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Use of ^{137}CS Activity to Investigate Sediment Movement and Transport Modeling in River Coastal Environment

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ABSTRACT

Conflicts between human and environment always triggered to sedimentation and erosion problems within the coastal areas, Therefore understanding sediment transport processes in a river estuary and coastal waters was important when studying sediment transport and mobility within the river coastal environment. This article aims to investigate the sediment transport and mobility of the Kemaman River estuary, Terengganu Malaysia. In this article, it was demonstrated that anthropogenic activities within a watershed, such as agriculture and urbanization affected the sediment yield from the watershed. Over four months observation (November 2008-February 2009), the delivery of suspended sediment from the Kemaman River to the Kemaman Estuary had increased by about 25%. Based on the in-situ measurement of ^{137}Cs activity, the measure activity ranged between 5638-22421 cpm for backshore while for foreshore was between 2655-13354 cpm. The mean values for backshore and foreshore were 15153 and 6261 cpm respectively with suspended sediment concentration, recorded from 17 November to 10 February was between 110.5-218.8 mg L^{-1}. Using flow and suspended sediment discharge data provided by the Drainage and Irrigation Department (DID) revealed were possible increasing trend in suspended sediment discharge and concentration, particularly during the monsoon season. Temporal analysis indicates that the trend of sediment yield was increased during the monsoon season resulting over sediment supply adjacent to the river mouth and causing difficulty for fisherman to navigate the boats. In a broader context, this study can underscores the need to address the anthropogenic impacts and flood monsoon on sediment yield in the Kemaman-Chendor estuary system.

Keywords: Suspended sediment concentration, Sediment movement, ^{137}Cs, River Estuary, coastal system, sediment yield

1. INTRODUCTION

Understanding sediment transport processes in a river estuary and coastal waters is important when studying sediment transport and mobility within the river coastal environment. The combination of data and modeling analyses can be used to evaluate sediment characteristics for short and long term periods. In a natural environment, river estuary and nearby coastal can be considered as the most dynamic system. Many important reactions controlling the transfer of elements from the continents to coastal waters and the oceans are taking place in estuaries. For many elements, river estuaries can act as filters, capable of reducing the river load of dissolved and particulate elements to the oceans (Etienne *et al*. 2011). However, due to intensive human activities in the upstream as well as coastal development along the beach causing instability on process and respond within the system. As a result, some parts of the estuary registered beach and bank erosions while the other corner of the estuaries, sediment deposition occurred. In general, sediment mobility and its subsequent coastal erosion across the river estuary is one of a major concern around the world (He and Walling, 1996; Kamarudin *et al.* 2009; Toriman *et al.* 2009). It is well documented that most of the sediment sources are transported from the river itself and waves actioned through the seabed, beach and cliff erosions (Komar, 1998; Nielsen, 1992). The volumes of sediment yields from rivers are varied from 541, 000 t/km^2/y (Yangtse River), 120, 000 t/km^2/y (Mississippi River) to 92, 000 t/km^2/y (Kelantan River). Both sources generally provide sufficient sediment supply to develop a beach profile along the coastal shoreline. However, problems may arise when wave rushed onto the beach causing beach drift and later creating littoral erosion. As a result, sediments in the surf zone are transported along the beach in a zig-zag pattern (Pethick, 1984). How do the sediment mobilized, where the sediment goes and how far the sediment travels are of the interesting subjects focused among the hydrogeomorphologists, geologists and oceanographers.

