GEOSTATISTICAL CHARACTERIZATION OF GRAIN SIZE DISTRIBUTION OF INTERTIDAL SEDIMENTS IN BA LAT ESTUARY, VIETNAM

NGUYEN THI NGOC[1,2], KATSUAKI KOIKE[1]

[1]Graduate School of Science and Technology, Kumamoto Univeristy, Kumamoto, Japan

[2]Faculty of Geology, Hanoi University of Science, Vietnam National University, Vietnam

ABSTRACT: Intertidal estuarine sediment grain size is one of the environmental parameters that can explain the interaction between the marine and terrestrial environments. Geostatistics has been widely used to model spatial distribution of many geological objects. However, there has been a few researches concerning with application to grain size distribution. The aim of this study is to clarify surface sediment distribution of tidal flats based on the geostatistical approach. A total of 116 surface sediment samples were collected from the tidal flats in Ba Lat estuary. Grain size of these samples was determined by means of sieve and pipette. Data of sand content (percent of fraction > 0.063 mm) in the sediments were characterized by ordinary kriging (OK) to model sediment distribution. In the study area, four sediment types could be recognized: sand, muddy sand, sandy mud and mud. The sandy sediment types are dominant from the near sea shoals (Con Mo, Con Vanh, Con Thu) to centre of study area. The muddy sediment types concentrate on from inner edge to centre of study area, where mangroves cover partly these tidal flats. These results can contribute to explain the hydro-dynamic and environmental pollution processes in the estuarine area.

Keywords: grain size, sand content, tidal flat, ordinary kriging

INTRODUCTION

Tidal flats are defined as “sandy to muddy or marshy flats emerging during low tide and submerging during high tide” (Reineck, 1972). Intertidal flat limited between mean high water spring tide and low water neap tide is considered as an ecosystem with high biological productivity, significantly important roles as nesting, feeding and spawning grounds for large numbers invertebrates, fish, and migratory birds (Dyer et al., 2000). Intertidal area exhibits heterogeneous sediments in regard to grain size distribution from land to the sea ward (Shi & Chen, 1996) which resulted from environment of sediment transportation and deposition, and hydro-dynamic conditions (tidal energy, wave and tidal current) in the estuarine areas. Therefore, grain size distribution is an important property to understand the hydro-dynamic condition, biogeochemical cycle and contaminated process. Deposition is generally associated with low energy environments where fine grained material tends to accumulate. Whereas, where erosion dominates, sediment is over-consolidated (Dyer et al., 2000). Tubbs (1977) found that the organic and nutrient contents in intertidal sediments got negative correlation to particle size. The contaminant concentration is related to the spatial variation of sediment grain size. The smaller the size of the sediment fraction, the higher the content of contaminant accumulates in sediment (Whitney, 1975; Martincic et al., 1990; Zhang et al., 2001; Duquesne et al., 2006; Nobi et al., 2010). Studying grain size distribution of sediments is needed due to particular benefit to environmental management of estuarine area where is sensitive to natural processes and human activities.

Geostatistic is commonly applied for spatial analysis of soils, for example, soil properties, pH, organic matter, moisture and pollutant in soils (McBratney & Webster, 1983; Gotway et al., 1996; Laslett & McBratney, 1990; Bragato & Primavera, 1998; Western et al., 1998; Chu et al., 2010). Resembling such soil parameters, sediment grain size has been selected to create a map of sediment distribution by using geostatistical analysis (Leecaster, 2003; Méar et al. 2004; Goff et al., 2007). Additionally, making this map from modeling techniques may not require large number of data sampling in the field, much time and cost consumption (Goff et al., 2007). In order to find out spatial variation of sediments, they used sediment mean grain size data (Goff et al., 2007) or fine-grained content (percent of fraction < 0.05 mm) (Leecaster, 2003; Méar et al., 2004). In this study, for describing the sediments in detail by Folk sediment classification (see Fig. 2), percentage of fraction >0.063 mm in sediment called sand content was considered to map of surface intertidal sediment distribution in Ba Lat estuary by geostatistical analysis. This map has signification for monitoring change in tideland and understanding process that impact on the sediment distribution in Ba Lat estuary.

