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Article

Hydrokinetic Energy Assessment in Unregulated River for Hydrokinetic Performance Analysis Studies in East Malaysia

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Abstract: Electrification coverage in Sarawak is the lowest at 78.74%, compared to Peninsular Malaysia at 99.62% and Sabah at 82.51%. Kapit, Sarawak with its 88.4% populations located in rural areas and mostly situated along the main riverbanks has great potential to generate electrical energy by hydrokinetic system. Yearly water velocity data is the most significant parameter to perform hydrokinetic analysis study. Nevertheless, the data retrieved from local river databases are inadequate for river energy analysis, thus hindering its progression. Instead, flow rates and rainfall data had been utilised to estimate the water velocity data. This signifies no estimation of water velocity in an unregulated river by using water level data had been made. Therefore, 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 two regression model equations were generated to estimate both water level and water velocity on-site and proven to be valid as the coefficient of determination values had been $R^2 = 87.4\%$ and $R^2=87.9\%$, respectively. The combination of both regression model equations can be used to estimate long-term time series water velocity data for type-C unregulated river in remote areas.

Keywords: Hydrokinetic; Energy assessment; Unregulated river; Daily water velocity estimation; Daily water level estimation; IBM Statistical Package for Social Sciences (SPSS); Regression Analysis; East Malaysia

1. Introduction

To date, approximately 1.4 billion people worldwide lack access to electricity, with 85% of them residing at rural areas [1]. The electrification status of Malaysia in year 2010 showed that the coverage of electrification for Peninsula Malaysia was 99.62%, in comparison to East Malaysia (Sabah and Sarawak) with 82.51% and 78.74%, respectively [2]. Referring to the 10th Malaysia Plan towards 2015, the villages with electricity supply were projected at 100% for Peninsula Malaysia, while 99% for East Malaysia [3]. Until year 2010, the survey to Sarawak population carried out by the Sarawak Statistics Department revealed that about 88.4% of the population in the Kapit Division, Sarawak resided at rural areas, where grid-connected power supply was inaccessible. Electricity is a basic necessity for mankind apart from clean water and food supply, heat and light from the sun, as well as medical and transport facilities. Nevertheless, supplying electricity to small rural communities by distributing and stepping down the high voltage power line along inhabitable areas appear to be uneconomic and impractical in terms of initial cost and maintenance [2], [4]. The cost for grid extension varies from USD 6,340/Km in a densely populated country to USD19,070/Km in some nations [3]. As a consequence, diesel generators have turned popular for supplying electricity to villages and schools in remote areas due to their durability and reliability. However, diesel generators have some disadvantages, such as noise and air pollution, too heavy and difficult to carry to remote areas, aside from the expensive operating costs to supply diesel fuel and maintenance costs [4], [5]. In Malaysia, the use of decentralised diesel generator for schools in remote areas has also strained government finances, whereby over than RM1.0 million/ year [6] was spent for each rural school in Sarawak to bear the operating, maintenance, and diesel fuel costs in ensuring that the amenities in these rural schools are on par with those at urban schools, as initiated by the Malaysian Ministry of Education (MOE) [7]. Hence, in order to overcome the rising costs of operation and maintenance of diesel generator, as well as to address the global warming concern due to the increasing greenhouse gasses emission each year, the MOE has launched a remote area electricity program via green technology through the provision of RM1.5 billion from the green technology policy, in which the action plan has gained approval [8]. The benefits of this green energy policy in terms of profit and high return of investment have attracted the industry players to contribute their expertise in providing electric energy supply using renewable energy, particularly to rural areas.

Micro-hydro that uses renewable energy resources is classified in the hydropower family and is viewed as a solution for remote electrification, especially in small villages located at hilly terrains with a compulsory need of 10-meter head for small dam construction. In fact, A. K., Othman et al., [9] asserted that the small-scale micro-hydro power installed at six remote locations in Sarawak by University Malaysia Sarawak (UNIMAS) and Partners of Community Organization, Sabah (PACOS) from 1997 until 2008 signified that micro-hydro is indeed a viable solution for remote area electrification in future. However, M., Anyi [4] claimed that this system is unsuitable for those residing at lowlands or along the main riverbank. The author had evaluated a number of micro-hydro systems and concluded that the hydrokinetic system emerged as the most efficient and cost-effective approach, in comparison to the existing micro-hydro system.

The pattern of population in Sarawak is mostly near or adjacent to the schools, as illustrated in Figure 1, is mostly located along the main riverbank without elevation, thus implying the potential to generate electrical energy by using hydrokinetic system. As such, the Kapit District had been chosen as the case study venue due to the revelation by [2] that East Malaysia disclosed the lowest electricity coverage and the highest concentration of poor populations, but with 40 rivers available for potential electricity generation. Hydrokinetic technologies are designed to harness energy from free flow moving water to generate power without exerting any negative impact upon the environment [10], [11]. Unlike other renewable energy sources that are unpredictable and intermittent by nature, hydrokinetic energy sources are more stable, predictable, and unaffected drastically due to weather changes, thus allowing for estimation of accurate water velocity patterns at a few days earlier [12]. Prior studies concerning hydrokinetic system across nations heavily focused on the development of hydrokinetic turbine blade [5], [10], [11], [13], and the potential of studied site [2], [14]–[17], while only three studies had looked into the performance of hydrokinetic study in Riau, Indonesia and KwaZulu-Natal in South Africa [18]–[20]. As for Malaysia, only one study had been found to investigate the development of hydrokinetic turbine blade through Sustainable Hydrokinetic Renewable Energy (SHRE) research, as initiated by JKR Malaysia [21] in collaboration with University Putra Malaysia (UPM). This clearly shows that no study has probed into the performance of hydrokinetic system in Malaysia.