The specific aim of this article is to study the behavior of near-shore sediment mobility and transportation of the Kemaman River estuary, Terengganu. In conjunction with the questions addressed above, this study sets two main objectives namely:

- To study the sediment mobilization patterns due to wave action during the monsoon seasons of December 2008-February 2009
- To relate the sediment mobility with sediment properties and suspended sediment concentration in the study area

2. MATERIALS AND METHODS

Kuala Kemaman was selected as the study area because the area had suffered from serious destruction of houses and properties during the 1996, 2003, 2004 and 2006 monsoon seasons due to coastal erosion. Geographically, Kuala Kemaman is located within the boundaries of Kemaman District Council covering an area of about 2, 536 km square or about 19 percent of the total area of Terengganu. Kuala Kemaman faces the South China Sea at 4^{o}16’ to 4^o 38’ N and 103^o 23’ to 103^o 31’ E. Most of the sediment from upstream sites were transported through a river network scattered within the catchment. Sg Kemaman is a major river drain flows toward the eastern part of Kuala Kemaman. Following Figures are the location of the study catchment and river network (**Fig. 1**) and geological characteristics of the study area (**Fig. 2**).

The fingerprint technique has been widely used to trace the sediment mobility in river channels. However, the use of tracers in river estuary research is, however, relatively scarce. In general, different methods for tracing and quantifying sediment mobilization in the river estuary have been developed over the last 40 years. Most of the techniques used are focused on the *in-situ* survey, sediment sampling and airborne remote sensing. All of these methods have advantages but also potential problems and limitations. This study used multiple fingerprints to quantify the pattern of sediment mobility namely the use of environmental radionuclide *Caesium-137* and sediment properties analysis. Both techniques found to be satisfactory to define the two objectives listed above. Meanwhile, the equilibrium beach profile modeling was applied for estimating volume of sand to be created along the Kuala Kemaman beach after the eroding episode.

To date, most studies involving sediment mobility have focused on the use of radionucliders such as Caesium-137 (^{137}Cs), Beryllium-7 (^{7}Be) and Excess lead-210 ($^{210}Pb_{ex}$). Since that earlier study by Ritchie *et al.* (1974) and Rogowski and Tamura (1965) the ^{137}Cs have been successfully used in tracing sediment sources in many areas of the world (Ajayi (2001) and Ai-Zahrani (2001). Technically speaking, the ^{137}Cs is an artificial radionuclide, a group 1 in chemical series with half-life time 2.05 years. It behaves as a conservative element in seawater, similar to other alkali element (e.g., K and Na). In an original form, the ^{137}Cs is a soft silvery-gold which is one of the three metals (gallium and mercury) that are liquid at room temperature. In this study, the *in-situ* measurements were applied to trace the sediment mobility within the estuary system. Two plots from backshore and foreshore of Kuala Kemaman river estuary were selected and labelled with the radioactive tracer ^{137}Cs. These plots were subjected to highly potential eroded as reported by local villagers and the Drainage and Irrigation Department (DID) (**Fig. 3**).

