Sedimentological Characteristics of sediments of the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters

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ABSTRACT

Surficial investigation of bottom sediments was conducted within the waters off the coast of Sabah, Sarawak and Brunei Darussalam. Two sampling of bottom sediments were conducted, one before (September 1996) and one after (April 1997) the Northeast monsoon period, which normally lasts from November to February annually. During the pre-monsoon cruise, fifty-one samples were collected while 52 samples were collected during the post-monsoon exercise. The collected samples were analysed for their sedimentological characteristics of mean, sorting, skewness and kurtosis. Analyses revealed that the post-monsoon sediments are finer, better sorted in arrangement, more symmetrical and less peaked than the pre-monsoon sediments. Deeper water sediment shows the same characteristics as described above when compared to shallow water sediments. In general, the near-shore sediments are coarsest, more poorly sorted, more positively skewed and most peaked in characteristics when compared to the mid-shore and off-shore sediments.

Introduction

South China Sea (SCS) covers a vast area of approximately 959,160 nm^2. It contains a variety of living and non-living marine resources, which are of interest to the littoral states bordering it. Nevertheless, research concerning the characteristics of the SCS is very much lacking although very much more is needed to be done if the resources available are to be harvested in a sustainable manner. In addition, the multiple claims for the SCS by the bordering littoral states demand that cooperative effort be made to properly manage and exploit the available resources. To achieve this, more information concerning available resources and characteristics of the SCS are required so that proper harvesting of living and exploitation of non-living resources can be planned in an optimal manner.

Several scientific reports containing extensive data on the South China Sea resources and sediments are those published by University Pertanian Malaysia and Kagoshima University through their previous joint expeditions aboard research vessel-Kagoshima Maru. The expeditions were referred to as Matahari expeditions and were conducted in 1985, 1986, 1987 and 1989. These expeditions, however, cover only small areas of the SCS at one time and were not extensive in coverage even if the different study areas are combined together.

In the early part of 1995, SEAFDEC's Marine Fishery Resource Development and Management Department (MFRDMD) in Malaysia and the Training Department in Thailand in collaboration with the Fishery Departments of Thailand and Malaysia and university researchers from both countries have embarked upon a broad program of information gathering on the South China Sea. The vessel used was a modern vessel-M.V. SEAFDEC. Initially two cruises were carried out during the pre-monsoon (September 1995) and post -monsoon period (April, 1996) periods covering the Gulf of Thailand and the EEZ waters bordering the eastern board of Peninsular Malaysia (area I). Another two expedition covering the areas off the coast of Sabah, Sarawak and Brunei Darussalam (area II) were done in September 1996 and April 1997 to represent pre and post monsoon conditions respectively.

This paper focuses only on the information gathered and data analyzed from the bottom sediment samples collected for the third and fourth cruises covering area II. This paper highlighted mainly the sedimentological characteristics of bottom sediments, since they relate directly and indirectly to living resources productivity and in addition act as indicators to the dominant processes and the evolution of the resources.

Description of Study Area

Study area II lies between longitude 109oE to 117oE and 5oN to 7oN as shown in figure 1A. Compared to area I, this area is deeper since it is not located on the continental shelf. It has an average depth of 94 m. Minimum depth of 20 m was recorded at station 46 while the deepest station with a depth of 528 m was recorded at station 24. Additionally, it is an entirely open area in contrasts to area I, which has a semi-enclosed body of water-the Gulf of Thailand.

Near-shore areas have depths ranging from 0 to 70 m, mid-shore areas are enclosed by depths ranging from 70 to 120 m, while the off-shore areas have depths exceeding 1000 m. However, the maximum depth of the sediment sampling station during the two cruises were only 528 m. This was due to the logistic constraint imposed on each sampling station.

Similar to area I, the current direction in the South China Sea, particularly, is controlled by seasonal winds of the monsoon. The predominant wind is from the north during the Northeast monsoon seasons and from the south during the Northwest monsoon period (Wrytki, 1961).

In order to facilitate the description of study areas, the sampling stations are divided into 3 classifications based on distance from the shoreline and another 2 classifications based on depth. For the first category of classification (distance) the stations were divided into near-shore, mid-shore and off-shore stations. Near-shore stations are stations 1, 2, 4 , 5, 6, 7, 8, 16, 17, 18, 30, 31, 32, 33, 45, 46, 47, 48, 59, 60, 69, 70, 76, 77, and 79. Midshore stations on the other hand are stations 3, 9, 10, 14, 15, 19, 20, 28, 29, 34, 35, 43, 44 and 49. Meanwhile the remaining stations are classified as off-shore stations and they are stations 11, 12, 13, 21, 22, 23, 24, 25, 26, 27, 36, 37, and 42.

The cutoff point for the purpose of station classification into shallow and deep categories is 100 m. Based on this, the deep water stations are stations 11 to 13, 21 to 26, 36 to 43, 49, 60, 70, and 76 while the remaining stations fall under shallow water stations category.

Samples and Sampling Method

Sampling technique

Sediment samples were collected using both a gravity corer and a Smith McIntyre grab. During both the pre and post-monsoon cruises, 51 and 52 stations out of the 79 stations planned were successfully sampled for sediment respectively. Due to some technical problems, the other 24 stations, located in the deeper water, were not sampled for both cruises.

Laboratory Methods

For sedimentological analyses, only the sediment samples recovered using the Smith McIntyre grab was used. Similar to area I, the methodology chosen to analyze the sedimentological characteristics depended upon the amount of coarse (>63 microns) or fine sediments (<63microns) available in each sample. Samples consisting mostly fine sediments with less than 10% coarse sediment were analyzed using a laser diffractometer. However, if the opposite occurs then the sieving method is employed.

When sieving method is used, approximately 100 grams of split sediment samples were passed through a set of ASTM standard sieves with intervals of approximately 0.25 ø. The sediments were

Table 1A : STATISTICAL PARAMETERS OF BOTTOM SEDIMENTOLOGICAL CHARACTERISTICS.

	ALL STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.87	5.25	-0.4	2.03	1.9	0.13	0.39	0.16	0.23	2.94	2.41	0.53
Min	2.34	3.23	-0.9	1.17	1.31	-0.1	-0.5	-0.6	0.07	1.64	1.55	0.09
Max	6.22	6.44	-0.2	2.59	2.49	0.1	3.3	1.8	1.5	15.7	5.09	10.6
Range	3.88	3.21	0.67	1.42	1.18	0.24	3.84	2.41	1.43	14	3.54	10.5

	SHALLOW WATERS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.8	5.13	-0.3	2.04	1.98	0.07	0.44	0.2	0.24	3.23	2.42	0.82
Min	2.34	3.23	-0.9	1.17	1.31	-0.1	-0.5	-0.6	0.07	1.64	1.55	0.09
Max	6.22	6.44	-0.2	2.59	2.49	0.1	3.3	1.8	1.5	15.7	5.09	10.6
Range	3.88	3.21	0.67	1.42	1.18	0.24	3.84	2.41	1.43	14	3.54	10.5

	DEEP WATERS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	5.02	5.51	-0.5	1.98	1.74	0.25	0.28	0.07	0.21	2.29	2.41	-0.1
Min	3.76	4.34	-0.6	1.61	1.31	0.3	-0.1	-0.4	0.28	1.94	1.87	0.07
Max	5.84	6.21	-0.4	2.23	2.2	0.03	1.13	0.55	0.58	3.25	3.34	-0.1
Range	2.08	1.87	0.21	0.62	0.89	-0.3	1.21	0.91	0.3	1.31	1.47	-0.2

Table 1B : STATISTICAL PARAMETERS OF BOTTOM SEDIMENT WITH RESPECT TO SHORELINE.

	ALL NEARSHORE STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.72	5.06	-0.3	2	1.99	0.01	0.54	0.24	0.3	3.67	2.52	1.14
Min	2.34	3.23	-0.9	1.17	1.46	-0.3	-0.5	-0.6	0.07	1.64	1.63	0.01
Max	6.22	6.37	-0.2	2.59	2.4	0.19	3.3	1.8	1.5	15.7	5.09	10.6
Range	3.88	3.14	0.74	1.42	0.94	0.48	3.84	2.41	1.43	14	3.46	10.6

	ALL MIDSHORE STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	5.12	5.4	-0.3	2.1	1.89	0.21	0.17	0.06	0.11	2.13	2.28	-0.2
Min	3.61	4.18	-0.6	1.69	1.31	0.38	-0.3	-0.6	0.25	1.81	1.55	0.26
Max	6.12	6.44	-0.3	2.46	2.49	-0	1.21	0.84	0.37	3.07	2.97	0.1
Range	2.51	2.26	0.25	0.77	1.18	-0.4	1.53	1.41	0.12	1.26	1.42	-0.2

	ALL OFFSHORE STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.87	5.44	-0.6	1.99	1.75	0.24	0.35	0.11	0.24	2.36	2.36	-0
Min	3.76	4.34	-0.6	1.61	1.31	0.3	-0.1	-0.4	0.29	1.94	1.75	0.19
Max	5.81	6.21	-0.4	2.31	2.37	-0.1	1.13	0.54	0.59	3.25	2.92	0.33
Range	2.05	1.87	0.18	0.7	1.06	-0.4	1.2	0.9	0.3	1.31	1.17	0.14

Diff - Difference between September 1996 and April 1997
Aug. denote - August 1996 sediment (Pre-monsoon)
April denote - April 1997 sediment (Post-monsoon)

Table 1C : PERCENTAGES OF SAND, SILT AND CLAY.