STUDY AREA

The Ba Lat estuary, an arrow-shaped jutting out into the sea, is the major and typical delta of the Red river system in Northern Vietnam (Fig. 1). About 31×10^6 m^3 of sediment occupying nearly 38% of the annual amount of sediment carried by the Red river system is discharged into the South China Sea through Ba Lat mouth (Duc et al., 2006). Ba Lat estuary belongs to a meso-tidal region with diurnal tide and a tidal range from 2.0 to 3.7 m.

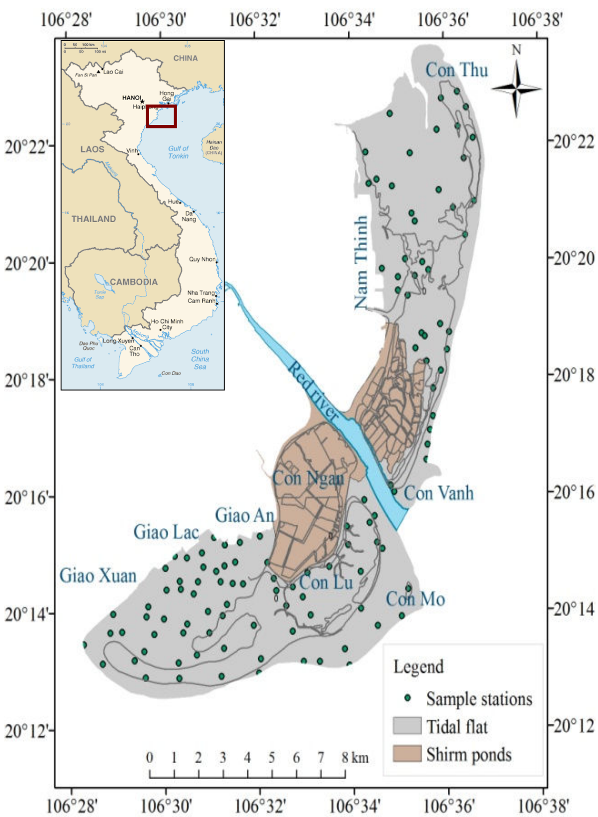


Figure 1 Locations of sample points in Ba Lat estuary.

This study focused on the tidal areas at the 2 m water depth composed of Con Lu and Con Vanh islands formed by accretion, Con Mo and Con Vanh shoals - active bars - in front of Ba Lat mouth, and the Giao Xuan, Giao Lac, Giao An, Nam Thinh coastal areas. The Con Mo and Con Vanh shoals exhibited mainly sand with very good sorting and rather uniform (Duc et al., 2006). Mangroves grow naturally in the north of Con Lu and along the channel banks and were planted in the muddy flats from Giao An to Giao Xuan commune from 1997. Nearly all tidal flats covered by mangroves at Con Vanh, Con Ngan islands have been converted to aquaculture ponds since the early 1980s. The muddy sand flats in the northeast and southwest parts are enclosed for clam (*Meretrix lyrata*) aquaculture.

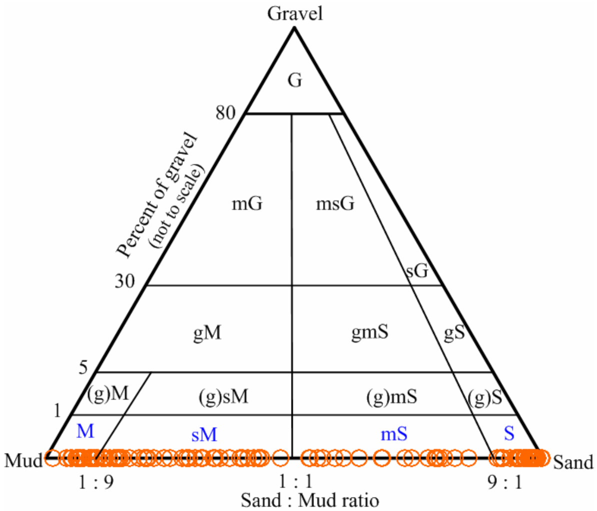
METHODS

Sampling and sample analysis

Field survey was carried out in June 2010 during neap tide when tidal flats were completely exposed. Sampling points were selected to cover the wide range of grain size present in intertidal sediments and located by using ETrex Vista HCx Garmin GPS with an accuracy of less than 10 m. A total of 116 sediment samples were collected from upper 3 cm surface in bare tidal flats and vegetated tidelands (mangrove forest - swamp) by plastic scoop.

