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FUNCTION AND RATING CURVE OF DRAINAGE DENSITY ALTERATION ALONG THE MOUTH OF THE RANOYAPO AMURANG RIVER

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ABSTRACT

The concentration of suspended sediment and stream discharge is the relationship between a density containing wash load and suspended load as well as stream discharge. This relationship indicates that the increase of stream discharge will increase the density.

This research determines the function and rating curve of density variable along the mouth of the Ranoyapo river during the low tide and high tide. The data on density includes the result, close-to-riverbed layer measurement (ρ_0) and the measurement on the depth of 0.6 ($\rho_{0,\ 6h}$) in three flow path based on the river width. Doubling and modeling technique was used to decide function and rating curve of density variable.

Function and rating curve produced is the function and rating curve of subsiding water density (ρ_0) in the form of exponential function. Density (ρ_0) function of flood tide is in the form of exponential. Density (ρ0) function of subsiding water is in the form of a negative gradient. Density ($\rho_{0,\ 6h}$) function of flood tide consists of two function i.e. a linear form for the distance range of 82 m ≤ x < 305 and exponential of distance range of 305m ≤ x ≤ 655 m.

Keyword: Rating Curve Function of Density

1. Introduction

Drainage density shows that the concentration of sediment transported is through one cross-section. All materials transported by water flow are known as total sediment load. It covers to bed material load and wash load. Bed material load alone includes suspended load and bed load. Wash load consists of smooth particles and colloid of erosion results of land surface at the upstream. This load settles down most slowly even though in the calm water. The quantity of this load is only a little compared to the bed load, so the calculation of drainage density and its influence alteration is not significant. A suspended load is a load that is not directly in contact with the riverbed but flying along the flow (for a certain period).

Material transport determining the changes of concentration of drainage density of the estuary includes bed load, suspended load, and wash load. As a result, material transport in one position of river section can be stated in the form of drainage density (water mass total added material transport per volume).

Concentration relationship between suspended sediment and flow discharge is a relationship between drainage density that contains wash load and suspended load and stream discharge. This relationship shows that the increase of stream discharge will increase the drainage density. Theoretically, the function and the rating curve of drainage density, based on the distance along the estuary for density data measured on the spot around the mid-depth and close to the riverbed, will show the alteration of erosion rate and riverbed sedimentation on the estuary area.

Variable analysis of drainage density and its alteration along the estuary is mathematically used for modeling result data, while its interpolation can be illustrated in the form of the function and rating curve so that partially and in an integrated way can study the characteristics of river flow. This research aims to measure and determine the function and the rating curve of variable alteration of stream density along the mouth of the Ranoyapo river during low tide and high tide. The research result will describe the availability of data and profile (function and rating curve) of a physical variable of drainage density which then the interpretation of regression function of stream density alteration can be conducted to study and evaluate the process of material transport distribution along the estuary.

2. Materials And Methods

Literature Review

Drainage density is the water sample mass (containing sediment) per volume sample. Water mass (sample) is measured using a balance, while the volume was using a measuring cylinder having a volume measurement. River stream mass brought from a spot of river section is water density that contains three categories of material transport, namely, wash load, suspended load and bed load. Drainage density shows that the concentration of sediment transported is through one cross-section. All materials transported by water flow are known as total sediment load. Total sediment load comprises a bed material load and wash load. Bed load itself comprises suspended load and bed load. Wash load consists of soft particles and colloid of sedimentation result of land surface in the mouth of the river, this load move most slowly although in the calm water. This load quantity is extremely small compared to the basic material load. Bed load is only found on the layer next to the surface of the riverbed, while material transport found in the spots of mid-layer until the river surface consists of the wash load and suspended load (C. Yang, C. Jiang, and Q. Kong, 2010), Chen and K. Wang (2008). Because the composition of suspended load is higher so that theoretically, stream density profile in a vertical position and the concentration of suspended load floating to the estuary will be getting higher. This is in accordance with what conducted by Kumajas Marthen (2005) indicating that vertical profile of drainage density is in the form of an exponential function as in Figure 1 of the second left.