	ALL STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	42.68	32.96	9.718	45.93	56.4	-10.5	11.4	10.57	0.827
Min	15.39	3.56	11.83	3.97	11.74	-7.77	1.22	4.8	-3.58
Max	94.79	83.11	11.68	69.67	83.84	-14.2	26.02	22.78	3.24
Range	79.4	79.55	-0.15	65.7	72.1	-6.4	24.8	17.98	6.82

	SHALLOW WATERS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	44.63	37.1	7.528	43.62	51.75	-8.14	11.84	11.05	0.787
Min	15.39	3.56	11.83	3.97	11.74	-7.77	1.22	4.8	-3.58
Max	94.79	83.11	11.68	69.12	82.05	-12.9	26.02	22.78	3.24
Range	79.4	79.55	-0.15	65.15	70.31	-5.16	24.8	17.98	6.82

	DEEP WATERS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	38.42	24.44	13.98	50.99	65.98	-15	10.44	9.582	0.854
Min	16.68	5.68	11	25	35.35	-10.4	3.9	7.06	-3.16
Max	71.09	57.6	13.49	69.67	83.84	-14.2	17.24	14.12	3.12
Range	54.41	51.92	2.49	44.67	48.49	-3.82	13.34	7.06	6.28

Table 1D : PERCENTAGES OF SAND, SILT AND CLAY.

	ALL NEARSHORE STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	45.9	38.49	7.414	42.34	50.29	-7.95	11.66	11.08	0.576
Min	15.39	7.8	7.59	3.97	11.74	-7.77	1.22	4.8	-3.58
Max	94.79	83.11	11.68	69.12	81.7	-12.6	26.02	22.78	3.24
Range	79.4	75.31	4.09	65.15	69.96	-4.81	24.8	17.98	6.82

	ALL MIDSHORE STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	38.28	30.9	7.378	49.34	58.03	-8.69	12.6	11.07	1.527
Min	17.45	3.56	13.89	20.58	26.51	-5.93	5.23	8.01	-2.78
Max	73.2	65.49	7.71	69.67	82.05	-12.4	22.18	14.42	7.76
Range	55.75	61.93	-6.18	49.09	55.54	-6.45	16.95	6.41	10.54

	ALL OFFSHORE STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	41.1	25.54	15.55	49.44	65.26	-15.8	9.459	9.196	0.263
Min	16.68	5.68	11	24.88	35.35	-10.5	3.9	7.06	-3.16
Max	71.09	57.6	13.49	68.71	83.84	-15.1	14.98	11.73	3.25
Range	54.41	51.92	2.49	43.83	48.49	-4.66	11.08	4.67	6.41

Diff - Difference between September 1996 and April 1997
Aug. denote -August 1996 sediment (Pre-monsoon)
April denote - April 1997 sediment (Post-monsoon)

TABLE 1E : T-test RESULTS FOR PRE-MONSOON (Aug-96) VS. POST-MONSOON (April-97)

PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS	% SAND	% SILT	% CLAY
PROBABILITY	< 5 %	< 5 %	< 5 %	> 10 %	< 5 %	< 5 %	> 10 %
CONCLUSION	Significant	Significant	Significant	Not Significant	Significant	Significant	Not Significant
AVERAGE	4.866 < 5.253	2.025 > 1.897	0.393 > 0.157		42.678 > 32.960	45.929 < 56.404	

TABLE 1F : T-test RESULTS FOR DEEP WATER VS. SHALLOW WATER

PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS	% SAND	% SILT	% CLAY
PROBABILITY	> 10 %	< 5 %	> 10 %	> 10 %	< 5 %	< 5 %	> 10 %
CONCLUSION	Not Significant	Significant	Not Significant	Not Significant	Significant	Significant	Not Significant
AVERAGE		1.856 < 2.010			31.215 < 40.863	58.712 > 47.684	

TABLE 1G : ANOVA RESULTS FOR DISTANCE FROM SHORE (NEAR : MID : OFFSHORE)

PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS	% SAND	% SILT	% CLAY
PROBABILITY	> 10 %	> 10 %	> 10 %	< 10 %	> 10 %	< 5 %	< 10 %
CONCLUSION	Not Significant	Not Significant	Not Significant	Significant	Not Significant	Significant	Significant
AVERAGE				3.107>2.358>2.205		57.96>53.68>46.2	11.84>11.38>9.32

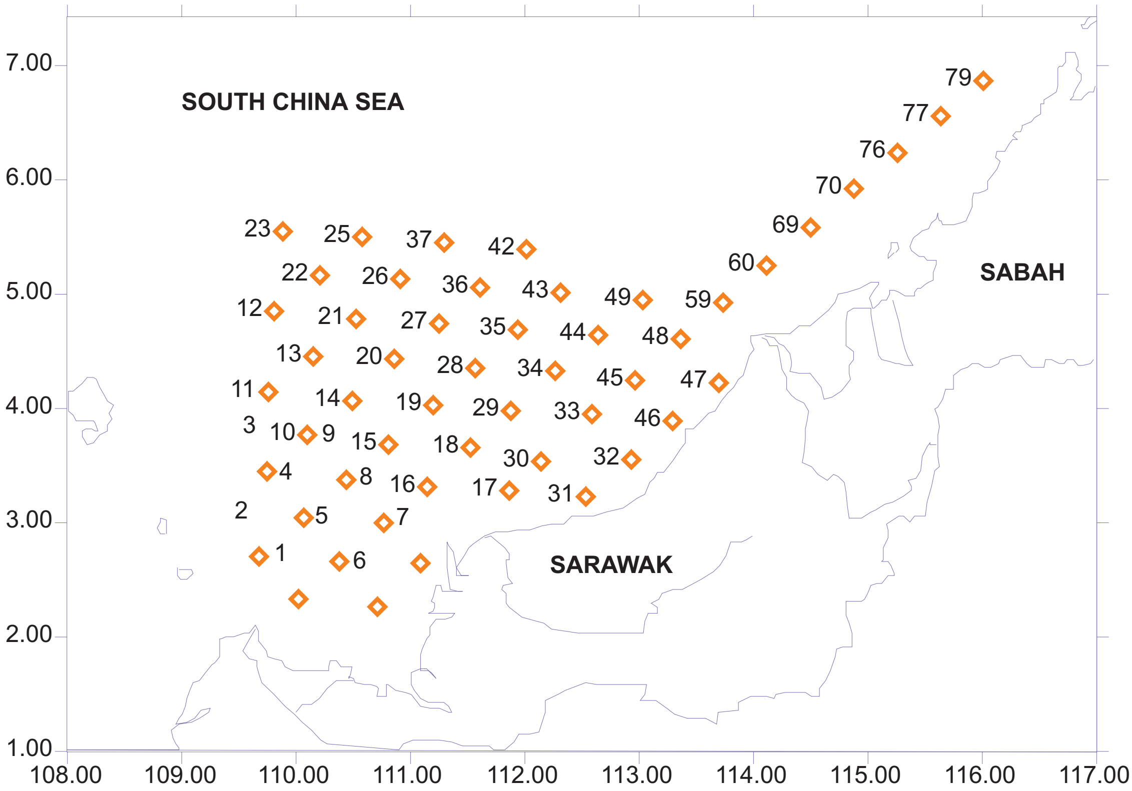

Figure 1A : Pre-monsoon sampling locations within Sabah & Sarawak Sea.