In the laboratory, grain size of sediment samples were determined by combination of two methods: sieve and pipette that used for sandy fraction (0.063-2.000 mm) and finer grained size (less than 0.063 mm), respectively. Sediment samples were firstly dried at 105 °C and weighed 20-30 gram for the sieve and 5-15 gram for the pipette. The sand-rich samples were wet sieved through a sieve of 0.063 mm to get rid of mud from the samples. The particles coarser than 0.063 mm after drying at 105 °C were gently pounded with fingers and dry sieved at 0.50, 0.25, 0.125 and 0.063 mm by using AS 200 Retsch sieve shaker (made in Germany). For pipette analysis, the fine fraction passing through the 0.063 mm sieve after wet sieving was poured into liter glass cylinder and added distilled water to 1000 ml exactly. At the end of 40 seconds, 16 minutes, 59 minutes and 15 hours as soon as the stirring rod was emerged for the last time, an exactly 25 ml was withdrawn by pipette for each time (Folk, 1968). These suspension volumes were evaporated at 105 °C and weighed to calculate amount of particles corresponding with 0.01, 0.005, 0.001 and less than 0.001 mm in sizes. Content of these fractions reported as percentage of the total sample weight.

In order to distinguish between sediments, a textural classification system by Folk (1968) was used. This is a triangular diagram shows percentages of gravel (fraction coarser than 2 mm), sand (fraction range in 2 and 0.063 mm) and mud (material finer than 0.063 mm). Depending on the relative proportions of these three components, fifteen textural classes are distinguished. In this study, by lack of gravel constituent in sediment samples, four classes were discriminated based on the sand content (percent of particle coarser than 0.063 mm): Sand (>90 %), muddy sand (90-50 %), sandy mud (50-10 %) and mud (<10 %) (Fig. 2). The contour lines using values of 10 %, 50 % and 90 % sand were boundary lines of the four sediment types on the map of surface sediment distribution in Ba Lat estuary.



O	Sediments of Ba Lat estuary
M	Mud
sM	Sandy mud
(g)M	Slightly gravelly mud
(g)sM	Slightly gravelly sandy mud
gM	Gravelly mud
S	Sand
mS	Muddy sand
(g)S	Slightly gravelly sand
(g)mS	Slightly gravelly muddy sand
gmS	Gravelly muddy sand
gS	Gravelly sand
G	Gravel
mG	Muddy gravel
msG	Muddy sandy gravel
sG	Sandy gravel

Figure 2 Ternary plot illustrated sediment types in Ba Lat estuary.

Geostatistical Analysis

Geostatistical methods have been widely applied in modeling spatial-temporal distribution of regionalized variables based on the spatial correlation structure to estimate value of variable at an unsampled location. There are numerous geostatistical interpolation techniques as simple kriging, universal kriging, ordinary kriging (OK), cokriging. Comparisons between these modeling techniques were examined in many researches (McBratney & Webster, 1983; Gotway Crawford et al., 1996; Laslett & McBratney, 1990; Bragato & Primavera, 1998; Peter & Chris, 1998; Lloyd & Atkinson, 2001; Leecaster, 2003) and found that OK and cokriging interpolated more accurately than others (Leecaster, 2003). We attempted to used both OK and cokriging in this study but cokriging was not adaptive. Bathymetry and mean grain size data could be considered as a secondary variate to estimate sand content by co-kriging method; however, water depth data are not available while number of mean grain size data equals number of sand content data. Consequently, we used OK to characterize grain size distribution of sediments in Ba Lat estuary.

