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Sediment grain-size distribution in the Lake Laut Tawar, Aceh Province, Indonesia

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Abstract. The objective of the present study was to evaluate the grain size distribution in Lake Laut Tawar. The study was done in May and June of 2012 at 5 locations: Boom, Klitu, Ujung Mumpar, Bintang and Toweran. The samples were collected using a grab sampler. The collected samples from the respective locations were sun dried and then sieved to examine the grain-size distribution. The result showed that the sediment types were divided into three categories: gravel, sandy gravel and gravelly mud. The Boom location had gravelly mud (predominantly mud) that was well sorted, while gravel was a major portion of the sediment in Ujung Mumpar and it was moderately well sorted. In addition, all of the locations had negatively skewed values, which indicates a coarse-skew particle distribution.
Key Words: granulometric analysis, geostatistics, lake sediment, sorting, skewness.

Introduction. Grain size is one of the most important sediment parameters and it is necessary to interpret the depositional environments (Friedman & Sanders 1978). Variations in grain size distribution of lake sediments may reflect the earth's surface processes such as the developmental processes of landforms through changes in precipitation (Sivasamandy & Ramesh 2014). The grain size distributions are affected by various factors including transportation by rolling, suspension and saltation (Inman 1952; Dyer 1986; Folk 1974). Critical studies of the sediment grain size have been carried out by Udden (1914) and Wentworth (1922), who introduced the Udden-Wentworth scale. Furthermore, Friedman (1961) developed sediment statistical reviews based on arithmetic and moment methods, while Folk & Ward (1957) approached grain size distribution through a graphical method. Frequency distributions of sediment grain size (namely mean, sorting, skewness, and kurtosis) were used frequently to interpret the precipitation of sediment when they re-enter the natural environment (Folk & Robles 1964; Dyer 1986; Wachecka-Kotkowska & Kotkowski 2011; Weltje & von Eynatten 2004).

Lake Laut Tawar is one of the oldest volcanic caldera in Indonesia and it has an important ecological role as the habitat for some endemic species of fishes i.e. *Rasbora tawarensis* and *Poropuntius tawarensis* (Muchlisin & Siti-Azizah 2009; Muchlisin et al 2012; Muchlisin et al 2015). This lake is situated about 1200 m above sea level. It is 16 km long and 4 km wide and surrounded by mountains reaching above 2000 m. The watershed is covered by rain forests which are extremely affected by deforestation and agricultural activities (Muchlisin et al 2010). Adhar (2008) stated that the erosion condition of Lake Laut Tawar was in a poor state and this has led to silting the bottom of this lake. In addition, Setiawan (2013) carried out a study of grain size in Laut Tawar Lake, but did not compromise the grain distribution analysis based on the statistical approach. Hence, this paper examines statistical analysis of the sediment grain size based on a previous study reported by Setiawan (2013).

The grain size affects the water turbidity then influences the primary production of the lake and foraging behaviour of aquatic organisms (Jones et al 2015; Tirok & Scharler

2014), for example in guppies, *Poecilia reticulata* that turbidity could lead to a decreased collective response to predators and a loss of the protective benefits of shoaling (Kimbell & Morrell 2015). In addition, it was strong interactions between turbidity, prey density and substrate type on shrimps predation by Thorn fish *Terapon jarbua* (Macia et al 2003). Ferrari et al (2010) stated that turbidity alters the quality and quantity of visual information received by the minnows, eliminating their ability to generalize learned recognition of some predators. This paper provides the understanding the sedimentary depositional processes in the Lake Laut Tawar, this information is crucial in relation to plan a better conservation strategy of Lake Laut Tawar.

Material and Method

Sediment sampling. Lake Laut Tawar is located in Central Aceh, Aceh Province, approximately 1200 m above sea level. Several short tributaries discharge into Lake Laut Tawar, which are affected by deforestation and agricultural land conversions (Muchlisin et al 2010). The sediment samples were collected from May to June in 2012 at 5 stations in Lake Laut Tawar at the depths of 1.2 to 2.4 meters: Klitu (N 4°38'16": E 96°54'04"), Bintang (N 4°35'31": E 96°59'35"), Toweran (N 4°36'19": E 96°53'49"), Boom (N 4°37'50": E 96°51'33") and Ujung Mumpar (N 4°37'44", E 96°56'39") (Figure 1).