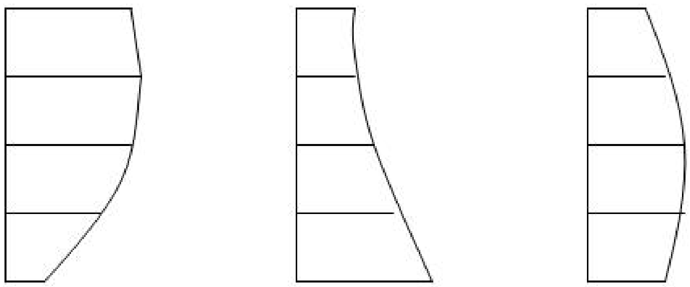

Figure -1: Vertical distribution (based on the depth) (a) stream speed (b) sediment concentration (c) suspended sediment transport (Schwab et.al, 1981)

Jansson (1992) conducting a measurement and a research of the relationship between rain duration, stream discharge, and concentration of transportation sediment, found a significant relationship in the form of log-linear regression function between duration and discharge, between duration and concentration, and log-log regression function between stream discharge and suspended sediment. R. J. Uncles and J.A. Stephens (2001) carrying out a study of sediment transportation proposed that on the river stream, the size of sediment transported depends on the hydraulic condition (stream speed, turbulence, and the slope of riverbed).

Concentration relationship between suspended sediment and flow discharge is a relationship between drainage density that contains wash load and suspended load and stream discharge. This relationship shows that the increase of stream discharge will increase the drainage density. Time series analysis is underlined on the rating curve of sediment on the discharge. Summer et.al. (1992) concluded that there is no time delay between discharge increase and sediment transport increase (which also increases stream density). Stream density alteration along the estuary shows the existence of sediment deposition in that region. Theoretically, the rating curve of drainage density, based on the distance along the mouth of the river for density data measured from the spot around the mid-depth and close to the riverbed, will show the rate of transport sediment on the estuary area.

Method

This research actually wants to study the physical variable of river flow density defined as water sample mass (containing sediment) per volume sample. Density data for every spot of measurement is collected from dividing data of water sample mass by its volume using an equation:

$$\rho = \left(\frac{m}{V}\right) \quad (1)$$

m is sample mass and V is sample volume. A unit of measurement result is stated in gram.cm^{-3} or kg.liter^{-1}. Drainage density data for every segment comprises measurement data on every layer next to the riverbed surface (ρ) and the data of measurement result in 0.6 depth. For the sake of analysis of physical function changes and the rating curve determination of drainage density variable along the estuary, therefore; it is determined that stream flow based on the direction of flow vector and three segments (path) of stream fits the river width, this can be done to make alteration description of stream density variable fulfill the steady assumption, non-turbulent, and all the same.

Suspended sediment concentration with stream discharge is drainage density that contains wash load and suspended load contained in the stream discharge. Concentration variation of suspended load in a vertical position requires measurement on several discrete spots in a vertical position. Since the distribution of suspended load is more determined by a hydrological parameter, thus the data collection can be simplified by developing “sediment rating curve” that connects the average concentration of sediment and stream discharge. Unlike the wash load, Ongley (1992) stated that the diversity of wash load vertical is quite small so can be used a “single point sampling” method.

Data analysis used includes (1) data multiplexing, (2) data modeling technique for rating curve determination of stream density variable. For the sake of modeling, the data is multiplied by using linear interpolation technique as proposed by: Foster et al, (1992), Kumajas Marthen (2005), tendean Maxi, M. Bisri, M. Luthfi rayes and Zetly E. Tamod. 2012. General form of data interpolation equation (Cheney and Kincaid, 1934) is:

$$p(x) = y_0 + \frac{y_1 - y_0}{x_1 - x_0}(x - x_0) \quad (2)$$

(x_0,y_0) and (x_1,y_1) is two coordinates (couples of the dependent variable and independent variable data) whose price has been known. p(x) is the price of a dependent variable for the price of independent variable x. Data modeling of research variable as a function of distance x is a determination process of a coefficient and experiment function constant, formulated based on the data distribution of measurement result and its interpolation. Correlation criteria used was $r > 0.99$ and the percentage average of modeling result data bias on the data of interpolation result < 5% which then generates a general equation with the function and rating curve of stream mass density along the estuary.