After Lloyd & Atkinson (2001), the percent of sand fraction in sediment at unsampled location ($Z(x_0)$) is predicted based on the data sampling points ($Z(x_1)$, $Z(x_2)$,…, $Z(x_n)$) by using OK can be expressed as:

$$\hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (1)$$

where λ_i are the weights assigned to the available observations. The sum of the weights requires to one for unbiased estimator.

One key tool of most kriging methods is semivariogram which describes the variability of the measure with distance of separation. The experimental semivariogram for n pairs of sampled locations separated by the distance h is defined the following equation:

$$\hat{\gamma}(h) = \frac{1}{2n} \sum_{i=1}^{n} [(Z(x+h) - Z(x)]^2 \qquad (2)$$

The most important step in OK was fitting parametric semivariogram γ(h) by the weighted least square method to select the best fit semivariogram model. The adequate fitted model was spherical model based on satisfy the criteria of cross validation statistics (mean error, root mean square standardized error). In this study, all steps of OK method applied for sediment grain size data were performed using Geostatistical Analyst extension in ArcGIS 9.3 (ESRI, Inc., 2009).

RESULTS AND DISCUSSION

The sand content of 116 sediment samples was represented to create map of sediment distribution. Data were firstly checked for distribution property. The sand content in the intertidal sediments varied in wide range from 1.32 to 99.77 %. The highest frequency was samples with sand content larger than 90 % (Fig. 3). However, data were not exhibitive a perfect normal distribution even data were transformed to logarithm or square root. Mean grain size ranged from 0.0054 to 0.1731 mm corresponding with mud to sand grade and increased with increasing the sand content in sediments due to high correlation coefficient (R=0.96) between them (Fig. 4). They had the same number of data; hence, mean grain size of sediments could not be integrated to interpolate sand content by cokriging technique.

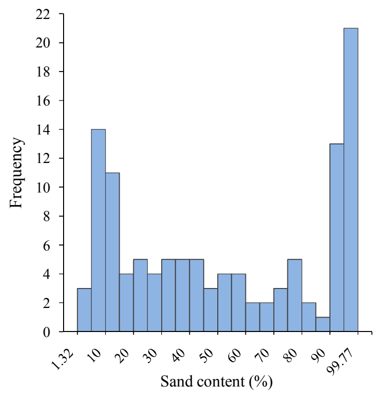


Figure 3 Frequency distribution of sand content in sediments.

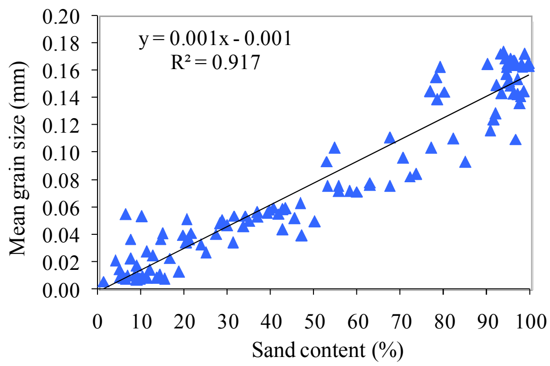


Figure 4 Scatter plot of mean grain size and sand content of sediments.

OK method was performed and its experimental semivariogram model was omnidirectional after checking anisotropy and fitted with spherical model. The lag size, number of lags, nugget, sill and range for modeling semivariogram were obtained to be 600 m, 12, 135, 1,400 and 5,800 m, respectively (Fig. 5).

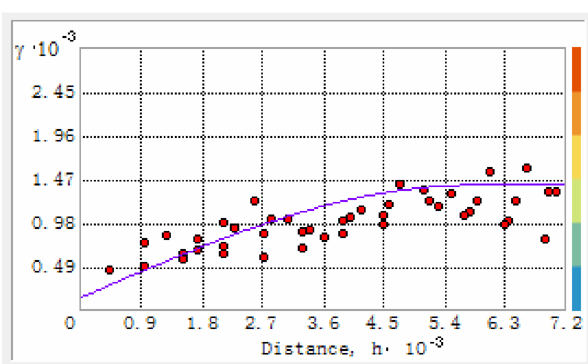


Figure 5 Empirical semivariogram (circles) and spherical model (continuous line).