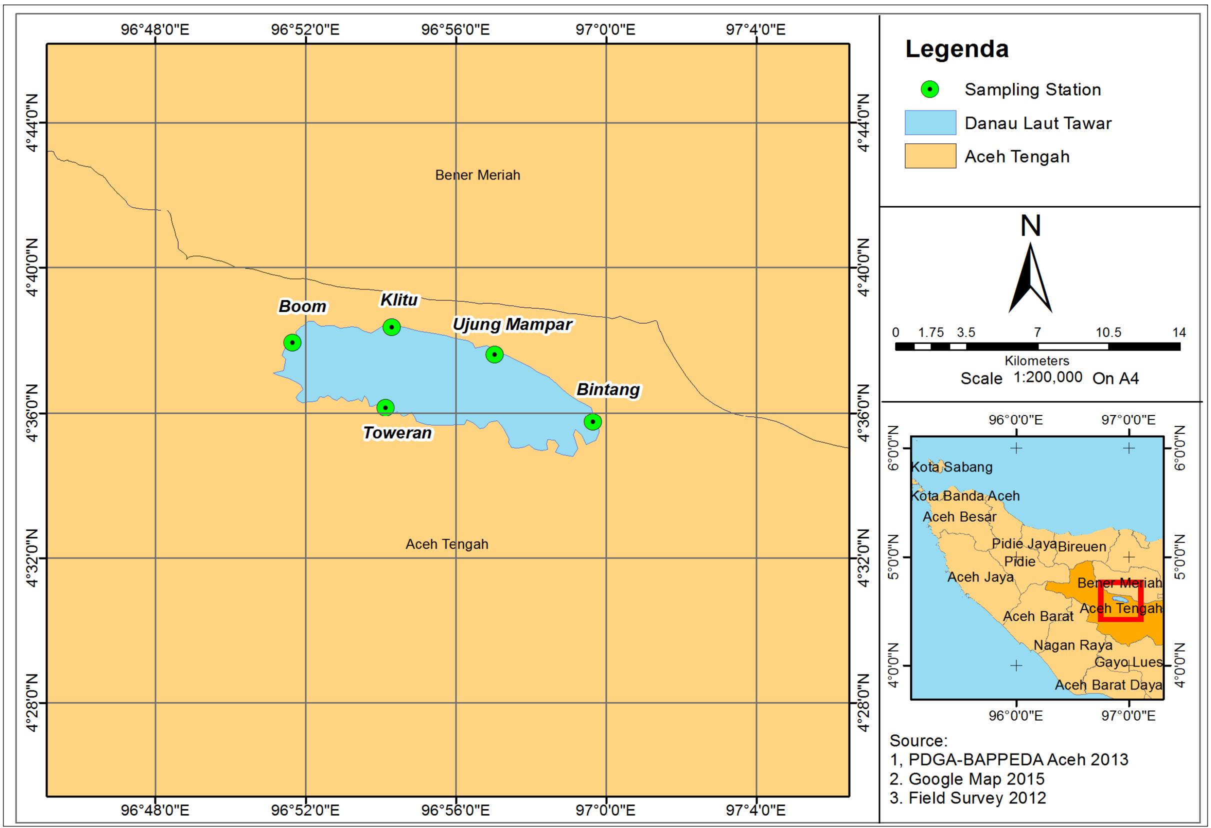

Figure 1. The map of the study area shows the sampling locations: Boom, Klitu, Ujung Mumpar, Bintang, and Toweran.

Sediment analysis. The samples were taken by using a grab sampler of sediment, and then were dried to remove the moisture. Approximately 500 g of dried samples were taken and then sieved using six levels of sieve mesh size: 4.75 mm, 1.7 mm, 0.85 mm, 0.25 mm, 0.15 mm and 0.063 mm. The retained samples in the respective mesh sizes were weighed using a digital balance. Grain size distribution analysis consists of mean (x_a), sorting (σ_a), skewness (Sk_a), and kurtosis (K_a) derived from a statistical approach and moment method following Friedman (1961):

$$\bar{x}_a = \frac{\Sigma f m_m}{100}$$

$$\sigma_a = \sqrt{\frac{\sum f (m_m - \bar{x}_a)^2}{100}}$$
$$Sk_a = \frac{\sum f (m_m - \bar{x}_a)^3}{100\, \sigma_a^3}$$
$$K_a = \frac{\sum f (m_m - \bar{x}_a)^4}{100 \sigma_a^4}$$

Where, *f* is weight frequency (%) in each class, m_m is median in each class.