In analysing hydrokinetic performance, the daily water velocity data collected throughout the year are the significant parameter that ascertains 24-hour operation of the system. Nonetheless, such data are not supplemented by the Malaysian Department of Irrigation and Drainage (DID). Hermas J., Vermaak and K., Kusakana [5], in their hydrokinetic review study until 2014, highlighted the scarcity of hydrokinetic resources assessments, as the global river databases from DID are impractical for river energy analysis. Similarly, Emilia Lalander [22] noted the same in her hydrokinetic assessment study in Sweden. Due to limited water velocity data retrievable from global river database, water flow rate data had been applied to estimate water velocity data in hydrokinetic performance analyses, provided that the project sites are located close to hydrological station [22]–[25]. In the absence of hydrological station, rainfall data were gathered by Kunifii [19] in a hydrokinetic performance analysis study in Riau, Indonesia, so as to estimate the daily average water velocity for unregulated river. Although the methodology seemed non-intricate, it provided

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inaccurate results. In practice, the installation of rain gauge stations by DID is within a radius of 50 Km. Nevertheless, Mishra Anoop Kumar [26] discovered that if the distance of radius between rain gauge stations exceeds 15 km, the rainfall data would be highly varied and inaccurate. Instead of using rainfall data to estimate daily average water velocity on-site, the usage of water level data seems more accurate as they reflect the total amount of rainfall in the upper reaches of the river regardless of the distance of the river to upstream. As for the Baleh River in Kapit, Sarawak, its water level may rise dramatically from 4 m up to 14 m with strong river flow if continuous rain pours for 72 hours. The cross-sectional area of the river cannot be measured using ADCP during high water levels (8 m and above) due to safety reasons, such as to avoid strong river flow and floating logs. Estimating water velocity through water flow rates is impractical due to safety reason for almost all rural rivers in East Malaysia. The nearest hydrological station in Entawau, unfortunately, does not provide flow rate data, but only daily water level data. M., Previsic, R., Bedard, and E., Lalander emphasised that water level does influence water velocity, and the correlation between velocity and water discharge is non-linear [17], [22]. The gap that this research seems to bridge refers to the absence of study that has estimated water velocity of river by using water level data. As such, this research proposes a new technique that estimates daily average water velocity data throughout the year in unregulated rivers for further hydrokinetic performance analysis. Regression modelling equations for water velocity and water level estimation were modelled by using IBM Statistical Package for Social Sciences (SPSS), version 22 analysis software [27]. These data can be used to analyse the performance of hydrokinetic system with relevant simulation software programs.

Figure 1. Pattern of population placement in rural area of Kapit, Sarawak.[28]

2. Estimation of Water Velocity Data On-site

The Batang Balleh River is a branch of the Batang Rajang, especially at Sekolah Kebangsaan Nanga Sempili (Sk.Nanga Sempili), which has been classified as type-C channel rivers with a gradient less than 2% [29], [30]. The river profile and its cross-sectional area are portrayed in Figure 6. The regression equation models for water levels and water velocity estimation at this site are suitable for this type of river only, and not for the rest. The changing pattern of water velocity against water level differs based on the type of river, the slope of river, and the cross-sectional profile of the river [22], [29]. Due to availability of daily average of water level and rainfall data throughout the year from the Hydrological Station at Entawau (HSE) located 20 Km upstream from the project site, that data could be applied to estimate water level and water velocity on-site at two stages of mathematical modeling regression methods by using IBM SPSS Statistics V22 software. All gathered variable data in this study must go through the correlation analysis process in order to determine the correlation between the variables before proceeding to the next process. Estimating the daily water velocity data for a year period demands two-stage regression modeling, as shown in the flowcharts displayed in Figures 2 and 3.

Stage one estimates the daily average water level data on-site throughout the year by using the actual water level data accumulated from HSE. However, this stage can be omitted due to absence of a nearby hydrological station at upstream or unavailability of water level data. The regression analysis method has been used to determine the relationship of water levels at both sites by using the mathematical model equation shown in the flowchart portrayed in Figure 2.