The cross validation results of OK method were summarized in Table 1. The root mean square error standardized of OK (0.998) was close to 1 and mean prediction error (-0.521%) was also close to zero. There was a linear relationship between measured and predicted sand contents with correlation coefficient R=0.83. In addition, sand content predictions were between 4.04 and 99.04 % close to the range of observed sand content (Table 2, Fig. 6). It could be an evidence for the precision of OK estimation due to the fact that the sand content in sediments is impossible to be less than 0 or greater than 100 %.

Table 1 Cross validation results of OK.

Cross validation parameters	OK
Mean prediction error	-0.521
Root mean square error	19.55
Average standard error	19.73
Mean standardized	-0.013
Root mean square standardized	0.998
Correlation coefficient	0.72

Table 2 Comparison the measured sand content (%) in sediments with predicted values by OK.

	Min	Max	Mean	Median	St.dev.
Real values	1.32	99.77	52.17	47.02	34.94
OK	4.04	99.04	51.66	51.35	28.12

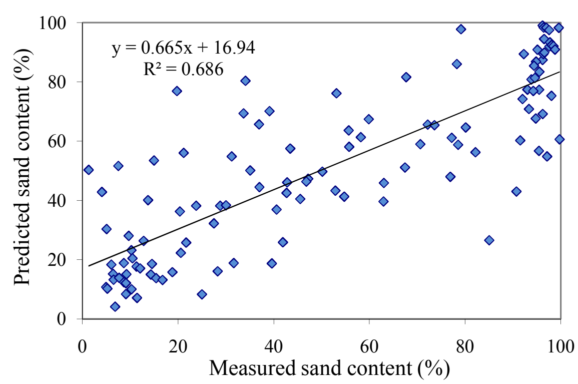


Figure 6 Scatter plot of predicted and measured sand contents in sediments.

Prediction map of sand content distribution with 10% interval established by OK showed a tendency coarsen seaward of sediments in Ba Lat estuary (Fig. 7). Sand content in sediments increased gradually towards offshore direction. High sand content sediments were concentrated on the areas where direct contiguous to the sea, while sediment zones of low sand content were adjacent to mainland.

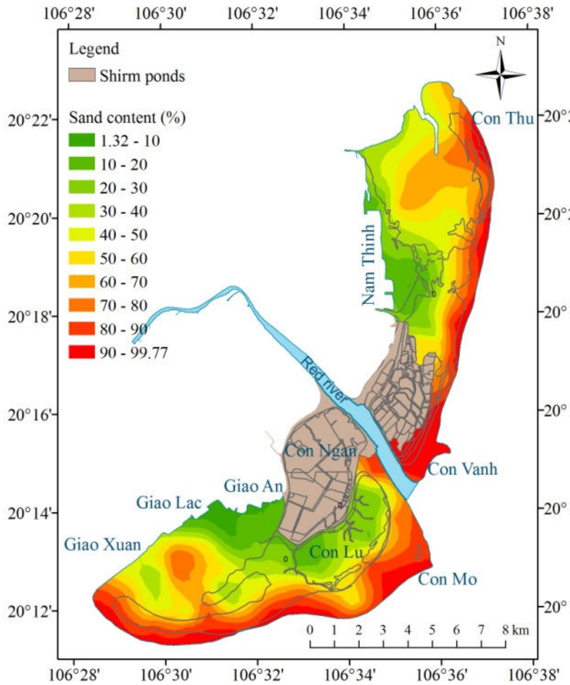


Figure 7 Prediction map of sand content in sediments in Ba Lat estuary

By delineating contour lines at 10 %, 50 % and 90 % sand content, four sediment types in Ba Lat estuary could be recognized: sand, muddy sand, sandy mud and mud. Similar to sand content, their distribution changed towards the sea direction (Fig. 8). Sand was mainly located in the isolated shoals (e.g., Con Mo, Con Vanh and Con Thu) and other parts along the outer edge of the study area. These sandy shoals have been extended at a rate of about 15-100 m/year (Duc et al., 2006). Whereas, only a small patch of mud was existed in the southwest innermost of the study area. The most abundant sediment was sandy mud covering large inner parts of the southwest and northwest Ba Lat estuary where mangroves are widespread. Muddy sand was widely predominant at the remaining parts that filled a gap between the sand and sandy mud fields.