3. Results And Discussion

Data analysis and presentation of stream density physical variable are conducted among segments through three flow paths so that the description of density variable alteration along the estuary can fulfill steady assumption, non-turbulent and all the same. Drainage density data for every segment includes the data of measurement result on the layer next to the riverbed (ρ_o) and the data of measurement result on the depth of 0.6 ($\rho_{o,6h}$).

Interpolation and data modeling produce drainage density function on the layer next to the riverbed (ρ_o) during the low tide and high tide with a general equation :

$$\rho_0 = k_0 + k_1 e^{-k2X} \quad (3)$$

Modeling accuracy (ρ_0) is determined by the average price of data percent bias of modeling result on the data of interpolation result which is smaller than 5%. Mean percent bias (ρ0) for measurement during the ups and downs by 0.079 and 0.036 respectively. Constant and coefficient of density function (ρ_o) is presented in Table-1.

Table-1. Constant summary of density rating curve (ρ_o) and mean percent bias %. General equation : $\rho_0 = k_0 + k_1 e^{-k2xx}$.

No Measurement	No Flow Path	Density Function	Water Condition	Constant function/*rating curve*			Mean
				k_0	k_1	k_2	% bias

		gr.cm^{-3}		(gr.cm^{-3})	(gr.cm^{-3})	(m^{-1})	Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
01	1	ρ_0	Low tide	1.089525	0.016069	0.002484	0.0790
			High tide	1.087512	0.003110	0.009013	0.0306
02	2	ρ_0	Low tide	1.087592	0.015884	0.002622	0.0260
			High tide	1.087027	0.027892	0.008878	0.0077
03	3	ρ_0	Low tide	1.100233	0.015743	0.002575	0.0306
			High tide	1.087641	0.027228	0.008724	0.0138

Until the distance of 400 meters from the reference point, the rating curve (ρo) during the high tide has a bigger gradient than the rating curve during the low tide, but for distance x > 400 meter, the rating curve becomes flat.

Function modeling ($\rho_{0,6h}$) of path-1 results in a row of data during the low tide and high tide. Modeling accuracy is shown by the mean bias which is smaller than 5%, that is 0.005 and 0.003 during the low tide and high tide respectively. Modeling result function during the low tide is in the form of a linear function with a negative gradient, the general form of the equation is:

$$\rho_{0,6h} = k_0 - k_1 .x \quad \text{..(4)}$$

x is the distance from the reference point, k_0 and k_1 are a constant and coefficient of density function ($\rho_{0,6h}$) respectively whose price and measurement can be seen in Table-(2). The rating curve ($\rho_{0,6h}$) and plot data of interpolation result ($\rho_{0,6h}$) of the downs condition is presented in Figure-(2).

Table-2. Constant summary of density rating curve ($\rho_{0,6h}$) and mean percent bias of low tide, the general equation is : $\rho_{0,6h} = k_0 - k_1 . x$.

No Measu rement	No Flow path	Density function gr.cm^{-3}	water condition	Constant function k_0 (gr.cm^{-3})	k_1 (gr.cm^{-4})	Mean % bias Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)
01	1	$\rho_{0,6h}$	Low tide	1.0882120	0.00000052918	0.004893
02	2	$\rho_{0,6h}$	Low tide	1.0883914	0.00000049788	0.003740
03	3	$\rho_{0,6h}$	Low tide	1.0883664	0.00000049460	0.002700

The data of measurement result ($\rho_{0,6h}$) during the high tide shows a great change around the position of 305 meter so that the data modeling must be conducted separately for the distance of 82 m x < 305 m and 82 m x < 305 m. The general equation of 82 m x < 305 m, is:

$$\rho_{0,6h} = k_0 - k_1.x^{k2} \quad \text{...(5)}$$

x is a distance along the estuary, calculated from the point of reference. Constant k_0, coefficient k_1, and square k2, its measurement and price are presented in Table-(3).

Table-3 The constant summary of the density rating curve ($\rho_{0,6h}$) and mean percent bias during the high tide, for a distance from inlet : 82 m x < 305 m.

