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The Best-Fit Model to Predict Spatial Sedimentation Rates at Loagan Bunut Lake, Miri, Sarawak

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Abstract: Physical laws are fundamental to natural systems across many fields in environmental science. For example, a study of fluid dynamics can be used to describe the dispersion of water pollutants. In this study, the best-fit model was produced to predict spatial sedimentation rates at Loagan Bunut Lake. The lake is a flood plain lake that is located within the boundaries of Loagan Bunut National Park in the northeast part of the state of Sarawak. Twenty-two cylindrical traps were installed at the lake. The traps were placed in November 2005 until April 2008. Each sample was collected after about four to five months of deployment. A dry sedimentation rates and linear distances from Trap 1 located at the confluence of Bunut River were measured. Based on strong coefficient of determinant, the best-fit model of sedimentation rates distributed by advective force at the distance 0-600 m from Bunut River was $S = S_0\ e^{-kx}$ or $S = S_0\ e^{Rx}/_{ws}$. Reynold's theorem of mass flux was used to explain coefficient k in the equation.

Key words: Environmental physics, sedimentation rate, cylindrical traps, loagan bunut lake

INTRODUCTION

Loagan Bunut is a fresh water lake situated within the boundary of Loagan Bunut National Park, at the northeastern part of the state of Sarawak. It covers 6% of the Park area. Specifically, the lake area is between Tinjar River and Teru River of the Baram Basin flood plain. It has its own basin, which is mainly connected with Teru catchments by about 6.6 km of Bunut River.

About 61.9% of the catchments are Stateland on which logging licenses have been issued and where cultivation by local community takes place. Satellite images show a high road density in relatively steep areas (UNDP/GEF, 2007). The Teru catchment is made up of plantations and active subsistence farming areas (Noweg *et al*., 2006).

To the locals, the Berawan, the lake and its surrounding areas play an important livelihood support system and place abode. To the Sarawak State, the lake and its surrounding have economic value for its unique hydrologic phenomena, exotic fish species, water birds, medicinal plants and rich local culture that are marketable.

Even though the containing of water and the trapping of sediment at Loagan Bunut are natural downstream flood and sedimentation controller, an alarming high rate of sedimentation at the lake accelerates the filling of the lake which threatens its functions, natural physical, hydrological phenomena and biodiversity. The lake was experiencing 27 years of rapid sedimentation and it was estimated to be infilled completely within less than 60 years (Hunt *et al*., 2004). Reports have mentioned that the sediment flux along the main feeder stream, the Bunut River and in the lake were 15 and 0.6 kg/m^2/year, respectively (Lau *et al*., 2006).

Therefore in this study we are interested to contribute by producing the best-fit model that can be used to predict sedimentation rates at the distance 0-600 m from the Bunut River.

MATERIALS AND METHODS

Sediment traps: The study site and the sampling stations are as shown in Fig. 1. All the sampling stations were recorded using numbers and clearly marked on the site with bamboo stilts where the sediment traps were tied. The trap's positions and distances from Trap 1 were recorded (Table 1).

A selection of sediment trap design was based on the study objective, sediment trap review, site condition, material durability and cost. The sediment trap was design to trap downward flux that is to represent as close as possible with real sedimentation on the lake bed. An overtraping by cylindrical trap as reported by Flower (1991) and Kozerski and Leuschner (1999) is reduced by using funnel. In this field sampling, funnel was used to avoid sediment escape and to reduce overtraping in high-

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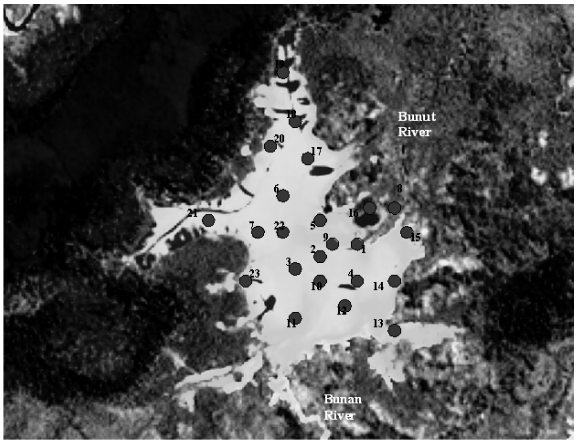