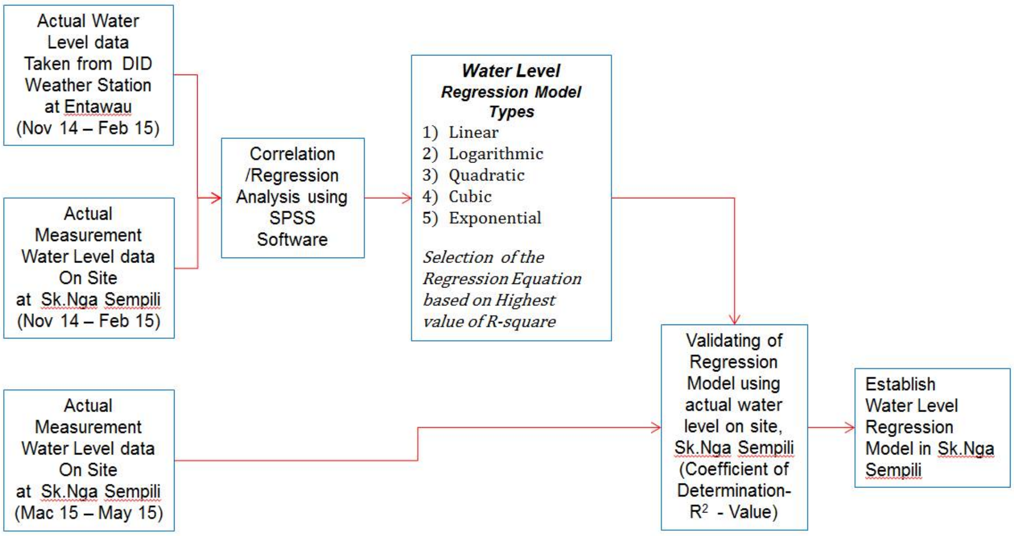

Figure 2. Flowcharts to estimate water level at Sk.Nanga Sempili School (on-site)

The daily average water level data from both locations at Sk. Nanga Sempili School and HSE had been measured concurrently for 4 months (120 samples) as training data. Next, both datasets were analysed via regression analysis method. The regression analysis incorporates five types of regressions, 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 S. A., Bhat et al., [31], which are the highest value of *coefficient of determination* (R^2) and the *significant coefficient of correlation* (P) less than 0.01 (Sig.< 0.01). The highest percentage of R^2 coefficient (near to 1 or 100%) reflects the accuracy of modelling if it is close to the real data point. The measurement of daily water level data on-site was continued for next 3 months (90 samples) to validate the regression model equation. Based on the validated regression model equation, the water level on-site was estimated throughout the year by referring to the actual daily water level data retrieved from HSE. Meanwhile, 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 3.

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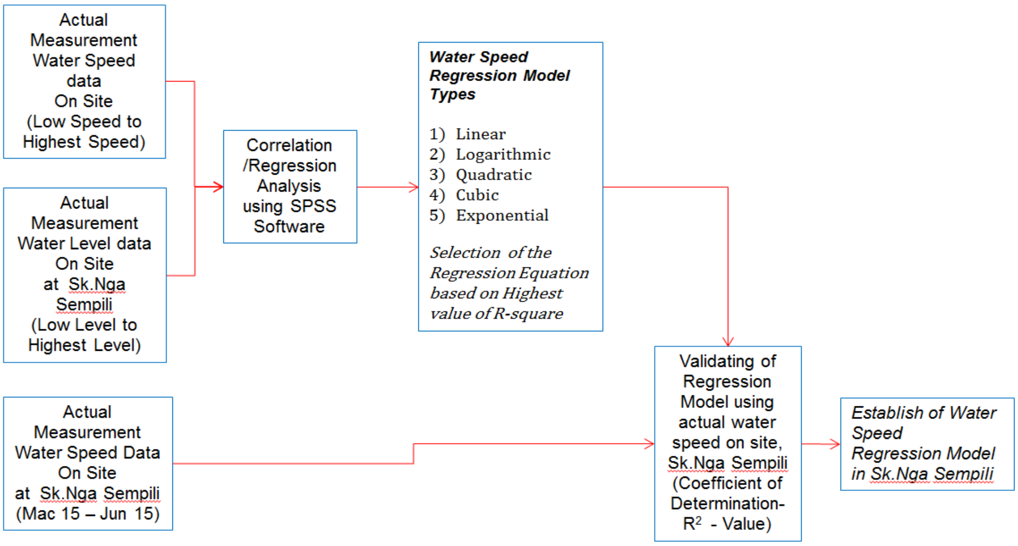

Figure 3. Flowcharts to estimate water velocity at Sk. Nanga Sempili School (on-site)

Water velocity data were measured on-site by applying the Surface Floating Method (SFM), as presented in Figure 7. Water velocity of the river was measured from the lowest level (dry season) up to the highest level (flood season) with 0.5-m intervals and measurement of five times for every water level recorded. As a result, 105 samples of actual water velocity and water level data were recorded concurrently on-site as training data for regression analysis. Both datasets were analysed by using the regression analysis method, which involved five types of regressions, such as Linear, Logarithmic, Quadratic, Cubic, and Exponential curve type. The regression model equation was selected based on two criteria that had been set using the similar steps in stage one, which are highest value of *coefficient of determination* (R^2) and the *significant coefficient of correlation* (*P*) less than 0.01 (Sig. < 0.01). The measurement of daily water velocity data on-site was continued for next 3 months (90 samples) to validate the regression model equation. Based on the validated regression model equation, the daily average water velocity data on-site was estimated by using the daily average water level data on-site itself. Finally, after combining both the validated regression equations of mathematical models, as discussed above, the long-term time series of the daily average water velocity data on-site had been estimated throughout the year by using the daily average water level data retrieved from HSE. These data could be employed to analyse the performance of hydrokinetic hybrid system using HOMER simulation software program.