General equation : $\rho_{0,6h} = k_0 - k_1.x^{k2}$

No Measu rement	No. Flow path	Density Func tion gr.cm^{-3}	Water Con dition	Constant function/*rating curve* k_0 (gr.cm^{-3})	k_1 (gr.cm^{-4})	k_2 -	Mean % bias Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
01	1	$\rho_{0,6h}$	High tide	1.0882080	0.00000000248	2.188850	0.0060
02	2	$\rho_{0,6h}$	High tide	1.0882248	0.00000001975	2.201642	0.0047

03	3	$\rho_{0,6h}$	High tide	1.0883167	0.00000000226	2.207423	0.0051

For 305 m ≤ x ≤ 655 m, the general form of linear equation and negative gradient is :

$$\rho_{0,6h} = k_0 - k_1.x \quad \text{.. .... (6)}$$

Measurement and price of k_0, k_1. is presented in Table-(4).

Table-4 The constant summary of the density rating curve ($\rho_{0,6h}$) and the mean percent bias during the high tide, for the distance from inlet : 305 m x 655 m

General equation : $\rho_{0,6h} = k_0 - k_1 . x$

No Measurement	No. flow path	Density function $gr.cm^{-3}$	Water Condition	Constant function k_0 $(gr.cm^{-3})$	Constant function k_1 $(gr.cm^{-4})$	mean % bias Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)
01	1	$\rho_{0,6h}$	High tide	1.0872777	0.00000011125	0.002000
02	2	$\rho_{0,6h}$	High tide	1.0872984	0.00000009585	0.002855
03	3	$\rho_{0,6h}$	High tide	1.0872888	0.00000009592	0.001878

k_1 price is very low so that the density in ± 305 meters to the measurement limit (±655 meters) is almost constant. The mean percent bias of modeling for the range of 82 m x < 305 m and 305 m ≤ x ≤ 655 m is 0.00605 and 0.002 respectively, while the mean percent bias for 82 m ≤ x < 655 m is 0.003 (smaller than the modeling criteria of 5%). The rating curve of modeling result function and the plot of interpolated result data ($\rho_{0,6h}$) during the high tide is presented in Figure-(2) together with the rating curve of data modeling at a low tide.

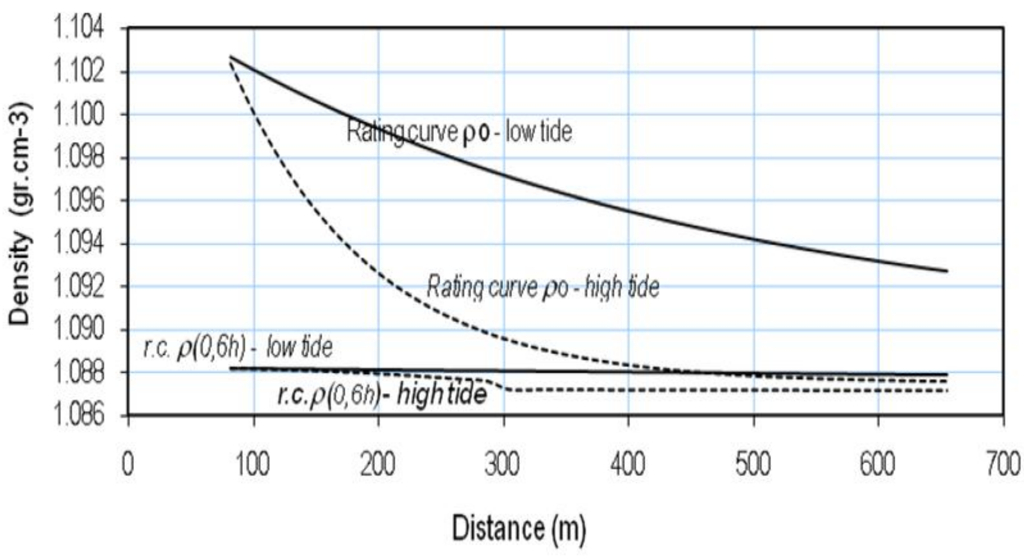

Figure-2. Rating Curve ρ_o and $\rho_{0,6h}$ during the high tide and low tide.

Measurement results, interpolation, and data modeling as well as the rating curve (ρ_0) during the low tide and high tide for lane-2 is almost similar to lane- 1. The rating curves and interpolation data plots for low tide and high tide are presented in Figure- (3).

