific skills for data measurement on-site.

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