2.1. Data Analysis using SPSS Software

In this study, the estimation of water velocity data at the selected site was carried out by employing the regression analysis method via SPSS version 22 analysis software program [27]. Correlation analysis was performed at the initial phase for all the variables involved so as to ascertain significant correlations between the variables in deciding if a variable should be dropped or retained for further analyses. The correlation analysis refers to the method of measuring the variables or the related rank orders. In this work, all tests were analysed by using the Pearson Correlation Analysis techniques to determine the strength of the correlations among the variables. The strength of the relationship between two variables depends on the value of *coefficient of correlation* (r), whereby nil relationship ranges from 0.0 to 0.3, weak ones from 0.3 to 0.5, moderate ones from 0.5 to 0.7, and strong relationship ranges from 0.7 to 1.0, thus signifying that r value closer to 1 is indicative of a perfect relationship [32]–[35].

In order to determine if the correlation between the variables is significant, comparison of *P*-value with significance level had been set. In this work, the correlation analysis employed two-tailed analysis and the test was run at $P < 0.01$ level of significance [31], [32], [36], [37]. The correlation is significant if $P < 0.01$, which means a null hypothesis is rejected and a strong relationship exists between the variables. Nonetheless, if a correlation is $P > 0.01$, the null hypothesis is true and the correlation is insignificant, whereby the variables are unrelated. Variables with strong correlations were retained for the next process, which was Regression Analysis, in order to obtain the best-fit model. Regression analysis refers to the statistical process that estimates the relationships between variables. The best-fit model was selected based on the highest value of *coefficient of determination* (R^2) and the *significant coefficient of correlation (P)* Sig. < 0.01. The highest percentage of R^2 coefficient (close to 100%) displays that the accuracy of modelling is close to the real data point.

2.2. Practical Installation Work for On-site Data Collection

Generally, river water levels at downstream is highly affected by the amount of rainfall at the upstream. In this study, the rainfall and water level data were obtained from the HSE, as illustrated in Figure 4, to determine the relationships and their impact upon water level changes on-site. Next, mathematical model equations were generated via regression analysis to estimate the water level on-site for long-term time series.

(**a**) (**b**)

Figure 4. Hydrological Station at Entawau for water level data collection (**a**) and (**b**) rainfall data collection

As there was no hydrological station at the project site, the daily average water level data are not available. Therefore, the daily average water level data were measured on-site by installing a stick gauge, as displayed in Figure 5. The installation of stick gauge on-site was carried out by the DID Sibu in Sarawak based on the existing Temporary Bench Mark (TBM) and the actual depth of the river according to the river profile recorded by using Acoustic Doppler Current Profiler (ADCP), as presented in Figure 6. The daily water level data on-site had been measured for seven months (210 days), whereby 120 data were employed as training data, while the remaining 90 data were used for validation purpose. In addition, the water level data had been taken twice a day at 6:30 am and 6:30 pm to adhere to the methods applied by the DID Sarawak so as to obtain daily average water level data.


(a)


(b)

Figure 5. Measurement of water level on-site (**a**) and (**b**): Stick gauge installation on-site.

The determination of the type of river on-site had been necessary to identify the pattern of water velocity against increment of water levels. David L. Rosgen [38] have divided the natural unregulated river into seven types of major streams distinguished based on channel entrenchment, channel pattern, floodplains, bedrock, cross-sectional area, and slope ranges. For that purpose, the ADCP was selected as the tool to measure the profile of the Baleh River, along with its equipment commonly applied in oceanographic studies [22]. The ADCP, as operated by an expert, was installed at the side of the boat and taken across the river in a straight line, as illustrated in Figure 6(a).


(a)

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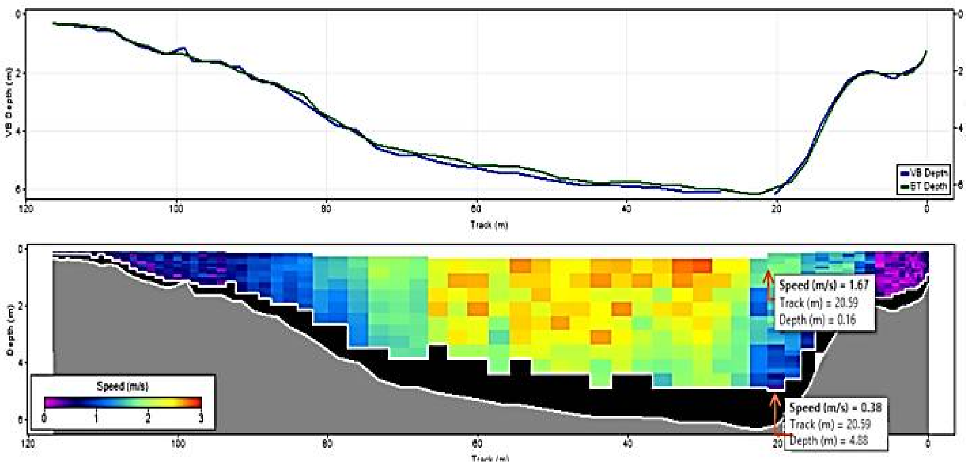