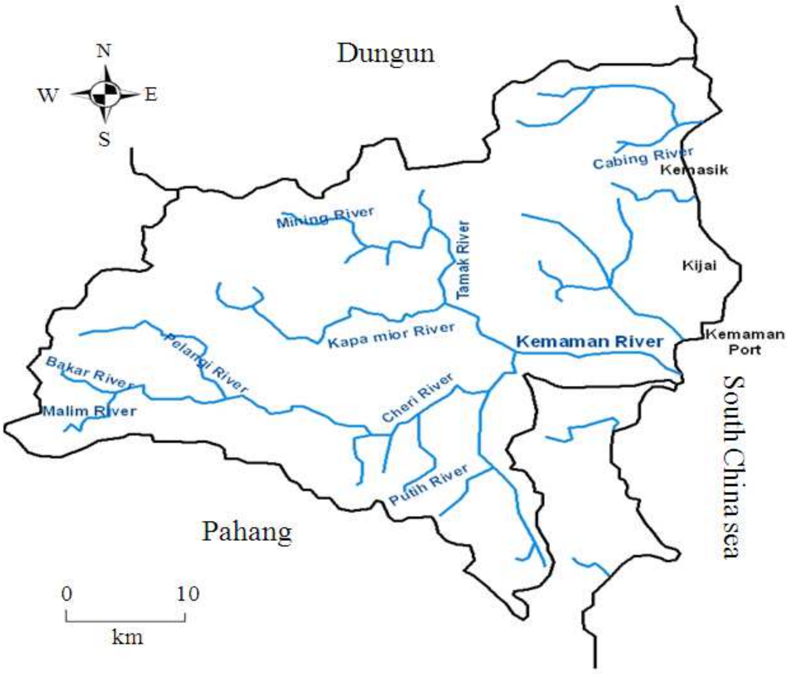

Fig. 1. Location of the study area

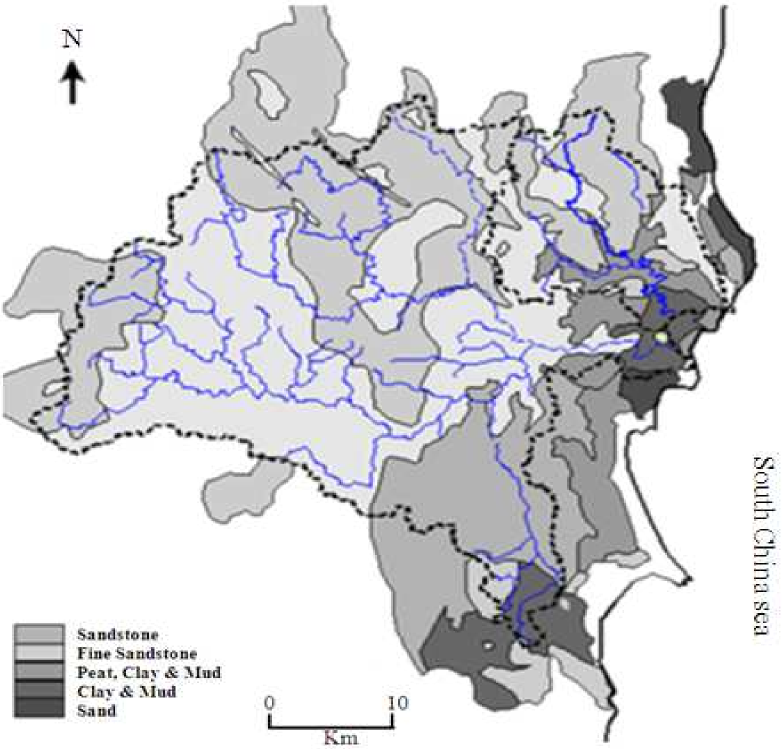

Fig. 2. Geological characteristics of the study catchment

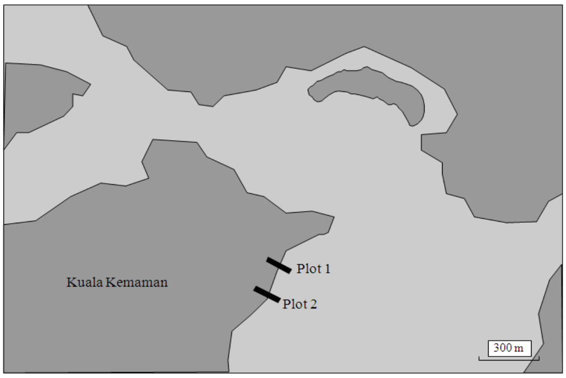

Fig. 3. Location of study plots

Tracer solution of ^{134}Cs with specific activity of 37×10^3 kBq mg^{-1} Cs was diluted with water and spread over the plots using two-wheel manual spraying equipment. On 10 November 2008, a total of 15.5×10^3 kBq was sprayed over the plots yielding a mean activity level of 65.3 kBq m^{-2}. The site was re-visited twice during the pick monsoon season on 17 November 2008 and the last once on 10 February 2009. The *in situ* NaI detector measurements (resolution of 1.95 keV at 1.33 MeV equipped with multichannel analyzer-Serie 10 plus 1004) were performed randomly along the estuary up to Pantai Chendoh, some 7 km south to the Kuala Kemaman. The measurement time was 30 sec.