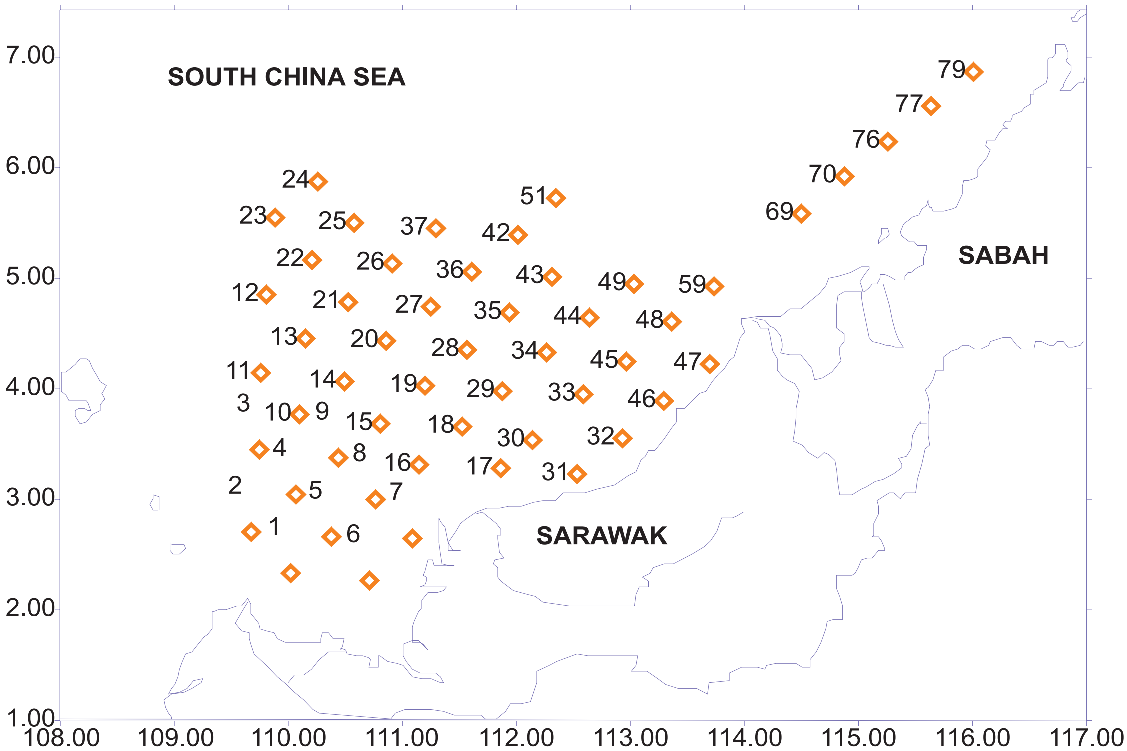

Figure 1B : Post-monsoon sampling locations within Sabah and Sarawak sea.

sieved using a sieve shaker for 15 minutes. The sediments trapped on each sieve were then weighed, recorded and used in the determination of the sedimentological parameters: mean, median and skewness and kurtosis.

The characteristics of the sediments are reported in terms of phi unit following standard convention in the study of sediments. The formula for phi is as given below:

$$\text{Phi } (ø) = -\log_2 D$$

ø = Particle diameter in phi

D = Particle diameter in mm

For laser diffraction analyses, the sediments are first rid off carbonate shell materials and organic matter using hydrochloric acid and hydrogen peroxide solutions respectively. Then a dispersing agent (sodium hexametaphosphate) was added to the sediment solution prior to passing it through the laser diffractometer. The Malvern-E particle size analyzer was used in this study.

Data obtained from both methodologies were calculated for the sedimentological characteristics of mean, sorting, skewness and kurtosis using the method of moments. Further details and formulae about the moment methods are given and discussed by Griffiths (1967), McBride (1971) and Folk (1980) among others.

Results and Discussions

Although study area II is in deeper water, the sedimentological characteristics of the seabed studied during the pre and post-monsoon periods show similarities to seabed of Area I, which is located in the shallower waters of the continental shelf. The post-monsoon sediments, in general, are finer in size when compared to those sampled during the pre-monsoon period. After the monsoon, the finer sediments are widely distributed covering a larger area when compared to the period before the monsoon. (Figures 2A and 2B). The mean size of pre-monsoon sediments was 4.87ø (coarse silt) while the mean size of post-monsoon sediments was 5.25ø (medium silt). The range of mean size for pre and post -monsoon sediments were 6.22ø (fine silt) to 2.34ø (very fine sand) and 6.44ø (fine silt) to 3.23ø (very fine sand), respectively.

On the average the pre-monsoon sediments are very poorly sorted (2.03) and gradually become better-sorted (1.9) during the calm period (after the monsoon season). Figures 3A and 3B show that almost all area of the seabed is covered with better sorted materials after the monsoon. The range between maximum and minimum sorting values is larger for the pre-monsoon sediments (1.42) compared to the post-monsoon sediment (1.18). The smaller range of sorting values for post-monsoon results in better sorting of sediments. As mean sediment size also decreases in values after the monsoon, as discussed above, it can be postulated that the finer sediments are more dominant in suspension and deposition during and immediately after the monsoon season. This may be due to the influence of the monsoon rain, which causes more silt and clay to be eroded and carried to rivers, which then transported the fine materials to the sea and eventually deposited.

Similar to area I, the post-monsoon seabed sediments of Area II also tend to be more negatively skewed (average value 0.16) compared to the pre-monsoon sediments (average value 0.39). This can be attributed to the dominance and addition of more finer materials during the monsoon season thus reducing the gap between the amount of fine and coarse and eventually reducing the positive skew value.

As can be observed from table 1A, although the post-monsoon sediments are less peaked (2.41) than the pre-monsoon sediment (2.94), figures 5A and 5B seem to indicate otherwise. From the figures it seemed that, except for a few stations with very high values, the pre-monsoon sediments are less peaked and have kurtosis values ranging mainly from 1 to 3. The higher kurtosis for the pre-monsoon sediments are due to two stations exhibiting anomalously high kurtosis values: stations eight and seventeen with values of 15.66 and 13.48 respectively. The accuracy of these figures is being ascertained by re-analysing the samples and cross analysing them with other parameters. With-

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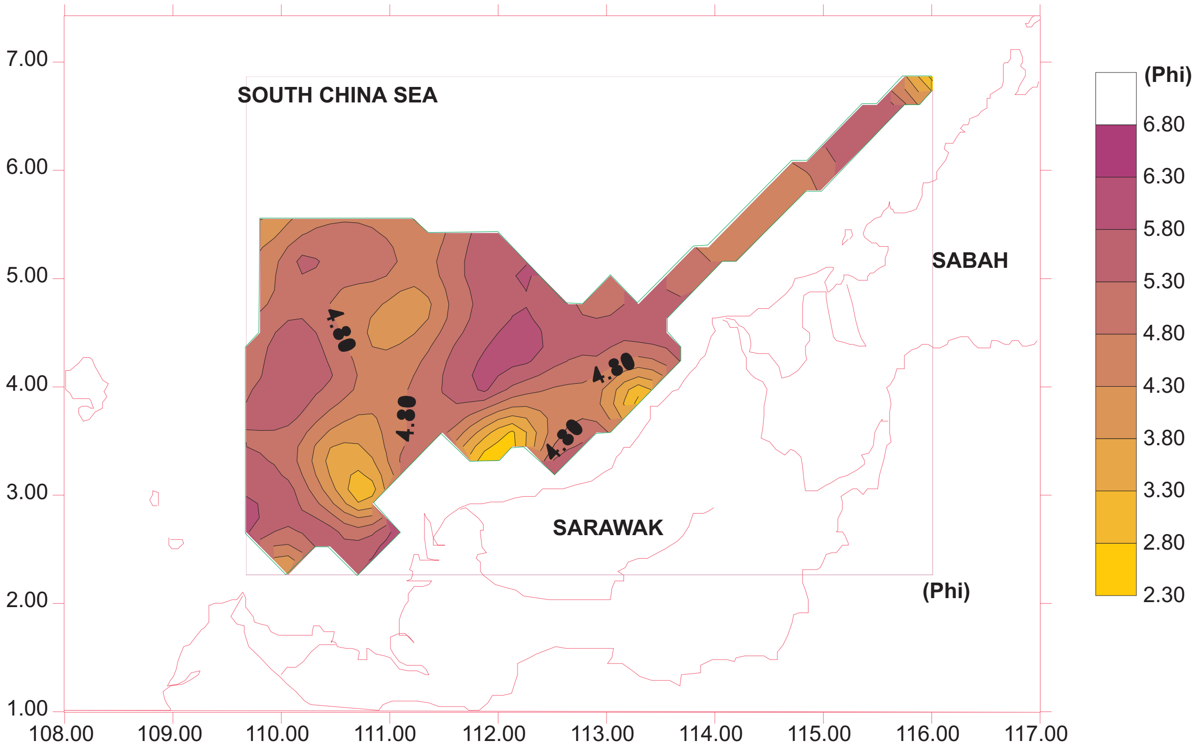