(**b**)

Figure 6. River profile measurement on-site using ADCP (**a**) and graph (**b**): river profile illustration

The on-site observation revealed that the Balleh River has a meandered appearance and a broad floodplain; while the cross-sectional area of the river, as presented in Figure 6(b), clearly shows that the Balleh River is classified into class C channel with a gradient less than 2%. The accuracy of water velocity measurement in unregulated river demands special equipment that can only be operated by experts. Hence, the most accurate method is by mounting the ADCP on rigid structures. However, as for sites without any rigid structure or bridge, the measurement should be done while in boat, which poses danger especially during floods and inaccurate outcomes of water velocity data due to the vertical and horizontal movements of the boat [39]. As for this study, the SFM, as displayed in Figure 7, 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 during flood season or throughout the year [18], [19], [29].

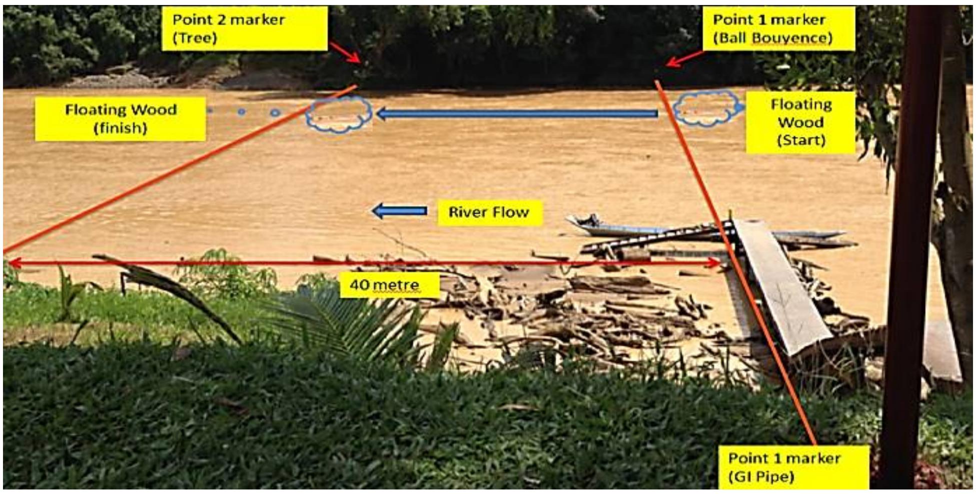

Figure 7. Measurement of water velocity data using Surface Floating Method

The measurement of water velocity was performed by measuring the time required for a floating material to travel at a fixed distance along the stream, as illustrated in Figure 7. The floating material employed in this study was a half-submerged natural driftwood, as proposed by Cheryl C., Harrelson [29]. The procedure was repeated as many as 5 times, where the average of the values reflects the mean velocity, which was then multiplied with velocity adjustment coefficient of 0.85 in order to calculate the mean velocity of the river. This coefficient can range from 0.8 to 0.95;

depending on the roughness of the channel to accommodate friction effects along the bottom and the sides of the river [29], [30].

3. Results and Discussion

3.1. Correlation Analysis

A total 120 samples of actual water level data on-site, as well as actual water level and rainfall data obtained from HSE (as reference site), were analysed by using the Pearson Correlation Analysis methods to determine the correlations between the variables, as depicted in Table 1. At this stage, variables that exhibited strong relationships were retained for the regression analysis process, while the rest were dropped.

Table 1. Correlation analysis result among variables

		Rainfall Data at Entawau (HSE)	**Water Level Sk.Nanga Sempili**
Water Level at Entawau (HSE)	Pearson Correlation	-0.062	0.939
	(Sig.) $P < 0.01$	0.503	0.000
	N	120	120
Water Level at Sk.Nanga Sempili	Pearson Correlation	0.07	-
	(Sig.) $P < 0.01$	0.941	-
	N	120	-

Based on the results retrieved from correlation analysis, as displayed in Table 1, the water level at Entawau displayed a strong relationship with the water level on-site (Sk Nanga Sempili) with *coefficient of correlation* (r) = 0.939. Nonetheless, rainfall data exhibited nil correlation for both water levels at Entawau and Sk Nanga Sempili with r = -0.062 and r = 0.07, respectively. The result also showed that the significant value (P) between water level at HSE and water level on-site is P =0.000 (Sig. <0.01), thus rejecting the null hypothesis and exhibiting significantly strong correlation between each other. This means; increment in water level at HSE caused the rising of water level on-site. A significant value (P) between rainfall data at HSE and water level at HSE is P = 0.523 (Sig.>0.01), while the water level at Sk Nanga Sempili is P = 0.941 (Sig.>0.01), which means that the null hypothesis is true; the rainfall data were unrelated to the water level for both locations. It also showed that rainfall data taken at one rain gauge station at HSE upstream failed in describing the total amount of rainfall at upstream of the river. Thus, rainfall data were omitted from the next regression analysis. The accuracy of measurement rainfall data highly depends on the density and the distribution of rain gauge in such territory, while A. K., Misyhar asserted that 4-6 rain gauge stations within 50km x 50km area may ascertain better accuracy [26].