Meanwhile, two samples 100 g each was collected at the zones which subject to sediment particle size analysis. The wet sieving technique was used to separate between coarse, sand and silts. The results then were compared with the samples taken randomly during the ^{137}Cs distribution measurement. Individual Suspended Sediment Concentration (SSC) was also collected frequently to relate with sediment mobility during the study period. In this study, direct measurement of the SSC in a stream is the most reliable method to investigate their formation and patterns of the flow and sediment characteristics. For marked, each sample locations were fixed using the Geographical Positioning System (GPS) (Jaafar *et al.* 2010).

3. RESULTS

The distribution of the tracer within the backshore and foreshore based on the day of application (17 November 2008) is shown in **Table 1**. The pattern shows higher ^{137}Cs activity in the backshore zone compared with foreshore. It is believed to happen due to ^{137}Cs is strongly adsorbed on fine sands and silts.

Table 1. Spatial distribution of ^{137}Cs activity (CPM) for backshore and foreshore zone on 17 December 2004

Ref. Points*	Backshore	Foreshore
1	7845	5334
2	5638	2655
3	8873	5422
4	9577	7344
5	16465	10945
6	19675	13354
7	20744	6744
8	22421	5236
9	18745	5574
10	21544	4655
Maximum	22421(8)	13354(6)
Minimum	5638(2)	2655(2)
Average	15153.000	6261.000
f factor	0.013	0.018

*; Reference points were chosen randomly

Table 2. Sediment particle size analyses based on wet sieving technique for backshore and foreshore zones (g)

	Backshore			Foreshore		
Ref. Points	coarse (g)	sand (g)	silts (g)	coarse (g)	sand (g)	silts (g)
1	13	34	53	10	75	15
2	8	22	70	41	38	21
3	12	49	39	32	19	49
4	14	42	44	38	47	15
5	27	26	47	19	37	44
6	19	52	29	58	40	50
7	2	55	43	26	24	2
8	7	32	61	33	35	32
9	15	23	62	24	16	60
10	10	38	52	55	32	35

Based on the in-situ measurement of ^{137}Cs activity. The measure activity ranged between 5638-22421 cpm for backshore while for foreshore is between 2655-13354 cpm. The mean values for backshore and foreshore were 15153 and 6261 cpm respectively. The counting efficiency (f factor) for the instrument (cpm Bq^{-1}) then was computed using the equation below:

$$f = R_t D_t^{-1}$$

where, f is counting efficiency, R_t = in situ measured ^{134}Cs activity in counts per minute (cpm) at time t, when the measurement is performed and D_t = disintegration rate of ^{134}Cs in Bq (1 Bq = 1 disintegration per second, dps) at time t, when the measurement is performed. The f factor for backshore was 0.013 while for foreshore was 0.018. The sediment particle analyses were also carried out for both zones. The results are presented in **Table 2**.

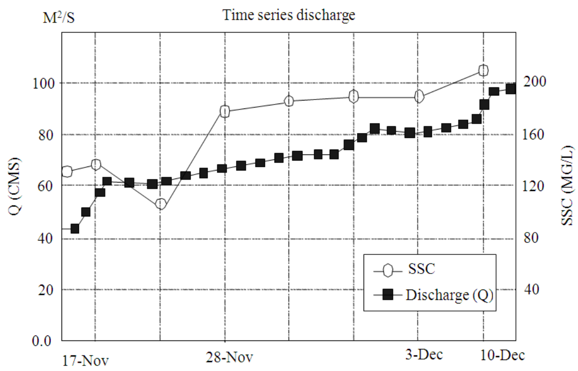

Fig. 4. Relationship between Discharge (Q) and Suspended Sediment Concentration (SSC)

The backshore zone characterized by highest percentage of silts with an average of 50% compared with sand (37%) and coarse (13%). At the foreshore zone, the results were inverted. Coarse immerged to be dominant with 37% followed by sand (36%) and silts (32%). When relates to ^{134}Cs activity, a good relation was found between the ^{134}Cs activity and the present of silts. Highest ^{134}Cs activity normally followed by highest present of silts as recorded at Ref. Plot No. 8 for backshore (22421 cpm and 61% silts) and Ref. Plot No. 6 for foreshore zone (13354 cpm and 50% silts). As mentioned before, one of a major ^{134}Cs characteristic was their capability to rapidly and firmly fixed with the fine sand and silt deposits. It is strongly bound and can be only displaced by ions of similar size and charge. The pattern obtained confirmed by other studies carried out by Volpe *et al*. (2002), Walling and Woodward (1995), Mongruel *et al.* (2011) and Toriman *et al.* (2010).

