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Application of Remote Sensing Image and Mathematical Model for Dispersion of Suspended Solid in the Upper Gulf of Thailand

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ABSTRACT

The total suspended solid (TSS) dispersion model was based on the principle of conservation of mass. The model was used to study the TSS concentration fields in the immediate vicinity of the rivers mouth and in the Upper Gulf of Thailand. The verification had been done by comparing the predicted diffusion patterns with the satellite image. There was 10 cruises survey in the Upper Gulf of Thailand by Kasetsart 1. Total suspended solid were analyzed by the gravimetric method. The comparison of the TSS dispersion pattern between the observed TSS dispersion and the simulated result was quite similar. It appeared that it might be possible to obtain TSS information in the Upper Gulf of Thailand by using the TSS dispersion model.

Key words: Upper Gulf of Thailand, dispersion model

INTRODUCTION

The knowledge on the motion and distribution of sediment particles coming from a given pollutant source is expected to provide the information on pollutant distribution, necessary for determining the region of influence of the source and to estimate probable tropic levels of the seawater and potential environmental risks. In that aim a numerical model has been developed to predict the fate of sediments introduced to the marine environment from different pollutant sources, such as river outflows, erosion of the seabed, transported material and drainage system.

Freshwater input is a major provider of nutrients and heavy metals in coastal systems. The rivers together with a complex system of irrigation channels contribute to the transport of water, nutrient pollutants and sediments from the adjacent land area to the Upper Gulf of Thailand. Elevated concentrations of TSS had been recorded in the riverine water of the Gulf due to utilization of water for irrigation urban and industrial proposes.

Mathematical models describing the transport and dispersion of sediments in the coastal environment that had been developed and applied were Eulerian solving the well-known 2 dimension differential equation of transport and diffusion of matter concentration where advection and diffusion of specific amount of mass was trailed with time or combined Eulerian-Lagrangian methods in which advection was expressed by particles whereas the dispersion was defined applying the finite differences scheme.

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MATERIALS AND METHODS

Topography

The Upper Gulf of Thailand is bounded by latitude 12° 40′N - 13° 30′N and longitude 100° E - 101° E or 600000 N-720000 N and 1400000 E-1500000 E. The Gulf was surrounded by the provinces of Phetchaburi, Samut Songkhram, Samut Sakhon, Bangkok, Samut Prakan, Chachoengsao and Chon Buri in the western, northern and eastern sides respectively, and is open to the Gulf of Thailand via the southern border. It has an area of approximately 100×100 km^2 with the maximum depth of 40 m near Ko Khram. This area experiences mixed tides with 2-3 m tidal ranges.

Four main rivers (Mae Klong River, Tha Chin River, Chao Phraya River and Bang Pakong River) enter into the bay in the northern part as shown in Figure 1. For the whole year, each river discharges fresh water with high sediment load. Most of suspended solid load from rivers was mixed with seawater in delta and near shore areas.

Sample analysis

There was 10 cruises surveys in the Upper Gulf of Thailand by Kasetsart 1. The Bang Pakong River mouth-Si Chang Island had 6 cruises on 18th November 2004, 18th January 2005, 15th March 2005, 19th May 2005, 19th July 2005 and 23rd September 2005. There were 12 stations in each cruise, except the 2 cruises with 17 stations around the upper Gulf of Thailand which were performed on 8th October 2004 and 25th January 2005. The rest of the cruises, Chao Phraya-Si Chang Island with 12 stations, were operated on 10th January 2004 and 17th September 2005. Water samples were collected at every hour during 26th -28th January 2005, near Ko Phai and Chao Phraya River mouth for 25 hours. The seawater samples at the sea surface were filtered for the total suspended solid (TSS).

TSS was analyzed by the gravimetric method as recommended by Strickland and Parsons (1965). That was weighing batch of 1.0 μm Glass Microfibre filters (GF/C 47 mm, Whatman) after washing with distilled water and heating for 2 hour at 450°C. Then each filter was placed in a plastic box. By using vacuum filtration, a suitable volume of water sample depended on the turbid of water. To determine the total suspended solid, the filtered papers were dried and weighed. The difference weight of the filter was divided by the volume of water sample to give TSS value.

Water samples were collected for conventional laboratory testing of the TSS, which was correlated with the spectral reflectance from

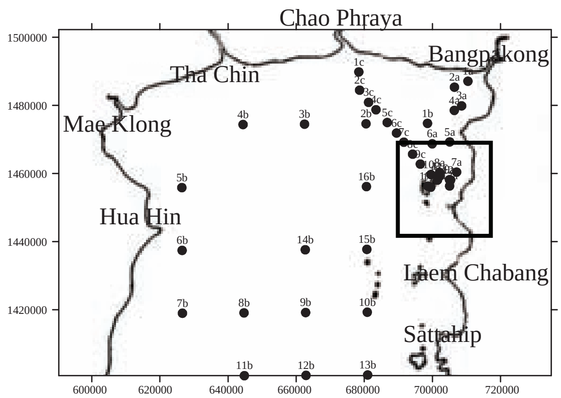

Figure 1 Study site and sampling stations.

different EM bands. TSS coincided with the digital values were used to figure out which equation and which band was suitable for creating the simple chart of the TSS. Three bands of LANDSAT 5 TM and masking technique were used. A mask was hand-digitized from all 3 bands with natural color composite on the screen.