3.2. Estimation of Water Level using Regression Analysis Method (Stage 1)

By using 120 samples of water level data at site and water level data at HSE, the regression analysis was performed by incorporating five types of regression models, as illustrated in Figure 8.

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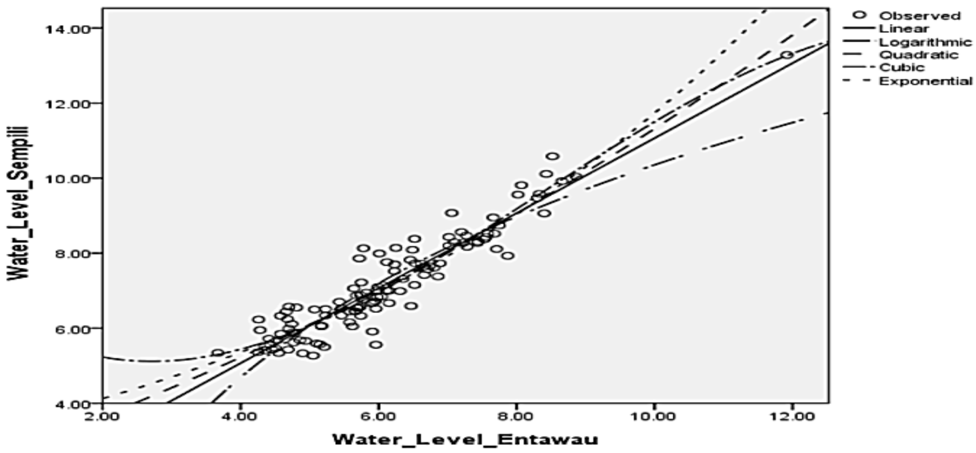

Figure 8. Analysis result of five types water level regression models

Five regression models were selected and analysed. As a result, the regression model Cubic curve (89.1%) exemplified the highest R-square value, followed by Quadratic curve model (88.6%), Linear curve (88.2%), Exponential curve (86.3%), and logarithmic curve model (84.1%), which successfully fulfilled the first criteria. Nonetheless, the regression models of linear curve, logarithmic curve, and exponential curve only satisfied the second criteria with *significant coefficient of correlation (P)* values below 0.01.

Table 2. Regression analysis result to estimate water level on-site (Linear regression curve)

R	R-Square	Adjusted R Square	Std Error of the Estimate
0.939	0.882	0.881	0.471

The independent variable is Water Level at Entawau.

Coefficients

	Unstandardized Coefficients (B)	Standardized Coefficients (Beta)	Sig.
Water level at Entawau (HSE)	0.999	0.939	0.000
(Constant)	1.073		0.000

Out of the five types of regression models analysed, the linear regression model was selected due to its highest value of $R^2 = 88.2\%$ and all the *significant coefficients of correlation* (*P*) were 0.000 is less than 0.01 (Sig. P<0.01) as shown in Table 2. This displayed that the water level on-site had a significantly strong correlation with the water level at HSE. From the coefficients table as shown in Table 2, the regression equation modelling is labelled as equation (1) with a *coefficient of determination* at $R^2 = 0.882$. This proves that the regression equation model is indeed accurate and required validation so as to ensure the reliability of the equation regression.

$$a = 0.999(b) + 1.073, \tag{1}$$

where a is the estimation water level at Sk. Nanga Sempili and b is the actual water level at hydrological station at Entawau.

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3.2.1. Validation of Water Level Regression Modelling

Based on the regression equation model (1), the estimated water level on-site for 3 months recorded from March 2015 until May 2015 had been obtained. At the same period of time, the actual water level data were measured concurrently on-site for validation process, as presented in Figure 9.