Fig. 1: Locations of 23 deployed sediment traps

Fig. 2: Cylindrical sediment trap

Table 1: The trap's positions and distances from Trap 1

Station	GPS positions		Trap's distance from Station 1(m)
1	N 3°, 45′, 55.5″	E 114°, 14′, 27.54″	0
2	N 3°, 45′, 52.86″	E 114°, 14′, 21.18″	212
3	N 3°, 45′, 50.76″	E 114°, 14′, 11.40″	518
4	N 3°, 45′, 46.92″	E 114°, 14′, 36.90″	391
5	N 3°, 46′, 2.58″	E 114°, 14′, 20.76″	302
6	N 3°, 46′, 14.64″	E 114°, 14′, 9.06″	820
7	N 3°, 45′, 59.40″	E 114°, 14′, 1.02″	825
8	N 3°, 45′, 56.4″	E 114°, 14′, 42.06″	At Bunut River
9	N 3°, 45′, 51.36″	E 114°, 14′, 25.14″	147
10	N 3°, 45′, 43.26″	E 114°, 14′, 22.62″	407
11	N 3°, 45′, 28.98″	E 114°, 14′, 17.88″	870
12	N 3°, 45′, 36.84″	E 114°, 14′, 41.46″	718
13	N 3°, 45, 23.22″	E 114°, 14′, 47.34″	1168
14	N 3°, 45′, 37.5″	E 114°, 14′, 50.04″	888
15	N 3°, 45′, 55.14″	E 114°, 14′, 43.5″	491
16	N 3°, 46′, 1.68″	E 114°, 14′, 34.2″	280
17	N 3°, 46′, 30.48″	E 114°, 14′, 33.36″	1094
18	N 3°, 46′, 44.04″	E 114°, 14′, 13.5″	1559
19	N 3°, 47′, 6.96″	E 114°, 14′, 11.1″	2263
20	N 3°, 46′, 34.08″	E 114°, 14′, 1.68″	1432
21	N 3°, 46′ 9.24″	E 114°, 13′, 41.58″	1477
22	N 3°, 46′, 0.60″	E 114°, 14′, 9.6″	574
23	N 3°, 45′, 46.08″	E 114°, 13′, 58.9″	928

energy area. The traps are made of 15.25-cm diameter funnel and 38.0 cm height pvc cylinder (Fig. 2). A total of 23 sediment traps were first deployed on 24 November 2005. Trap 1 was stationed close to the Bunut River.

Sediment samples: All sediment from the trap was transferred to sealable plastic bags very carefully to avoid any external material adding into the sample or to avoid any portion of the sample being excluded. Every component of the trap was checked and any damaged part was replaced and reinstalled for the next deployment.

The sediment sample was collected after four to five months deployment. The sample was transferred to a metal can for drying purpose. Oven Drying Method by Purusothama (1995) was employed. The sample was then dried in aired oven at 105 °C for a period until a constant weight. The sediment was weighted immediately when cool to get the total sediment mass.

Correlations between sedimentation rates and distance from Trap 1 and best fit equations were tested using Microsoft Excel Analysis ToolPak. A graphical scatterplots were produced and then regression type was chosen. A selected regression type was based on the strength of the relationship. The tool gives the strength of the relationship that is considered as a strong relationship. Then the best fit equation was discussed for its validity.

RESULTS AND DISCUSSION

Table 2 shows the general spatial sedimentation rate at each station for six samples. Trap 8 which was located at Bunut River has maintained the highest average amount of 47.50 g/day/m^2. Then followed by Trap 1 that was located at the confluence of Bunut River/Lake has 16.36 g /day/m^2. Generally, high sedimentation rate area was near to Bunut River. The lowest rates were at Traps 17, 18 and 20, which were far from Bunut River.