Sources and sinks of TSS

The major sources and sinks of TSS in the Gulf depend on the deposition of the sediment and reentry of sediment into the water column. Averaged TSS and discharge of main rivers which were recorded by the Harbor Department during years 1999-2000 were used as sources condition of the TSS dispersion model. The discharge of 4 main rivers and concentration of TSS were shown in Table 1.

Transport of suspended sediment

The variation of water carrying suspended sediment concentration (S_*) is governed by the fall velocity incorporating both particle size and specific gravity. Bogardi (1978) presented that the water carrying capacity for suspended sediment, for water with depth h, flow velocity V and settling velocity w, could be rewritten as:

$$S_* = \eta_1 \frac{V^3}{hw} \qquad (1)$$

where $V = \sqrt{u^2 + v^2}$

η_1 was often assigned a practically constant value for particular water. From the results of sediment measurements made under saturation conditions on a number of rivers, Rossinsky and Kuzmin (1950) suggested $\eta_1 = 0.024$. The boundary condition in sediment transport at which channel erosion was initialed had also been studied by Rossinsky (1970). In this condition which might be regarded as the critical, additional sediment was scoured from the channel owing to the excess energy flow. For this condition Rossinsky (1970) suggested $\eta_1 = 0.0005$.

Basic equations

The basic governing equation of the dispersion model was the substance balance equation which represents the principles of mass conservation. This equation included terms representing advective and dispersive transports as well as terms representing source and sink of the substance.

Table 1 Annual month recorded discharge (m^3/sec) and TSS (mg/l) in Maeklong River, Thachin River, Chao Phraya River and Bang Pakong River.

	Mae Klong River		Tha Chin River		Chao Phraya River		Bang Pakong River	
	Q(m^3/sec)	TSS(mg/l)	Q(m^3/sec)	TSS(mg/l)	Q(m^3/sec)	TSS(mg/l)	Q(m^3/sec)	TSS(mg/l)
November	491	1998	234	8714	1624	100	466	4734
December	192	5305	363	2377	1208	360	7	0
January	135	134	201	0	235	12	9	0
February	98	32	96	0	183	0	0	726
March	173	87	200	20	541	21	58	0
April	355	72	222	26	465	63	134	125
May	466	45	232	3	697	64	259	195
June	369	35	316	8	766	105	446	159
July	216	29	259	7	769	104	525	132
August	173	46	327	15	603	97	251	128
September	334	50	337	22	1058	99	487	87

The vertically averaged form of the TSS balance equation could be written as:

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} = \frac{\partial}{\partial x}\left(K_x \frac{\partial S}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial S}{\partial y}\right) - \alpha w\left(S - S_*\right) \qquad (2)$$

where S = depth-averaged suspended-load concentration
K_x, K_y = diffusion coefficient of sediment in x and y component
u and v = velocities in x and y component
α = constant coefficient
w = settling velocity (0.01 cm/sec)
S_* = water carrying capacity for suspended sediment

Stability and convergence of model

The solutions of finite differential equation were not approximate in sense of crude estimates. Finite difference methods generally gave solutions that were either as accurate as data warrant or accurate as was necessary for technical purposes for which solution were required. The TSS dispersion model had to be considered, when selecting the time step. For stability and convergence of TSS dispersion model, Ueno (1967) assumes that

$$4\frac{\Delta t}{\Delta s}\left(\frac{U}{2} - \frac{K}{\Delta s}\right) < 1 \qquad (3)$$

Successive over relaxation method (SOR)

For solving large linear system of finite differential equation, it requires iterative method for convergent predicted values. The iterative procedure close to be convergent when the difference between the exact solution and the successive approximates tend to be zero as the number of iterations increase.

In this study, SOR was selected since it converges very fast; Ueno (1967) expressed equation of SOR as:

$$^{v+1}S_{i,j}^{n+1} = {}^{v}S_{i,j}^{n+1} + \alpha_2 \, {}^{v}R_{i,j}^{n+1} \qquad (4)$$

where α_2 = acceleration parameter($1<\alpha_2<2$)
${}^{v}R_{i,j}^{n+1}$ = displacement or specified accuracy
${}^{v}S_{i,j}^{n+1}$ = th iterated value

Condition of the TSS dispersion model

For the modeling in the large area as the whole Upper Gulf of Thailand, the river topography was usually considered very small compared with the grid size of the elements. River boundary was determined when the local effects of the river flow was taken into consideration. For a channel with a small cross-sectional area, the flow component and the lateral variation in the substance concentration were small. In this case the dispersion process could be considered to be one dimensional. For large water bodies such as the coastal sea, the flow components as well as the substance dispersion varied in all directions, and caused more rapid decline of the substance concentration at the discharge point.