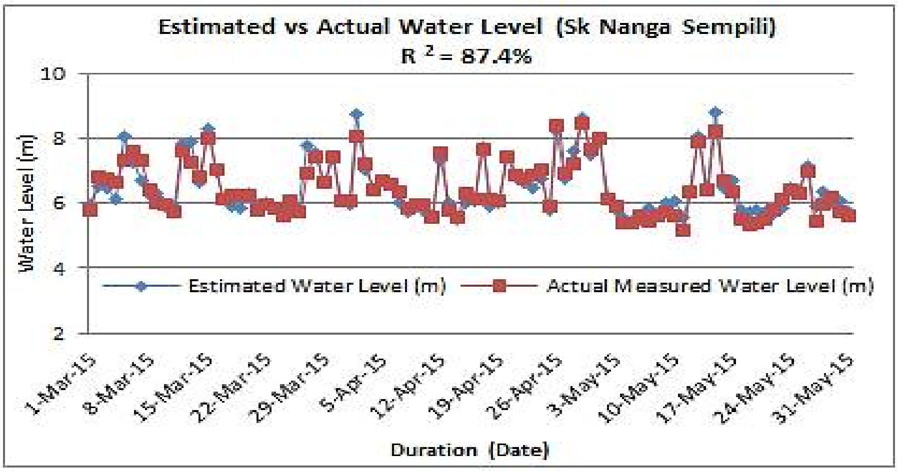

Figure 9. Variance between estimated and actual water levels on-site

The regression equation modelling (1) was validated by using equation (2) proposed by John R., Tylor [40]. The *coefficient of determination* (R^2) result for the regression model is R^2=87.4%, thus indicating that the regression equation modelling is accurate and could be employed to estimate long-term time series of water level on-site throughout the year.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y})^2}, \tag{2}$$

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 numerator of the ratio is the sum of the squared differences between the actual *y* values and the predicted *y* values. The denominator of the ratio is the sum of squared differences between the actual *y* values and their mean.

3.3. Estimation of Water Velocity using Regression Analysis Method (Stage 2)

The measurement of water velocity at site was performed by using SFM from the lowest level until the highest level of the river. A total of 105 samples of the actual water level data and water velocity data at Sk Nanga Sempili had been analysed by using the Pearson Correlation Analysis methods to determine the relationship between two variables. Based on the correlation analysis result depicted in Table 3, the water velocity and the water level at Sk Nanga Sempili displayed a strong correlation with *coefficient of correlation* at (*r*) = 0.969. The correlation analysis result, which presents the P-value of significant coefficient between water level and water velocity at Sk Nanga Sempili, is *P* = 0.000 (Sig. < 0.01), signifying that the null hypothesis is rejected as they exhibited significantly strong correlation between each other.

Table 3. Correlation analysis result of water level and velocity at Sk Nanga Sempili

		Water Velocity at Sk.Nanga Sempili
Water Level at Sk.Nanga Sempili	Pearson Correlation (*r*)	0.969
	(Sig.) *P* < 0.01	0.000
	N	105

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From the above result, it can be interpreted that increment in water level can significantly hike the water velocity on-site. As the parameters showed strong relationship between each other, they were retained for the next process that involved regression analysis modelling. The regression analysis was performed and involved five types of regression models, as illustrated in Figure 10 and Table 4.

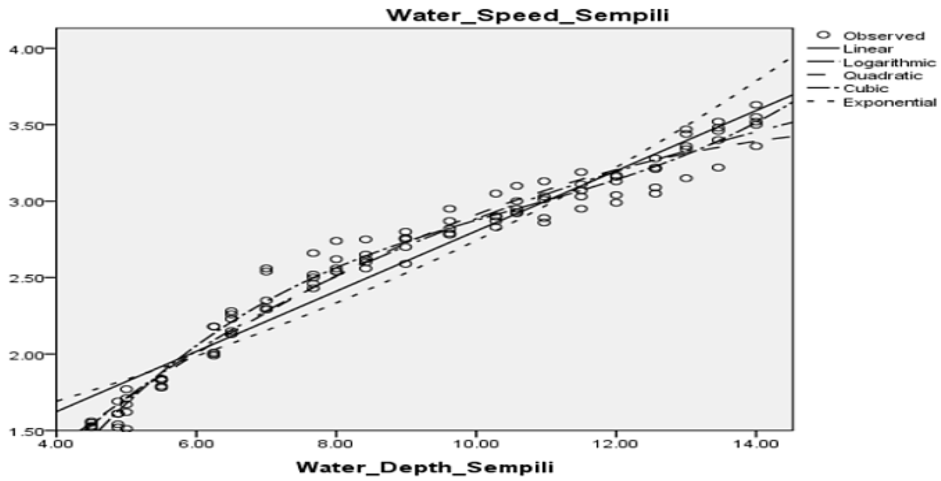

Figure 10. Analysis result of five types water velocity regression models

Five regression models were selected and analysed. As a result, the regression model of Cubic curve (97.7%) exhibited the highest R-square value, followed by Logarithmic curve (97.2%), Quadratic curve model (96.8%), Linear curve (94.3%), and Exponential curve model (89.6%). Nevertheless, the regression models of Cubic curve, Logarithmic curve, Linear curve, and Exponential curve only satisfied the second criteria with a *significant coefficient of correlation (P)* less than 0.01. Out of the five types of regression models that had been selected and analysed, the cubic regression model was selected as it fulfilled all criteria with the highest R^2 = 97.7% and all *significant coefficient of correlation* at $P < 0.01$, as depicted in Table 4.

Table 4. Regression analysis result to estimate water velocity on-site (Cubic Regression Curve)

R	R-Square	Adjusted R Square	Std Error of the Estimate
0.988	0.977	0.976	0.092

The independent variable is Water Level at Sk.Nanga Sempili.