Distribution of sand at the shoals in Ba Lat estuary was consistent with previous map performed by Duc et al. (2006) in the Red river delta. However, this map showed that sand occupied the whole of Ba Lat estuary resulting from investigation for the large coastal zone (between at a depth from 0 to 30 m) at the smaller scale. Trend in intertidal sediment distribution in Ba Lat estuary corresponded with the sediment exhibition rule of tidal flats: mudflats are common in the upper portion of the intertidal zone, sand flats appear in the lower portion and mixed sand-mud flats locate between the two parts (Reineck, 1972). This tendency was observed at many tidal flats over the world (e.g., the Danish Wadden Sea, Gomso bay, the Yellow Sea coasts of South Korea, the Bay of Fundy, coasts of China, Australia, New Zealand, Bangladesh, Thailand and the United Kingdom) (Holland & Elmore, 2008).

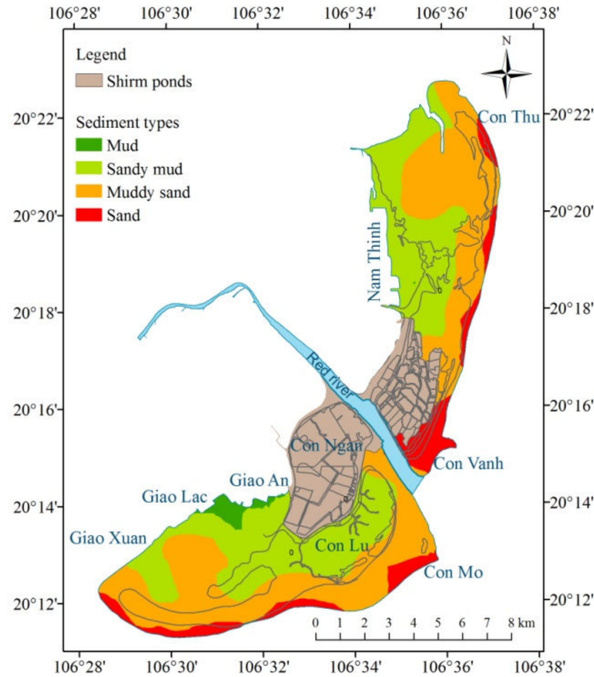


Figure 8 Map of intertidal sediments distribution in Ba Lat estuary

Differences in intertidal sediment distribution could reflect the energy of the depositional environment as a result of wave, currents and tide. Low tidal flats near the low water line exposed during ebb tide are influenced on high energy (strong currents and wave action) and therefore, coarser sediments are commonly deposited here. Whereas, muddy sediment are mainly accumulated at the high tidal flats that flooded at high water line during spring tide due to low energy water movement. Additionally, mangroves growth in the high tidal flats play important role to trap fine-grained sediments. About 80% suspended sediment in total of carried materials was retained in a mangrove swamp (Middle Creek, Cairns, Australia) by flocculation of the finer particles (Furukawa et al., 1997).

CONCLUSIONS

Grain size distribution of intertidal sediments in Ba Lat estuary was clarified by applying OK. Intertidal sediments in the study area exhibited heterogeneity in spatial distribution with the sand content (fraction > 0.063 mm) ranged between 1.32 and 99.77 % and increased with an increase distance from mainland. Sand, muddy sand, sandy mud and mud were identified based on their sand content in sediment that was higher than 90 %, 90 - 50 %, 50-10 % and less than 10 %, respectively. Sand and muddy sand dominated towards the outer side, while sandy mud and mud covered the inner side of the study area. These results can enable to understand the transportation and deposition conditions of sediments, the accretive and erosive processes as well as contamination in the estuarine area.

ACKNOWLEDGEMENTS

We are great thankful to the Graduate School of Science and Technology, Kumamoto University, Japan for financial support for field survey. The authors would like to thank colleagues at the Faculty of Geology, Hanoi University of Science, Vietnam for their help during the field trip and laboratory analysis.

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