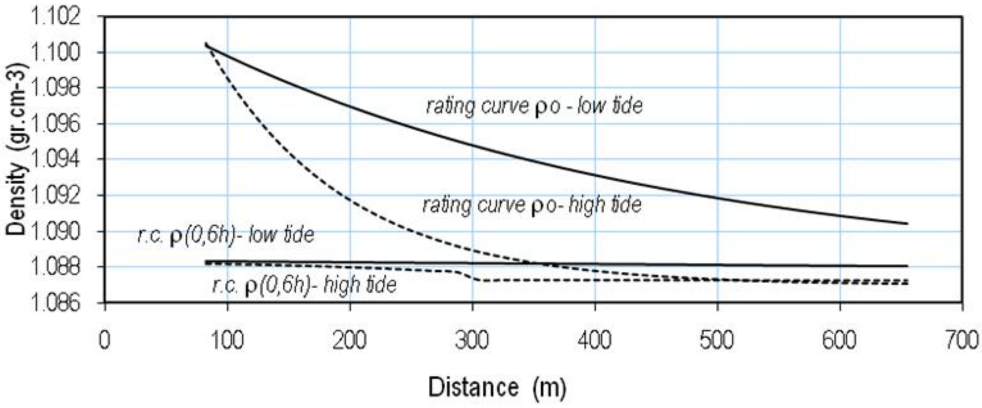

Figure-3 Rating Curve (ρ_o) and ($\rho_{o,6h}$) during the high tide and low tide.

The function (ρ_o) of the measurement results at low tide or high tide has an exponential function with the general form of the equation as follows:

$$\rho_0 = k_0 + k_1 e^{-k2X} \quad \text{... (7)}$$

The constants and the coefficient of a function is shown in Table- (5). Mean percent bias of modeling for low tide and high tide data is 0.0260 and 0.0077 respectively. It indicates that the density function has high accuracy and can be used to describe changes in water density along the estuary.

The constant summary of density rating curve (ρ_0) and mean percent bias %. General equation : : $\rho_0 = k_0 + k_1 e^{-k2x}$

No Measurement	No Flow path	Density function gr.cm^{-3}	Water Condition	Constant function/*rating curve* k$_0$ (gr.cm^{-3})	k$_1$ (gr.cm^{-3})	k$_2$ (m^{-1})	Mean % bias Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
01	1	ρ_0	Low tide	1.089525	0.016069	0.002484	0.0790
			High tide	1.087512	0.003110	0.009013	0.0306
02	2	ρ_0	Low tide	1.087592	0.015884	0.002622	0.0260
			High tide	1.087027	0.027892	0.008878	0.0077
03	3	ρ_0	Low tide	1.100233	0.015743	0.002575	0.0306
			High tide	1.087641	0.027228	0.008724	0.0138

The data of measurement result ($\rho_{0,6h}$) at low tide and high tide, as well as the interpolation produces the function of data modeling result at low tide having the form of a linear equation with a negative gradient like the following equation:

$$\rho_{0,6h} = k_0 - k_1 .x \quad \text{...(8)}$$

The constants and the coefficient of a function are presented in Table- (6).

Table-6. The constant summary of the rating curve density ($\rho_{0,6h}$) and mean percent bias at low tide, the general equation is : $\rho_{0,6h}$ = k0 - k1 . x

No measurement	No flow path	Density function gr.cm^{-3}	water condition	Constant function k$_0$ (gr.cm^{-3})	k$_1$ (gr.cm^{-4})	Mean % bias Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)
01	1	$\rho_{0,6h}$	Low tide	1.0882120	0.00000052918	0.004893
02	2	$\rho_{0,6h}$	Low tide	1.0883914	0.00000049788	0.003740

03	3	$\rho_{0,6h}$	Low tide	1.0883664	0.00000049460	0.002700

The accuracy of the modeling results function is shown by the mean percent bias of modeling data on interpolation data, which is 0.003740

The measurement results ($\rho_{0,6h}$) during the high tide shows the same density change pattern as lane-1. As with the line-1 data, the data of the measurement result shows a significant change around the 305 position from the reference point, so the modeling must be separated for a distance of 82 m x < 305 m, and 305 m ≤ x ≤ 655m. The position density function of 82 meters which less than 305 meters have a shape like an equation- (5), with the constants and the coefficient of a function presented in Table-6. For positions of 305 meters up to 655 meters, the function has a general form as equation (6) whose constants and the coefficient of function are presented in Table-3. The average percent bias that becomes the modeling accuracy level ($\rho_{0,6h}$) when the high tide of 82 m ≤ x < 305 m and 305 m ≤ x ≤ ± 655 m is 0.0047 and 0.002855 respectively (smaller than the criteria 55). The rating curves of modeling result and interpolation data plots ($\rho_{0,6h}$) at low tide and high tide are presented in Figure- (3).