The graphs and the coefficient of determinant, R^2 are in Fig. 3. The coefficients of determinant were 0.8 or higher. At this area, sedimentation rate decreased exponentially with distance from Trap 1. All samples showed highly similar decay exponential pattern with distance from Trap 1. An initial value of sedimentation rate before entering the lake was ranging from 8.42 to 22.24 g/day/m^2. The exponential index was ranging from-0.0007 to-0.0021. An average of sedimentation rate with distance from Trap 1 for all samples at the area has R^2 = 0.94 (Fig. 4). The graph is presented with error bars of ±1.5 g/day/m^2 and ±70 m.

Table 2: Sedimentation rates for each station from all six deployments

Traps	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average
	(g/day/m)						
1		25.19		19.70	13.16	7.40	16.36
2	7.65	16.39	15.85	16.20	12.67	7.28	12.67
3	4.37		6.74	7.77	6.83	5.65	6.27
4	4.75	16.67	13.25	17.13		7.86	11.93
5	5.33	12.70	7.93	15.30	9.76	7.08	9.68
6	4.16	9.90	6.17	8.98	5.78	5.32	6.72
7	4.18	9.14	5.57	6.09	8.32	5.63	6.49
8	25.7	69.30					47.5
9		13.68	11.23	12.39	9.26	9.28	11.17
10		12.55	9.93	9.93	7.57	6.07	9.21
11		5.03	3.40	3.00	6.26	4.76	4.49
12		9.17	7.32	7.06	6.99	4.53	7.01
13		2.62		3.84	1.60	2.37	2.61
14		6.57	6.48	7.12	7.43	6.07	6.73
15		9.49	7.17	14.32	6.01	4.63	8.32
16		3.95	3.73	4.20	5.38	5.40	4.53
17		3.34	2.46	1.98	2.70	3.59	2.81
18		5.15	5.25	4.50	4.73	5.48	5.02
19		2.73	4.92	2.78		3.63	3.52
20		5.25	5.17	5.28	5.48	4.84	5.20
21		7.04	7.64	8.56	5.87	5.69	6.96
22		7.90	4.02	5.96	6.89	5.97	6.15
23		7.39	6.04		6.87	5.47	6.44
Avg.	8.02	11.87	7.01	8.67	6.98	5.64	9.03

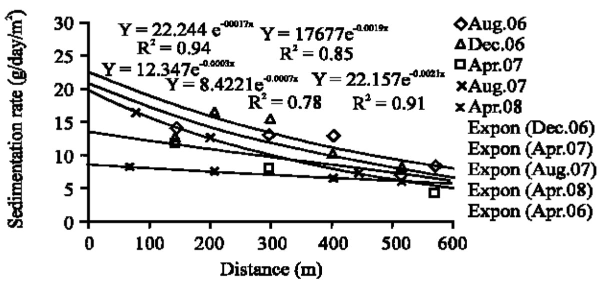

Fig. 3: Best-fit graphs of sedimentation rates at 0-600 m from Trap 1 for five samples

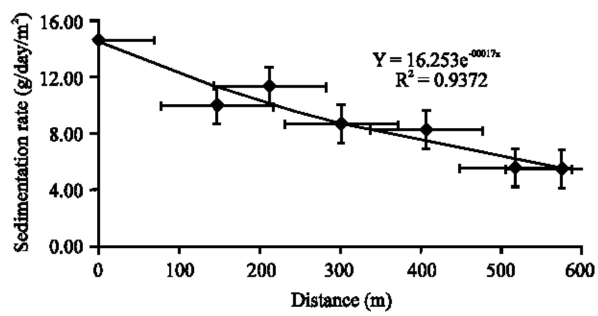

Fig. 4: Best-fit graph of an average sedimentation rate at 0-600 m from Trap 1

The best fit of average sedimentation rates distributed by advective force of inflow at the distance 0-600 m from Bunut River was:

$$S_x = 16.25\, e^{-0.0017x}$$

where, 16.25 = sedimentation rate at Bunut River/Lake confluence in units g/day/m^2, S_x = sedimentation rate at x distance from Trap 1, x = linear distance from Trap 1 in unit m, 0.0017 = a coefficient of sedimentation rate.