Meanwhile, the SSC at the Kemaman River estuary ranged from 67.8-286 mg L^{-1} with CV of 152%. The relationship between SSC and Discharge (Q) is presented in **Fig. 4**. Good relationships can be seen in the Figure with the fact that sediment supply increased during the periods of rainfall which normally occurred during the monsoon.

The study area was re-visited during the northeast monsoon on 10 February 2009. The results show a tremendous change in ^{134}Cs activity. Over four months, there was a general decrease in the activity levels within the both backshore and foreshore zones. All the ref. points recorded ^{134}Cs activity less from 4.2% (Ref. Plot No. 2) to 23.2% (Ref. Plot No. 5) for backshore and minimum 26.5% (Ref. Plot No.2) to 65.2% (Ref. Plot. No.1). Decrease in ^{134}Cs activity indicates that coastal erosion has occurred during the period.

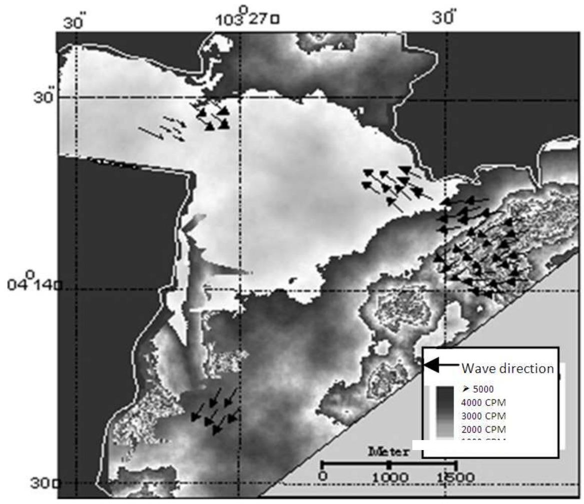

Fig. 5. Schematic diagram of 134Cs activity measured on 17 December 2008

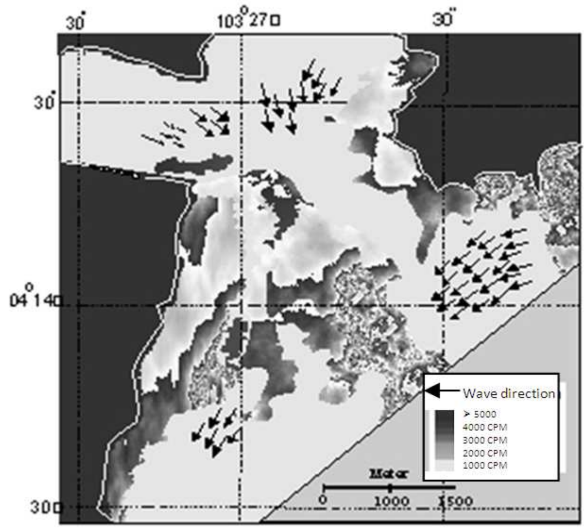

Fig. 6. Schematic diagram of 134Cs activity measured on 17 February 2009

As reported by local villagers, severe erosion has occurred close to the main road to the jetty and up to 2 km stretching along the beach. As a result, The Kuala Kemaman District Office took a drastic action in conjunction with the DID to repair the damage by installing the gabions about 200 m along the beach.