Figure 2A: Pre-monsoon patterns of sediment mean size

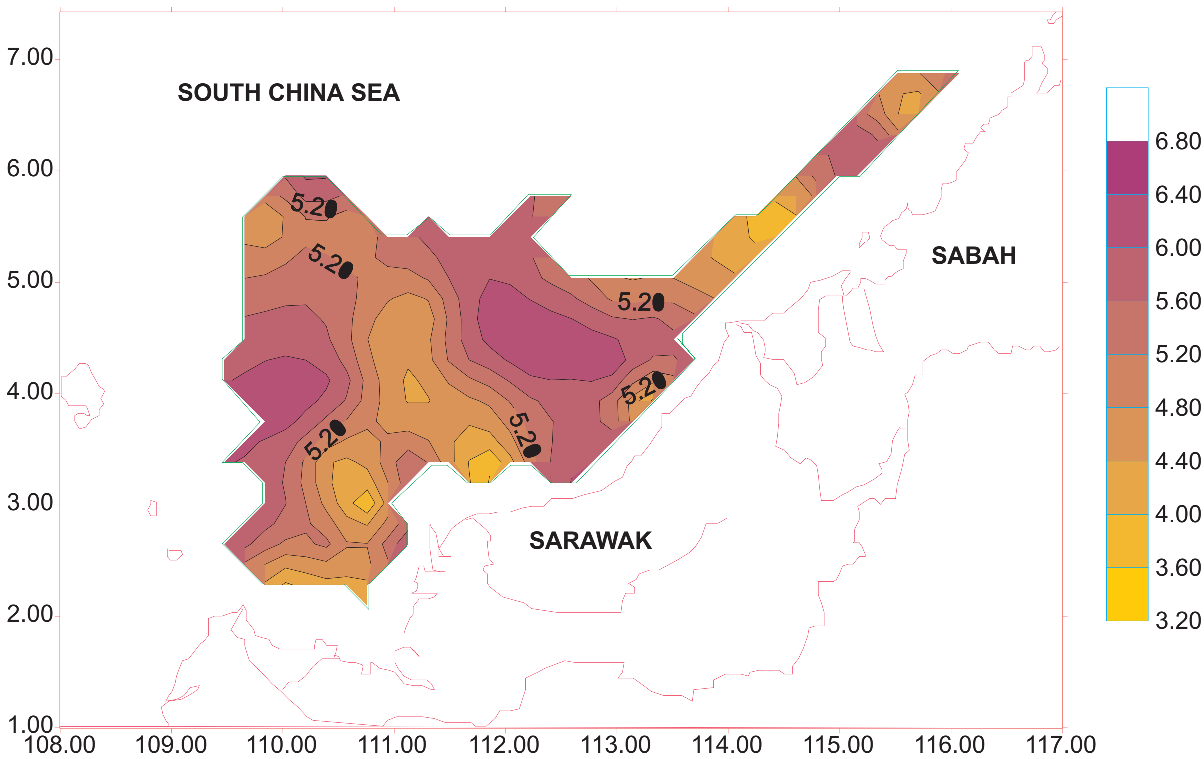

Figure 2B: Post-monsoon patterns of sediment mean size

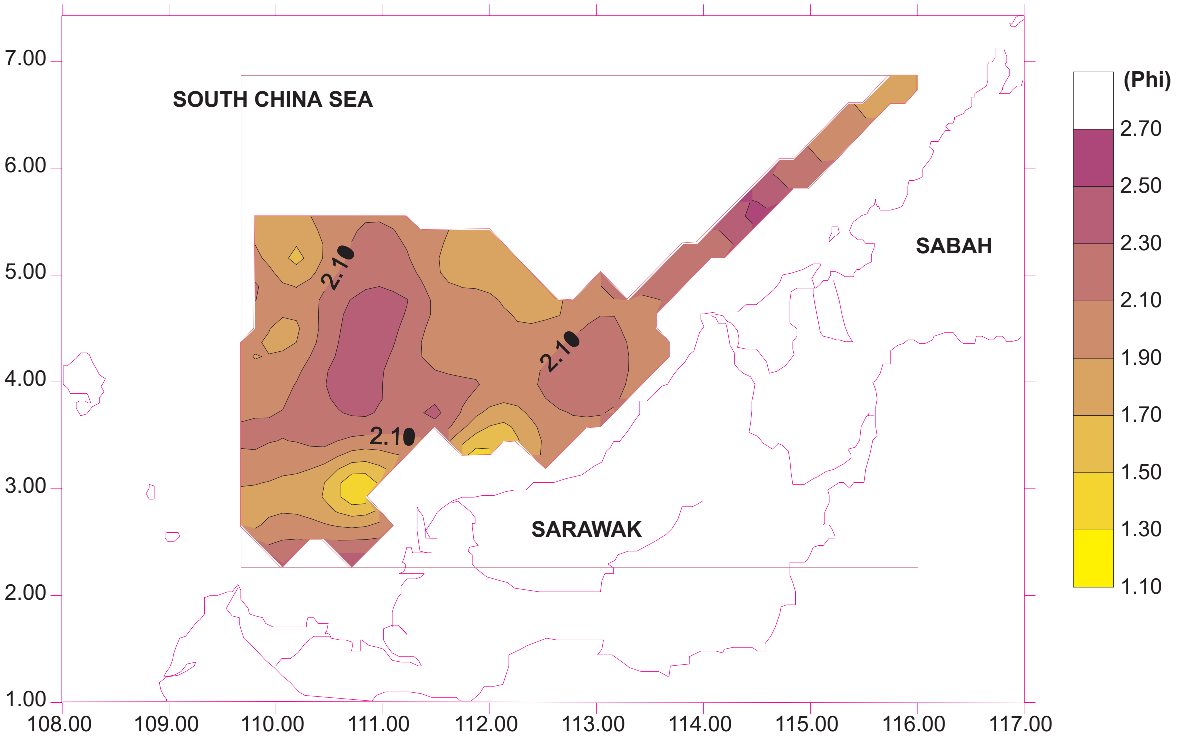

Figure 3A: Pre-monsoon patterns of sediment sorting

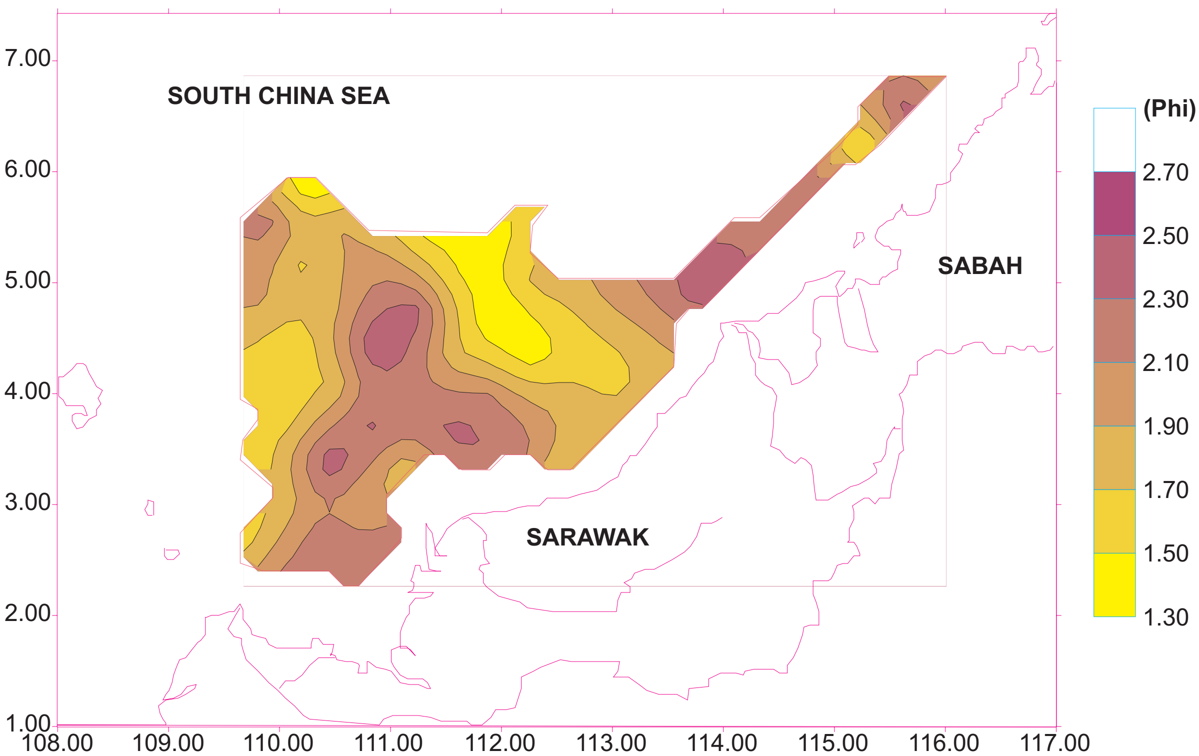

Figure 3B: Post-monsoon patterns of sediment sorting

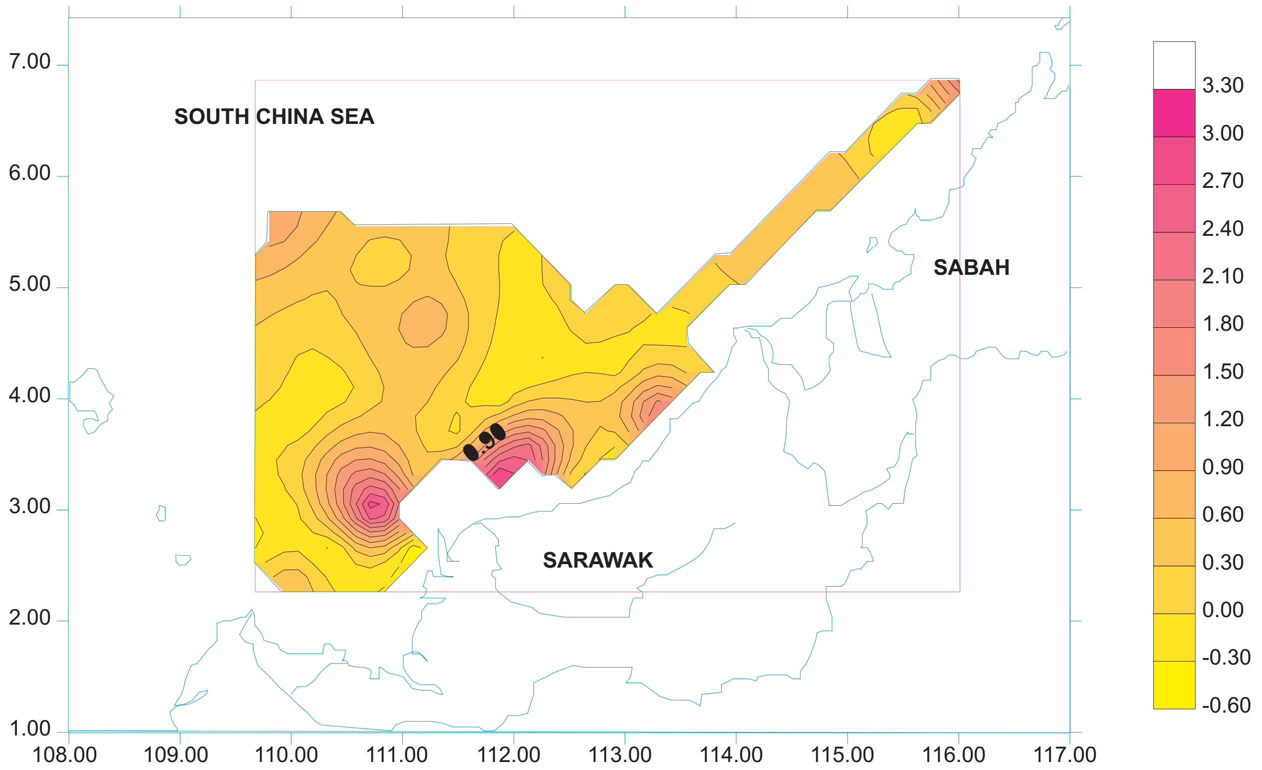

Figure 4A: Pre-monsoon patterns of sediment skewness

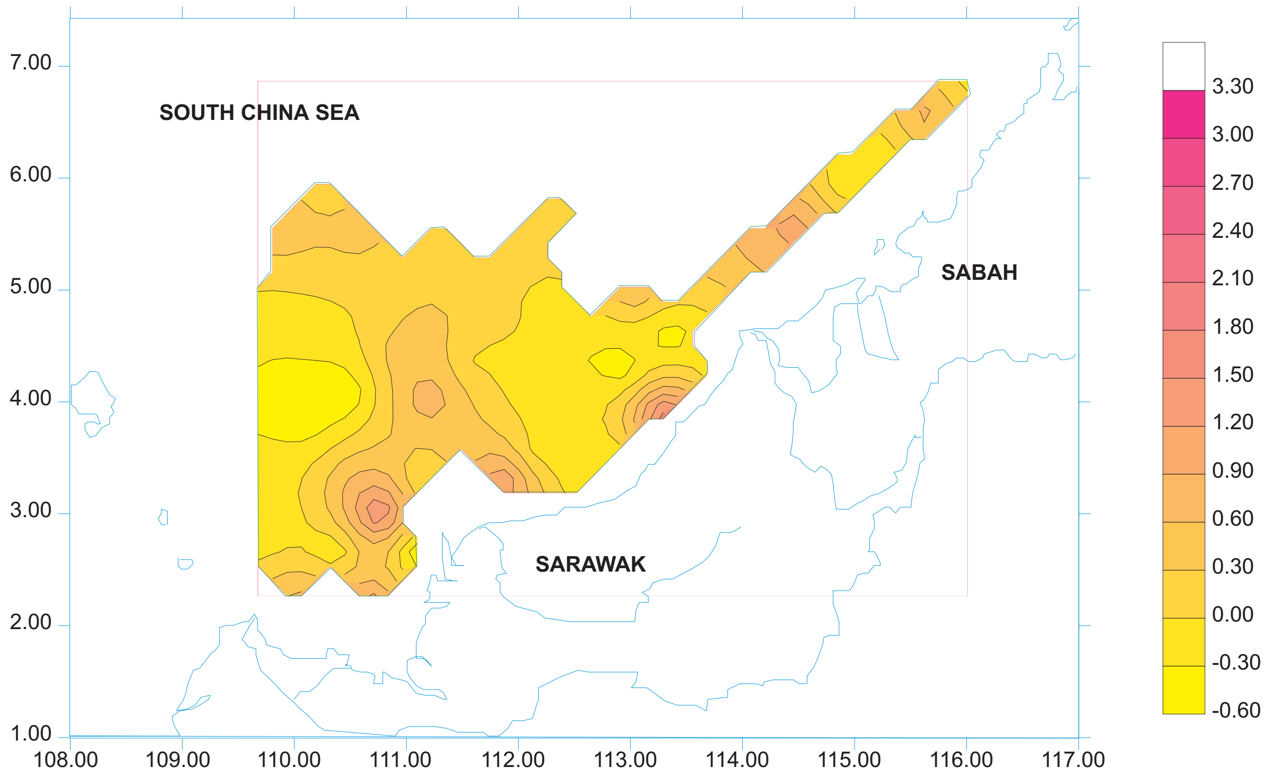

Figure 4B: Post-monsoon patterns of sediment skewness

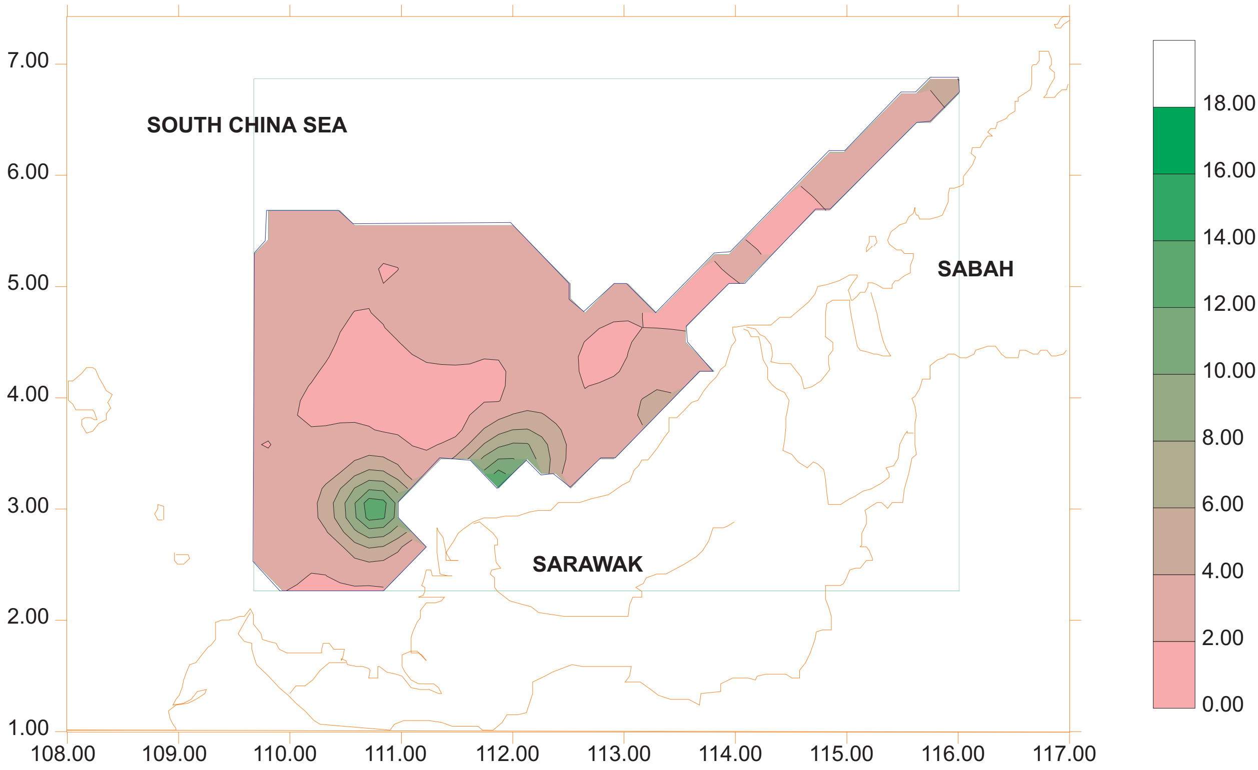

Figure5A: Pre-monsoon patterns of sediment Kurtosis

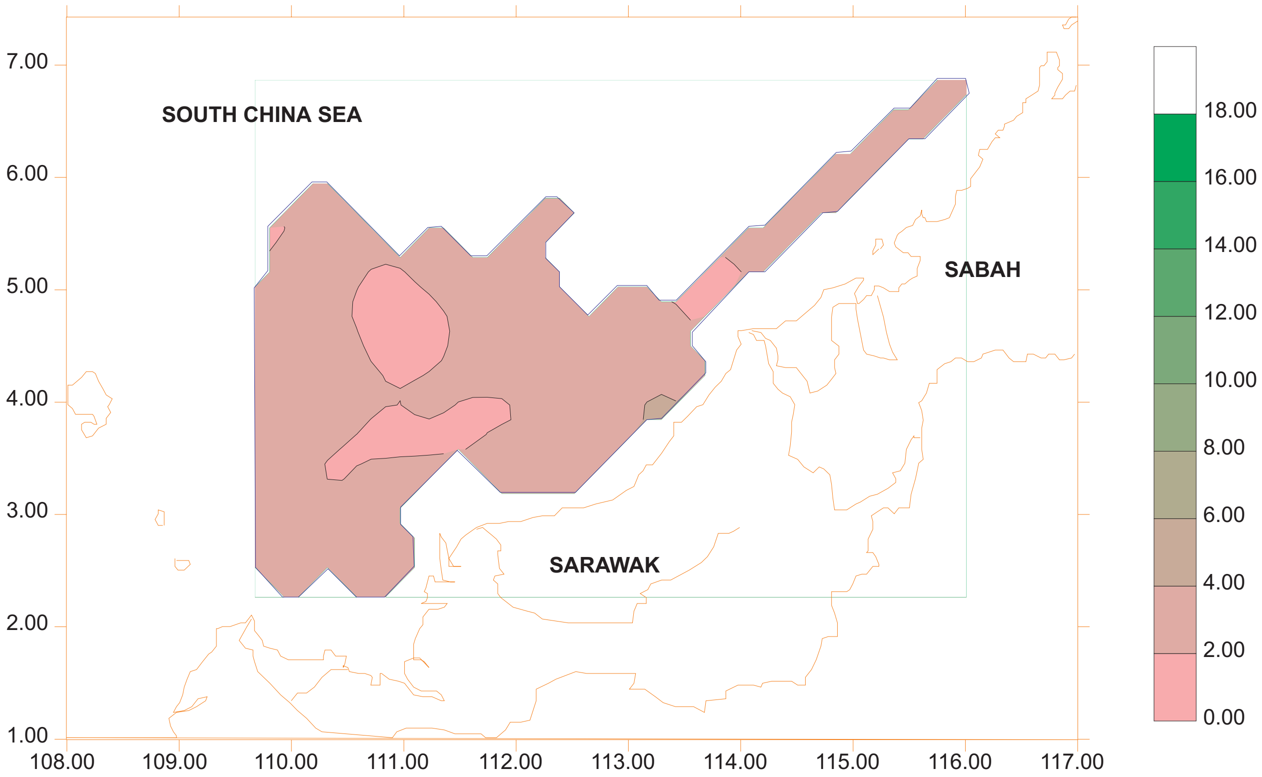

Figure5B: Post-monsoon patterns of sediment Kurtosis

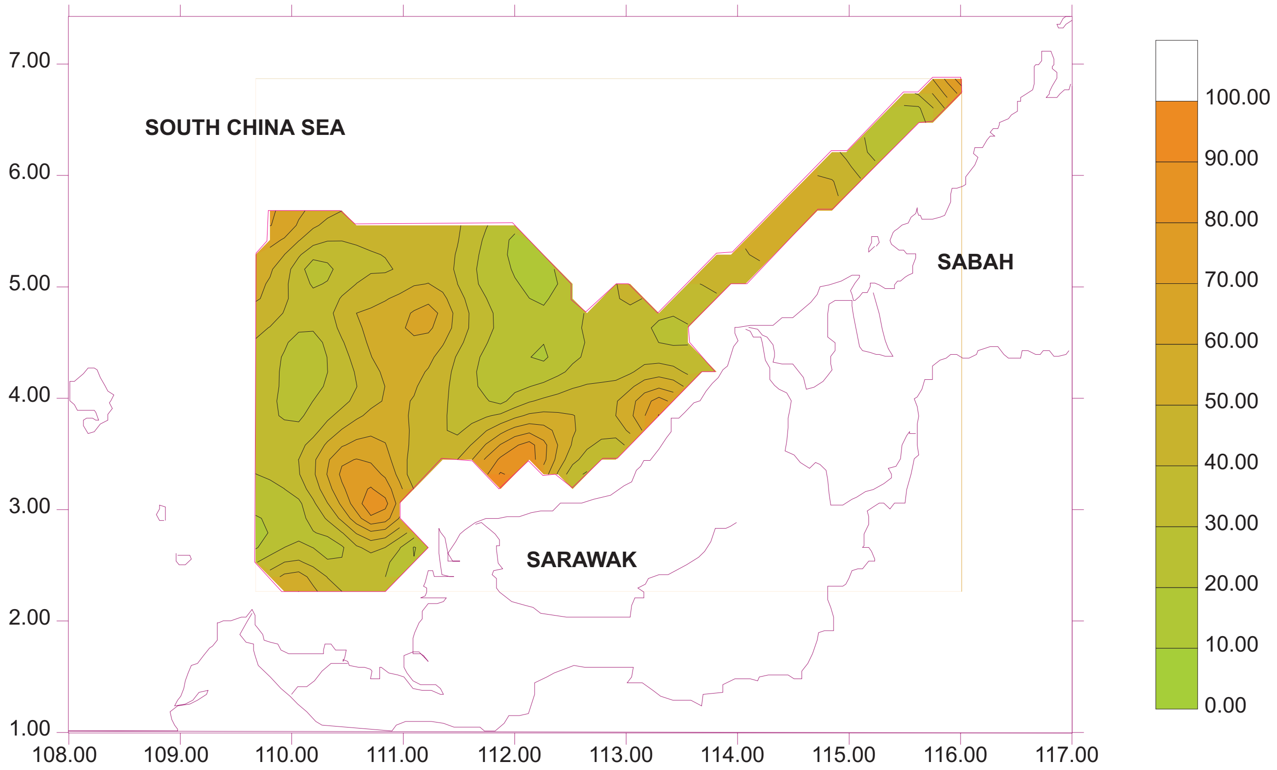