The data of measurement (ρ_0) at low tide and high tide for lane-3, its interpolation has a price and distribution pattern along the same estuary with data on lane-1 and lane-2. That data modeling produces a function (ρ_0) at low tide and high tide with a general form like this below:

$$\rho_0 = k_0 + k_1 e^{-k2X} \qquad \text{……………………………………………………..(9)}$$

The constants and the coefficient of a function of the modeling results (ρ_0) for low tide and high tide are presented in Table- (7).

Table-7. The constant summary of the rating curve density (ρ_0) and average percent bias.

General equation : $\rho_0 = k_0 + k_1 e^{-k2x}$

No Measurement	No Flow path	Density function gr.cm^{-3}	water condition	Constant function/*rating curve* k_0 (gr.cm^{-3})	k_1 (gr.cm^{-3})	k_2 (m^{-1})	mean % bias Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
01	1	ρ_0	Low tide	1.089525	0.016069	0.002484	0.0790
			High tide	1.087512	0.003110	0.009013	0.0306
02	2	ρ_0	Low tide	1.087592	0.015884	0.002622	0.0260
			High tide	1.087027	0.027892	0.008878	0.0077
03	3	ρ_0	Low tide	1.100233	0.015743	0.002575	0.0306
			High tide	1.087641	0.027228	0.008724	0.0138

Table-(7) also presents the mean percent bias of modeling data on the data of measurement result and interpolation (as an indicator of modeling function accuracy), for measurements at low tide and high tide is 0.0306 and 0.0138 respectively. The rating curves of modeling result and the data plots of interpolation result (for low tide and high tide) are presented in Figure-(4).

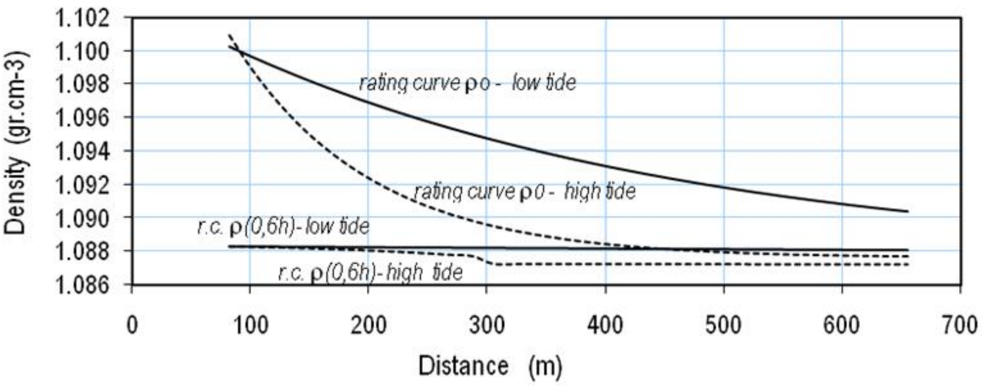

Figure-(4) Rating Curve (ρ_0) and ($\rho_{0,6h}$) during high tide and low tide.

Modeling Function and the density Rating Curve at 0.6 depth ($\rho_{0,6h}$) during the low tide produces a negative linear gradient function with a general form like this following equation:

$$\rho_{0,6h} = k_0 - k_1 .x \quad (10)$$

Constants and coefficient of function of measurement result at low tide are presented in Table- (8).