Based on Folk & Ward (1957) the sorted condition is categorized at seven levels:< 0.35 is very well sorted, 0.35-0.50 is well sorted, 0.50-0.70 is moderately well sorted, 0.70-1.0 is moderately sorted, 1.0-2.0 is poorly sorted, 2.0-4.0 is very poorly sorted, > 4.0 is extremely poorly sorted. Furthermore, the skewness values were divided into five levels: strongly fine skewed (>+0.3), fine skewed (+0.3 to +0.1), near symmetrically (+0.1 to –0.1), coarse skewed (-0.1 to -0.3) and strongly coarse skewed (<-0.3).

Results and Discussion

Sedimentological characteristic. The results showed that gravel was predominant at the four locations Klitu, Ujung Mumpar, Bintang and Toweran, while Boom was dominated by mud. The study showed that the percentage of gravel was higher in Ujung Mumpar (98.80%) and therefore the sediment type in this location was classified as gravel. The type of sediment samples were defined by the Folk triangle (Folk 1974) and thus fall into the categories of gravelly mud, sandy gravel, and gravel, as shown in Table 1. All parameter values obtained for the grain size distribution parameters through the statistical and moment methods are presented in Table 2.

Table 1

Grain size distribution according to sampling locations

Station	*Weight percentage frequency (%)*							*Type*
	>4.75	*1.7-4.75*	*0.85-1.7*	*0.25-0.85*	*0.15-0.25*	*0.063-0.15*	*<0.063*	
Boom	9.13	8.37	2.85	2.66	0.95	1.52	74.52	Gravelly mud
Klitu	45.65	17.67	13.41	20.78	1.55	0.8	0.14	Sandy gravel
U. Mumpar	92.05	6.75	0.64	0.33	0.06	0.09	0.08	Gravel
Bintang	42.95	22.17	10.98	13.33	7.56	2.61	0.4	Sandy gravel
Toweran	44.21	12.73	6.6	22.89	5.73	6.94	0.9	Sandy gravel

Table 2

Grain size statistical analysis

Station	*Mean*	*Sorting*	*Skewness*	*Kurtosis*
Boom	0.8183	1.5938	-0.0848	4.8029
Klitu	3.1417	1.9135	-0.7347	1.3731
U. Mumpar	4.8304	0.6269	-3.1983	24.0817
Bintang	3.0940	1.9216	-0.7742	1.4789
Toweran	2.8508	2.1046	-0.6154	1.2000

Sediment grain size distribution. Grain mean size is regarded as the main factor for an index of energy conditions referring to current or turbulence level (Folk 1966) where the finer grained sediment is deposited in a lower energy condition. The mean size of grain in Lake Laut Tawar ranged from 0.8183 mm to 4.8304 mm. These variations are a reflection of the average energy that has occurred in the water column and the energy of the depositing agent. The variation in mean grain size is an indication of the different energy conditions, which effects their deposition. For example, a higher grain mean size was recorded in Ujung Mumpar, while a smaller grain size was detected in Boom, indicating that a higher energy level was found in Ujung Mumpar, and a lower energy level was found in Boom. Based on these results it can be deduced that the deposition occurred at the Boom station. This is probably due to the fact that this location is adjacent to urban areas and receives a high amount of domestic waste from settlements and agriculture activities (Setiawan 2013). Furthermore, Boom is also the discharge of Lake Laut Tawar through Peusangan River, and therefore the fine-grained sediment from other locations are partially trapped and settle in this area. This process will raise the potency of silting, turbidity and water pollution. Klitu, Ujung Mumpar and Bintang are located near the side of the mountain that has steep land contours, and several river downstream (Adhar 2008). Hence, we speculate that gravel is carried-out by the river stream into the lake and then settles at the bottom. The steep contour is also probably triggering the erosion which erodes the rock and sediment materials from the mountain side (Gasiorowski 2008).