Figure 6A : Pre-monsoon patterns of sand distribution

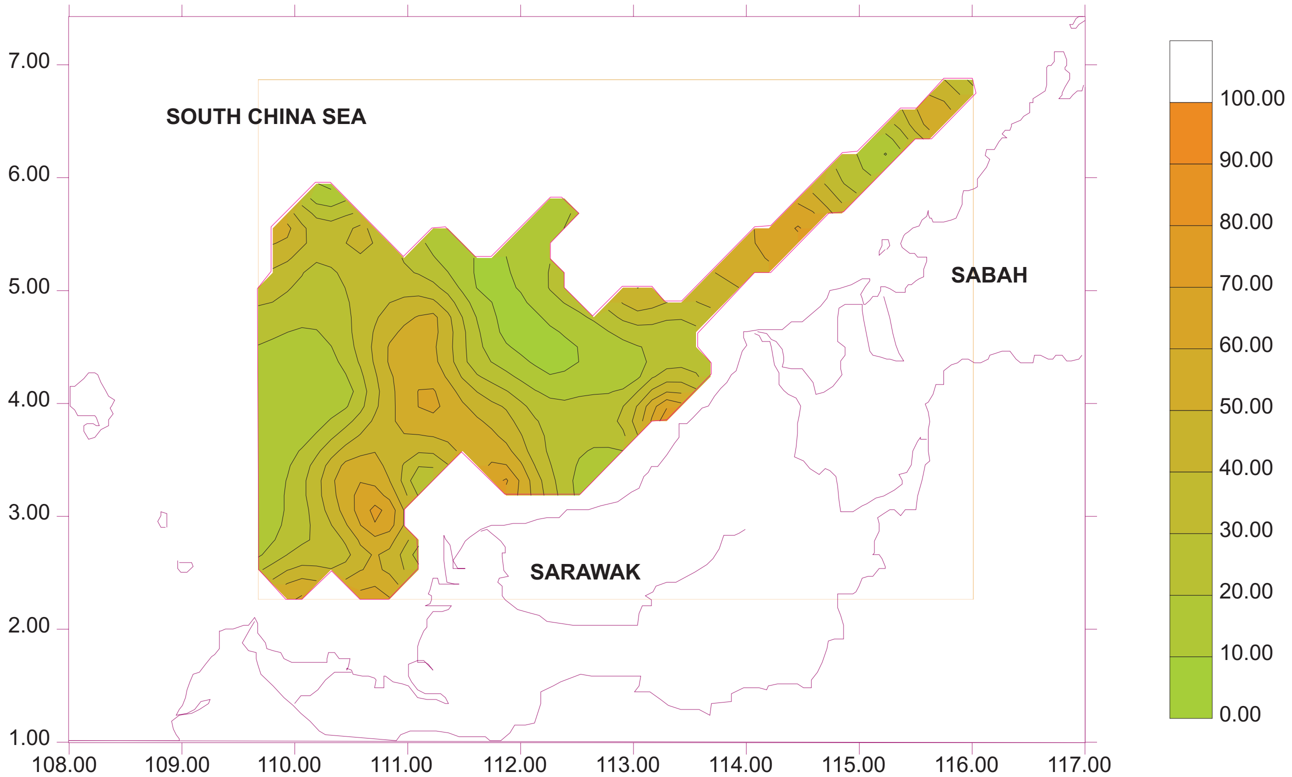

Figure 6B : Post-monsoon patterns of sand distribution

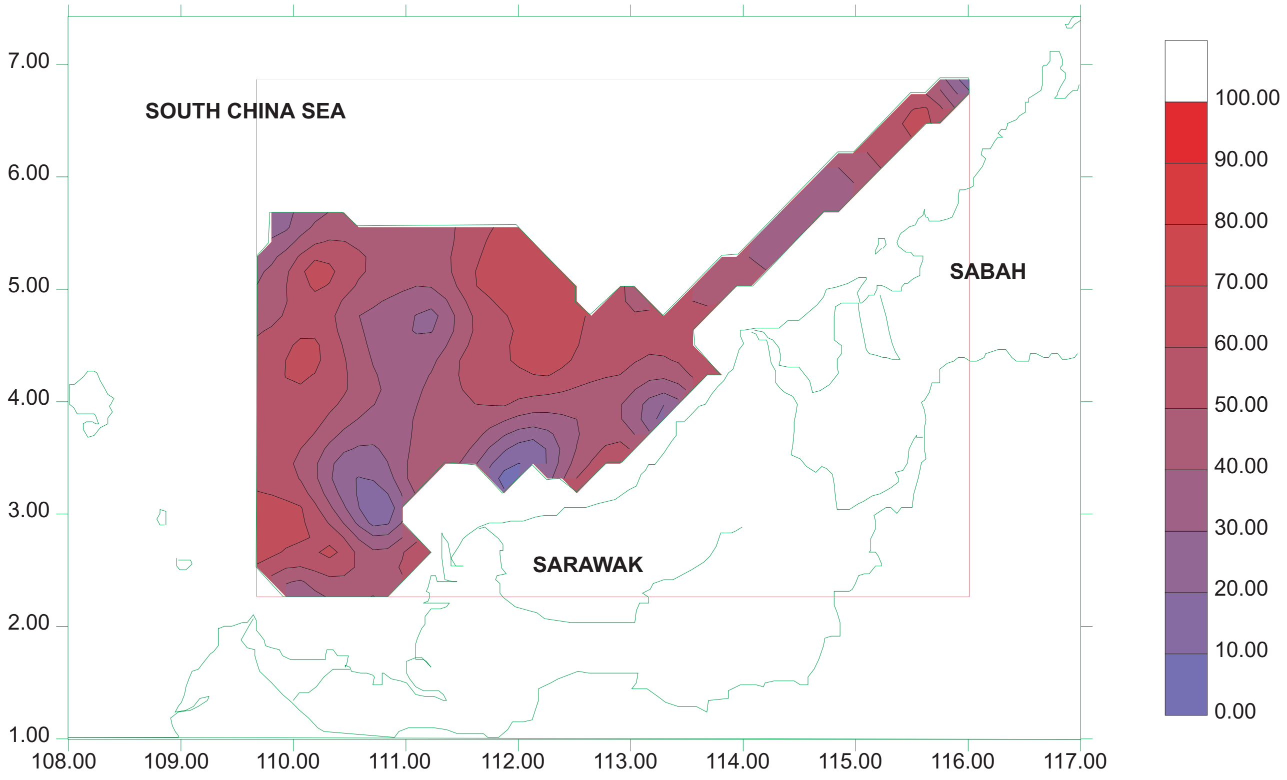

Figure 7A : Pre-monsoon patterns of silt distribution

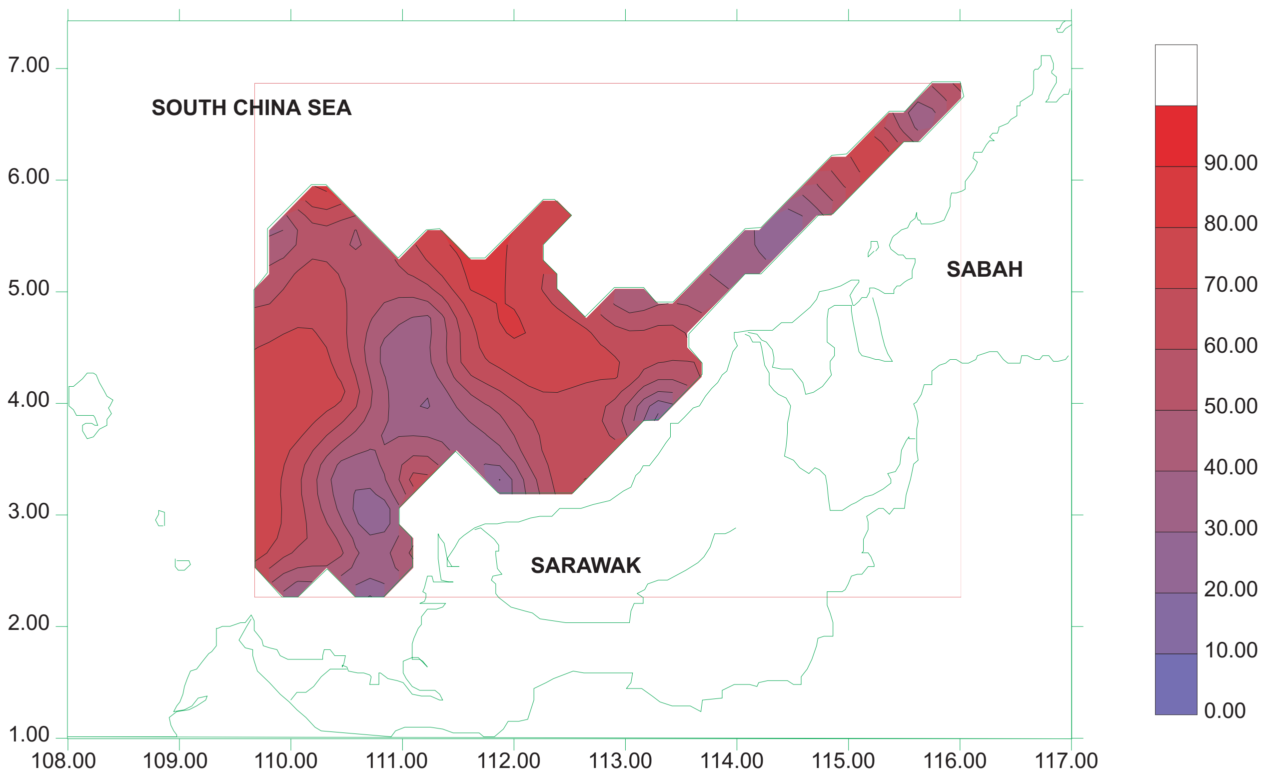

Figure 7A : Post-monsoon patterns of silt distribution

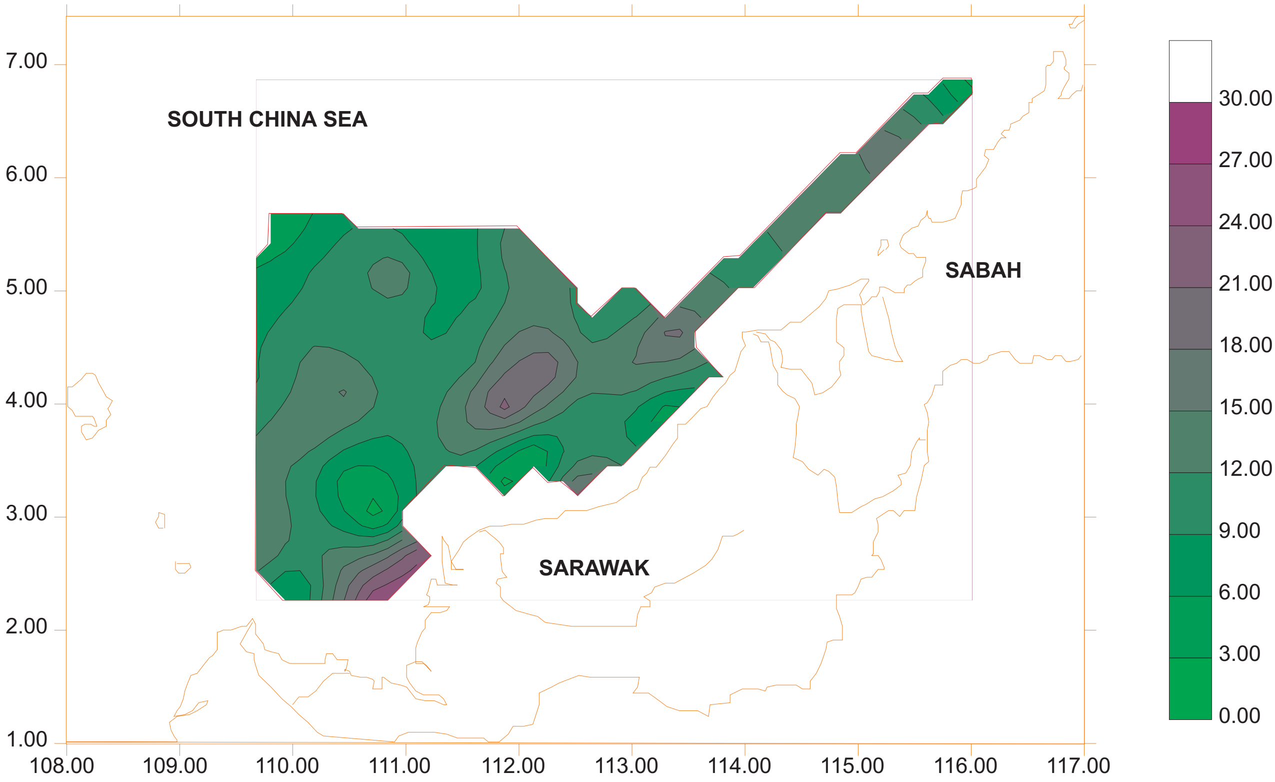

Figure 8A : Pre-monsoon patterns of clay distribution

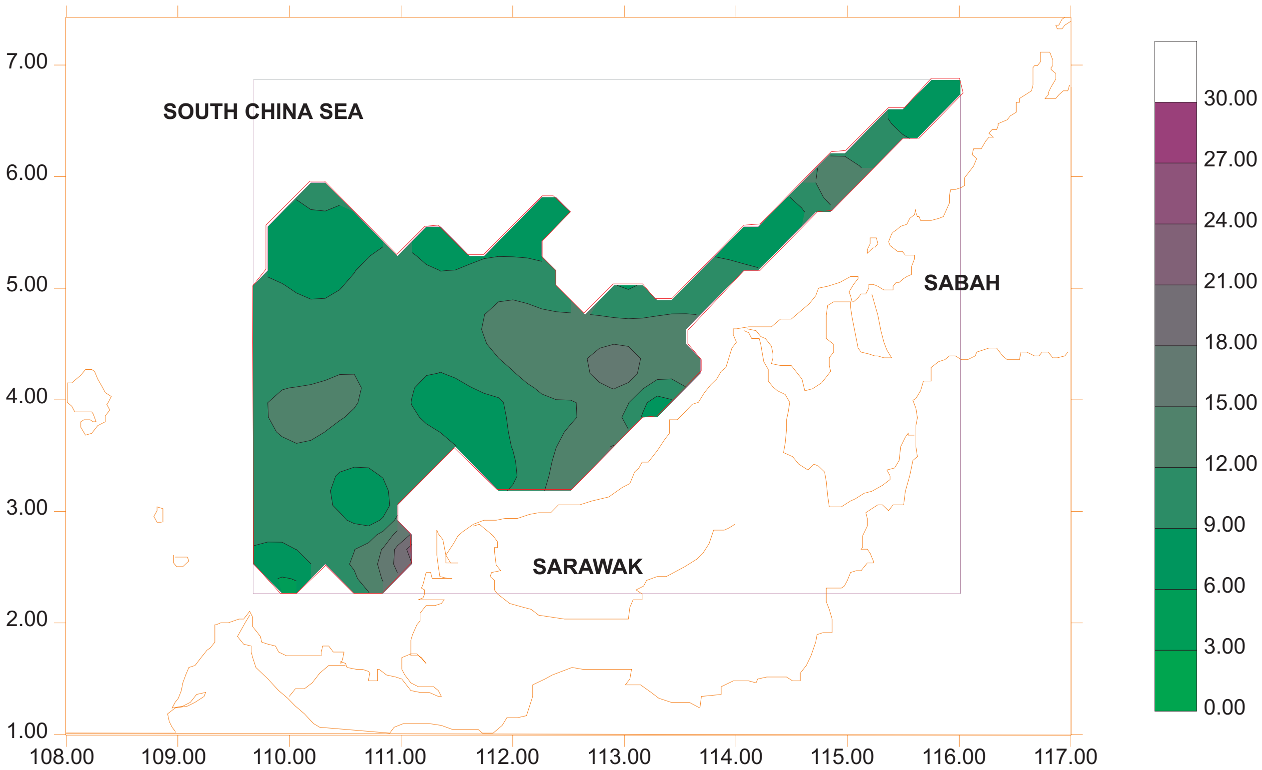

Figure 8A : Post-monsoon patterns of clay distribution

out these two stations the values for the pre-monsoon season will most certainly be below that of the post -monsoon thus making it similar to those described for Area I.