The coefficient k in the best-fit equation: Based on the significant correlation between sedimentation and distance, this part of the paper will discuss in more detail about the coefficient k.

One needs to understand what really determines the amount of sediment that is settled in the sediment trap that is installed vertically upward.

From Reynold theorem:

$$\frac{dB}{dt} = \frac{d}{dt}\int b\, \rho d\forall + \int b\rho(V.n)\, dA$$

tells a rate change of property at one control volume and control surface of suspended sediment is equal to the sum of a rate change of property in a control volume and net outward flux of the property out of the control surface. It is assumed that a change of sediment mass due to organic matter decomposition and organic matter oxidation are very small. Hence, the first term in Reynold theorem does not apply. The second term is the input and output through a control area. It is considered that the sediment that is trapped will not be resuspended since the resuspension needs at least 6 cm sec^{-1} of water speed. It is the second term in the theorem that is used to count an input rate of sediment flux through the control surface of the sediment trap's opening, thus the rate of sediment flux in this case is written, $\int b\rho\,(V.n)\,dA$ where b = 1, ρ = concentration of suspended sediment outside the trap, V = velocity of sediment which is a resultant of horizontal water velocity and Stoke' settling velocity, A = trap's opening area and n = normal line to the trap's opening area. Sedimentation rate into the trap's surface depends on suspended solid concentration (ρ) and a dot product of velocity and a direction normal to the control surface (V.n). The term (V.n) is equal to (V cos θ) which is positive for water entering and negative for water leaving the volume. The effective (V cos θ) at the trap's opening is equivalent to Stoke's settling velocity. Therefore, (V.n) = Stoke's settling velocity,

$$Ws = \alpha \frac{g}{18}\left(\frac{\rho_s - \rho_w}{\mu}\right) d^2$$

which is proportional to the particle's diameter square. This means that sedimentation rate is also determined by suspended sediment size. Therefore, sedimentation rate, $S = \rho w_s$.

Using $S = \rho w_s$: From Reynold's theorem of mass flux, sedimentation rate, $S = \rho w_s$ where w_s is a Stoke's settling velocity, it can be written that $\frac{dS}{dx} \alpha\ \rho$ if net w_s is approximately constant with distance x. Then:

$$-\frac{dS}{dx} = R\rho \tag{1}$$

(Note: The negative sign in indicates a decrease in sedimentation rate with distance from Bunut River.):

$$\frac{dS}{dx} = -R\rho \qquad \frac{dS}{\rho} = -Rdx \tag{2}$$

Integrate and let S_0 as the sedimentation rate at Bunut River/Lake confluence or at Trap 1:

$$\int_{So}^{S} \frac{1}{\rho} dS = -\int_{0}^{x} Rdx \tag{3}$$

Subtituiting $\rho = \frac{S}{w_s}$ then:

$$\int_{So}^{S} \frac{w_s}{S} dS = -\int_{0}^{x} Rdx \qquad w_s \ln\frac{S}{S_o} = -Rx \qquad S = S\circ e^{\frac{Rx}{ws}} \tag{4}$$

Therefore, the coefficient of sedimentation rate, $k = R/w_S$. It depends on Stoke's settling velocity and R. From S = pw_s, the value R must be associated with suspended sediment concentration that was mainly influenced by the lake cross-sectional area.

CONCLUSIONS

In this study, the best-fit exponential decay equation is produced to predict sedimentation rate at 0-600 m from the Bunut River. The equation was improvised to become. $S = S\circ e^{-Rx/ws}$ The improvised equation can be used to calculate sedimentation rate in a lake that is distributed by advective force of a single inflow. The value R in the equation can be used to reflect a lake's shape that determines a suspended sediment concentration.

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