Table-8 The constant summary of density rating curve ($\rho_{0,6h}$) and average percent bias at low tide, its general equation is as follows: $\rho_{0,6h} = k_0 - k_1 . x$

No Measurement	No flow path	Density function $gr.cm^{-3}$	water condition	Constant function		Mean % bias Model
				k_0 $(gr.cm^{-3})$	k_1 $(gr.cm^{-4})$	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
01	1	$\rho_{0,6h}$	Low tide	1.0882120	0.00000052918	0.004893
02	2	$\rho_{0,6h}$	Low tide	1.0883914	0.00000049788	0.003740
03	3	$\rho_{0,6h}$	Low tide	1.0883664	0.00000049460	0.002700

The function accuracy of the modeling results is shown by the mean percent bias of modeling data on interpolation data of 0.0027. This price is less than percent bias 5% so that the function of modeling results can be said valid and can describe changes ($\rho_{0,6h}$) along the estuary at low tide (without the influence of seawater).

As with the measurements on lane-1 and lane-2, the measurement results on lane-3 with high tide conditions indicate a price reduction ($\rho_{0,6h}$) which is quite sharp in a position of about 305 meters from the reference, so that data modeling produces two functions with common form in the distance ranges as in equation- (5) and equation- (6). The constants and coefficient of the function of the modeling results are presented in Table- (3) and Table- (4). Tables (3) and Tables (4) also present the average percent bias of modeling data on interpolated data from each function fragment, namely 0.0051 and 0.001878 respectively. This price is smaller than the modeling criteria (5%) so that those functions can be used to describe changes in flow density at 0.6 depth ($\rho_{0,6h}$) along the Ranoyapo river mouth. The rating curves of data modeling result at low tide and high tide, as well as plots of interpolation data, are presented in Figure- (4).

The analysis result of density function modeling (ρ_0) and ($\rho_{0,6h}$) carried out per flow path provides an interpretation that the form of the function generated for each density (ρ0,6h) during the low and high tide has the same shape for all three flow paths. A combined rating curve (ρ_0 and ρ_0,6h) of measurements result at low tide and high tide, each measurement/analysis pathway, of course, has a similar form because the data distribution patterns in the three flow paths are the same, so the interpretation of density changes along the estuary can be based on a one-way curve rating analysis.

The rating curve comparison analysis (ρ_0 and $\rho_{0,6h}$) at low tide indicates that the density at the layer near the surface of the river bed (ρ_0) has a higher price but the gradient decreases more than the density at the depth of 0.6. This means that at each measurement position (or distance x from reference), price (ρ_0) is always greater than the price ($\rho_{0,6h}$). This result corresponds to the theory that the layer near the surface of the riverbed has the highest flow density.

At high tide, the rating curve (ρ_0) decreases exponentially to the position of about 500 meters from the reference, then (towards the shoreline) the curve rating is almost flat (the density price is almost constant). Figure- (2), (3), (4), shows that the price is turbid (ρ_0) (high tide), for the position $x \geq 500$ meters is almost the same as the price (ρ_0,6h) at low tide. The rating curve (ρ_0,6h) when the high tide shows sharper gradient changes in more upstream positions, which is around the 305 meter. At position $x \geq 305$ meters, the rating curve (ρ_0,6h) is almost flat which means the price of (ρ_0) is almost constant.

The availability of data and profile (function and rating curve) of density flow physical variables, then become the theoretical basis for interpreting the flow density change regression function and assessing/evaluating the erosion and sedimentation process of river basins along the estuary, so that it can be a solution to the problem of sediment transport impacts on the deposition process estuary, as a result of material mining transporting, the community around the estuary intensively supply the needs of building materials in the city of Amurang and its surroundings.

4. Conclusion

Analysis and data modeling of drainage density produces a function and rating curve as follows:

1. The density function and rating curve (ρ_0) at low tide is in the form of an exponential function with a general form as in equation- (7) and figure- (2)
2. The density function (ρ_0) at high tide is in the form of an exponential function with a general form as in equation- (7) and figure- (2)
3. The density function ($\rho_{0,6h}$) for low tide is a linear function with a negative gradient; the general forms as in equation- (8) and figure- (3)
4. The density function ($\rho_{0,6h}$) of high tide consists of two functions with a general form as in equation- (9) and figure- (4) (for a distance range of 82 m $\leq x <$ 305 m) and equation- (10) and figure- (4) (for a distance range of 305m $\leq x \leq$ 655 m.

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