Coefficients

	Unstandardized Coefficients		Sig.
	(B)	Std Error	
Water level at Sk.Nanga Sempili	1.207	0.119	0.000
Water level at Sk.Nanga Sempili**2	-0.101	0.013	0.000
Water level at Sk.Nanga Sempili**3	0.003	0.000	0.000
(Constant)	-2.233	0.328	0.000

Based on the coefficients depicted in Table 4, the regression equation modelling had been derived as equation (3) with a coefficient regression at R^2 = 97.7%. It also displayed that the regression equation modelling was accurate, and required further validation to ensure the validity of the equation regression.

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$$c = 0.003\,(d^3) - 0.101(d^2) + 1.207(d) - 2.233, \quad (3)$$

where c is the estimation water velocity at Sk.Nanga Sempili and d is the actual water level at Sk.Nanga Sempili.

3.3.1. Validation of water velocity regression modeling

By applying the derivation of equation (3), the estimated water velocity data on-site recorded from Mac 2015 until May 2015 had been generated. At the time the measurement of actual water velocity data on-site had been measured, the validation of the regression model equation (3) had been carried out concurrently, as illustrated in Figure 11.

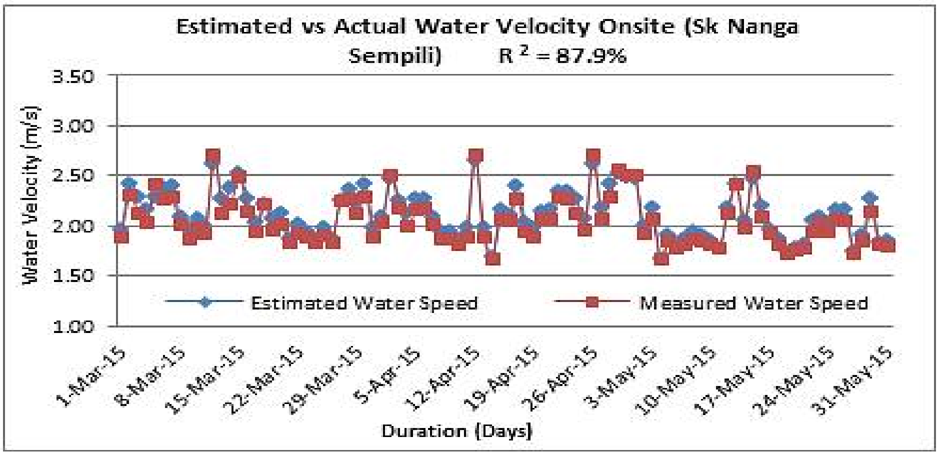

Figure 11. Variance between estimated and actual water velocity on-site

The regression equation (3) was validated by using the R-Square coefficient from equation (2). The *coefficient of determination* result for regression modelling at R^2=87.9% showed that the regression equation modelling is accurate and it could be used to estimate the long-term time series of water velocity on-site throughout the year. By employing the water velocity regression equation (3), together with water level regression equation (1), the time series of daily average water velocity data on-site had been estimated throughout the year by referring to the actual daily average water level data at the hydrological station at Entawau, as presented in equation 4 and Table 5.

$$c = 0.003\,(a^3) - 0.101(a^2) + 1.207(a) - 2.233, \quad (4)$$

where c is the estimation water velocity at Sk.Nanga Sempili and a is the estimated water level at Sk.Nanga Sempili.

Table 5. This is a table. Tables should be placed in the main text near to the first time they are cited.

Date	**Actual water level at Hydrological Station Entawau** *(b)*	**Estimated water level Sk.Nanga Sempili** *(Equation 1)*	**Estimated water velocity Sk.Nanga Sempili** *(Equation 4)*
1 Mac 15	4.82 m	5.89 m	1.99 m/s
2 Mac 15	5.50 m	6.57 m	2.19 m/s
3 Mac 15	5.44 m	6.50 m	2.17 m/s
4 Mac 15	5.03 m	6.10 m	2.05 m/s
5 Mac 15	6.99 m	8.05 m	2.50 m/s
6 Mac 15	6.28 m	7.35 m	2.37 m/s

4. Conclusions

The Batang Balleh River especially at Sk.Nanga Sempili School is consider as type-C river with a gradient less than 2%, showed that the rising water level at downstream is linearly proportional to the rise in water levels at the upstream of the river. It was also discovered that the velocity of the water is strongly affected by the rising water levels, while the relationship has been proven to be non-linear when polynomial/Cubic curve was applied. The validation of the mathematical model equation (1) for water level estimation and the mathematical model equation (3) for water velocity estimation on-site through regression analysis method at values R^2=87.4% and R^2=87.9%, respectively, are classified as rather accurate. The combination of both mathematical model equations (1) and (3) to produce mathematical model equation (4) can be employed to estimate the long-term time series water velocity throughout the year, especially for unregulated rivers in remote areas. The availability of daily average water velocity data throughout the year offers opportunities and encouragement to other researchers to continue studies pertaining to hydrokinetic power generation system, particularly for remote area electrification in Kapit, Sarawak.

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