For the sediment samples collected during the pre-monsoon and post-monsoon cruises, the differences in characteristics are statistically quite significant (Tables 1E to 1G). Except for percentage of clay, all other sedimentological parameters show that the differences between the pre and post-monsoon sediments are statistically different.

On a cross-shore basis the general trend of decreasing in size from pre to post-monsoon sediments are similar to those described for Area I. The mean size of near-shore, mid-shore and off-shore sediments are finer for post-monsoon sediments as compared to the pre-monsoon sediments. During both seasons, the coarsest sediment are those for the near-shore stations.

Although the study Area II is located further away from study Area I, both are comparatively close to the shore and therefore strongly influenced by terrestrial input by discharging rivers. The differences between the pre and post-monsoon sediments can most probably be attributed to the weather conditions prevailing during both seasons. The site conditions during and before the sampling period are vastly different. The large outflow of fine sediments to the ocean environment during the monsoon season may have contributed to a considerable volume of fine sediments being deposited on the sea bottom. This has contributed to the sedimentological characteristics of the post-monsoon sediments into finer, better sorted and less negatively skewed as compared to the pre-monsoon sediments. The differences on the cross-shore sediment are strongly attributed to the near-shore region being most affected by wave, which naturally act as a siever, removing the finer materials, and eventually allowing only coarser materials to settle. This has given rise to the smaller range of size and better sorting values.

Conclusion

The monsoonal factor which causes terrestrial erosion of fine particles to be transported by the rivers into the adjacent ocean environment is the primary reason for the significant differences in the sedimentological characteristics of seabed materials sampled during the pre and post monsoon periods. In addition, the forces generated within the near-shore region of the area have induced the sorting mechanism on the sediments that resulted in the nearshore region covered with coarser materials.

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