By knowing the prevailing surface wave direction/pattern which is from the north-east (70 % as measured by direct observation). The *in-situ* NaI detector measurement then was applied in order to trace the sediment fingerprints within the estuary system. **Figure 5** illustrates the pattern of ^{134}Cs activity. Clearly, the mobility of ^{134}Cs depends on the migration/moving of bottom sediments which generally generated by wave and current energies. During this period, most of the sediment was transported and accumulated along the foreshore of Kuala Kemaman beach. The ^{134}Cs counted for >5000 can be found scattered at 2 km towards the foreshore while the lesser 2000 ^{134}Cs was found mostly in the wave breaking zone. During the period, the sediment tracer also found at the Kemaman River mouth. This happened probably due to wave reflection that transported and accumulated the sediment temporarily in this zone.

As can be seen from the diagram, the ^{134}Cs fingerprints were inhomogeneously distributed within the estuary-coastal system. Higher activity levels were observed near to the study plots. The general pattern shows that most of the sediment was eroded and deposited along the foreshore lines to up to 4.6 km from the study plots. Meanwhile, the second *in-situ* NaI detector measurement was carried out on 10 February 2009. Over four months since the last measurement on 17 November 2008, the whole study plot at backshore zone was washed away. Several local villagers claimed that strong waves occurred in 12-16 December 2008 resulting severe beach erosion. Damage of properties and infrastructures were also reported particularly towards the jetty complex. **Figure 6** shows the sediment mobilization as detected by *in-situ* NaI detector.

Again, the spatial pattern of sediment mobilization follows the previous measurement which exhibit inhomogeneously distributed. Over four months, the sediment fingerprints were travelling as far as 5.4 km towards the southern direction. Maximum ^{134}Cs activity was recorded accumulated adjacent to backshore and foreshore zones in Pantai Chendoh. As a result, the beach was reported highly sediment deposition and causing problematic to fisherman navigation.

4. DISCUSSION

At this stage, the use of ^{134}Cs activity as sediment tracer found to be satisfied to study the spatial pattern of sediment distribution and mobilization within the Kuala Kemaman estuary system. It is clearly shown that one of a major source of sediment budget within the Kuala Kemaman estuary system is from Kemaman River as well as along the Kuala Kemaman beach. Land activities including development of new agriculture and residential areas at upstream sites were found contributes to higher sediment concentration in Kemaman River.

Although the study indicates several margin of error, i.e., difficulties in tracking sediment fingerprints dosed with ^{134}Cs in a random environment, sediment particles move in a stop and go pattern, the ^{134}Cs proved useful in the identification of actively eroding beach sediment deposits during the study period. During the study period, it was found that the sediment was transported and deposited towards Pantai Chendoh causing shallow beach along the coastal. This scenario causing a difficulty to local fisherman to navigate their boats especially during low tide whereby they has to push their boats about two km to the sea. Meanwhile, severe erosion at the study plots and along the Kuala Kemaman beach required full attention from the government (DID, District Office, LKIM). Temporary and long term measures are required to protect the beach from erosion. Coupled with good information on sediment characteristics, the problem perhaps can be minimized without further damaging on properties.

5. CONCLUSION

Effective watershed management in the coastal areas can be implemented only after a thorough understanding of sedimentary processes in river basins. Sediment processes involve erosion, deposition and sediment transport and, because of variability within a single watershed, are difficult to quantify. This study used multiple fingerprints to quantify the pattern of sediment movement and transport using environmental radionuclide Caesium-137 at the Kemaman River estuary, Terengganu Malaysia. Both techniques found to be satisfactory to define the characteristics of sediment mobility within the estuary system. The radioactive cesium moves with the eroded sands because it is tightly adsorbed. Nevertheless, due to the vast areas to be covered, the accurate methods for tracing the Caesium-137 need to be evaluated. These results show that techniques for accurately estimating values of sediment movement using cesium-137 need additional refinement but the method shown promise as a useful tool for measuring sediment movement and deposition in the estuary areas. The method also shows promise as a way to better understand the erosion process by studying the movement of the fine sand fractions containing cesium-137.

6. ACKNOWLEDGMENT

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