Sorting indicates the range of forces which determine the sediment size distribution (Briggs 1977; Dyer 1986; Folk 1974). Lower sorting values correspond to better sorting processes of sediment samples. The study showed that low sorting values were found in Ujung Mumpar, indicating a moderately well sorted condition, while Toweran and Bintang have the high sorting values that indicate a very poorly sorted condition, and the rest of the locations were classified as poorly sorted conditions. The land conversion caused mass waste of unconsolidated soil materials during rainy season and therefore it is presumed that land conversion along Lake Laut Tawar is one of the most important causes of erosion, particularly in Toweran. This condition has mixed the eroded materials with existing materials at the bottom of the lake which resulted in a poor sorting index.

Skewness measures the asymmetry of frequency distribution with respect to the median value of grain size (Friedman 1961). All of the locations showed negative skewness, which indicate that all of the locations have coarse skewed conditions. Klitu, Ujung Mumpar, Bintang, and Toweran were categorized as strongly coarse skewed, while Boom was categorized as near symmetrical distribution. The negative skewness has a correlation with the intensity and duration of a high energy depositional agent through displacement of fine-grained sediment from respective areas (Martins 1965; Friedman 1961; Duanne 1964). This indicates that Klitu, Ujung Mumpar, Bintang and Toweran have high energy levels at each location, and thus these locations tend to lose fine material due to high water currents. While Boom has a near symmetrical distribution (indicated by a skewness value near zero), this location is a trap area for fine grained sediments that deposited as mud.

The Kurtosis analysis shows the distribution curve, indicating the peakedness degree or flatness of the distribution, with the minimum value found at Toweran and the maximum value at Ujung Mumpar (Table 2). Toweran, Bintang and Klitu have leptokurtic curves, while Boom and Ujung Mumpar were categorized as extreme leptokurtic. Although Boom and Ujung Mumpar have the same category, their curves were derived from different processes. While high peaked kurtosis in Boom was derived from finer grained particles, the curve in Ujung Mumpar was derived from coarser grained particles. The highest kurtosis value was in Ujung Mumpar and was associated with the sorting process that occurred there. As mentioned before, the fine grained sediments in Ujung Mumpar were transported out of this area while coarse particles remained at the bottom. This phenomenon is in agreement with Boggs (2009), which explained that kurtosis values have a strong correlation to the sorting process, where a higher kurtosis value is in line with a better sorting process.

It is a strong relationship between grain size and water turbidity where small grain size resulted in high turbidity as recorded in this study, for example the small grain size was detected in Boom station, this is in correlation to low water transparency or high turbidity as reported by Nurfadillah et al (2012). As mentioned early that the catchment area of the Lake Laut Tawar has been deforested intensively and the water level has been decreased significantly during the last two decades (Muchlisin et al 2010; Muchlisin et al 2011). Deforestation has a profound influence on the rivers and streams that form an important feature of the forest ecosystem and their associated with aquatic flora and fauna (Wright & Flecker 2004). Intensive deforestation can also result in changes to invertebrate communities dominated by small burrowing forms, such as larvae chironomids which may be less available to foraging fishes. High turbidity hinders the sun light penetration into waters, it hamper photosynthesis of micro algea then decreases primary production of waters (Tirok & Scharler 2014). Turbidity is also affect predatory fishes to detect and caught their preys (Johnston et al 2007). In addition, increases of water turbidity would devastating of spawning and nursing habitats then reduced the productivity of fish communities (Craig 2000).

Conclusions. Based on the weight percentage frequency, it was concluded that gravel is a predominant portion of the sediment in Lake Laut Tawar. The calculations for sorting index indicate that Boom has a well sorted condition, Ujung Mumpar a moderately well sorted condition, and Toweran a very poor sorted condition. In addition, all of the locations have negatively skewed values, with Klitu, Ujung Mumpar, Bintang, and Toweran strongly coarse skewed. Boom and Ujung Mumpar have high Kurtosis values and an extremely leptokurtic curve.

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