In this study, we assumed that the discharge and TSS which related to tide were continually drained into the Upper Gulf of Thailand from only 4 main rivers. The parameters which used in the model were shown in Table 2. The river discharge and TSS concentration were considered in 2 steps that river discharge was QH and QL while TSS was SH and SL, respectively.

RESULTS AND DISCUSSION

TSS determination from LANDSAT data

For satellite image data, the classification and masking technique was essential for performing the image processing over areas that interested, which in this study was the water body.

Table 2 The parameters of TSS dispersion model.

Parameter	Unit	Symbol	Value
Study size		im,jm	65,55
Time step of computing	sec	dt_e	600
Time step of output	hr	dt_i	4
Grid size	m	dx,dy	1860
Diffusivity coefficient of coastline	m^2s^{-1}	K	10
Diffusivity coefficient of off shore	m^2s^{-1}	K	5
Constant coefficient		α	0.01
Practically constant		η_1	0.0005
Acceleration parameter		α_2	1.3
Discharge	m^3s^{-1}	Q_H, Q_L	Wet Dry
- Mae Klong River			400, 50
- Tha Chin River			400, 50
- Chao Phraya River			1000, 100
- Bang Pakong River			400, 0
Concentration of TSS	mg/l	S_H, S_L	
- Mae Klong River			50, 30
- Tha Chin River			30, 20
- Chao Phraya River			100, 50
- Bang Pakong River			120, 50

The remote sensing data (supported by Geo-Informatics and Space Technology Development Agency, GISTDA) used in this study were LANDSAT 5 TM images with the path/raw 129/51 and acquisition date on 5th December 2003, 20th October 2004, 21st November 2004, 8th January 2005, 13tV March 2005 and 19th July 2005. The bands which were used to estimate the dispersion of TSS were band 1, 2, and 3.

LANDSAT digital data are represented by dimensionless digital numbers ranging from 0-255 levels in each channel. They are quantitatively related to the intensity of reflected radiant energy with a linear relation. The relationship between the ratio of reflectance values of band 1 and sum of reflectance values of band 1 + band 2 + band 3 to TSS were determined.

The relationships of these values had relatively medium correlation coefficients of 0.3279 as shown in Figure 2. The TSS was computed by using the formulas of reflectance of band 1, 2 and 3 which were related to TSS. By empirical, the TSS distribution patterns of band 1/ band (1+2+3) seem to be closer than the others.

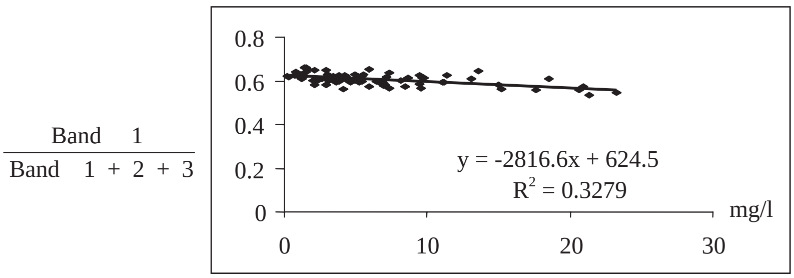

Figure 2 The relation of TSS and ratio of reflectance band 1, 2 and 3, respectively.

The relation formulas of the TSS and ratio of reflectance could be written as:

$$y = -2816.6x + 624.5 \quad (5)$$

where $R^2 = 0.3279$

$$y = \frac{\text{Band } 1}{\text{Band } 1 + 2 + 3}$$

x = TSS concentration

The computed results were represented by using the application software to determine the TSS around the Gulf. The comparison between the satellite images with the computed distribution TSS by band 1/ band (1+2+3) and the computed distribution TSS by TSS model were shown in the Figure 3. It showed similar trend in the diffusion pattern between observed and simulated results.

Comparisons of computed value with actual observation values were necessary for checking the results of TSS dispersion model. The variations of observed TSS at near Ko Phai and near Chao Phraya River mouth for 2 days are shown in Figure 4. The observed TSS near Ko Phai and Chao Phraya River mouth showed that the averaged magnitudes of TSS at offshore and near the river mouth were 4.5 mg/l and 7.1 mg/l, respectively.

The report of Doydee and Anong-ponyoskun (2004) that studied on remote sensing for determining the total suspended solids in the inner Gulf of Thailand found that the TSS

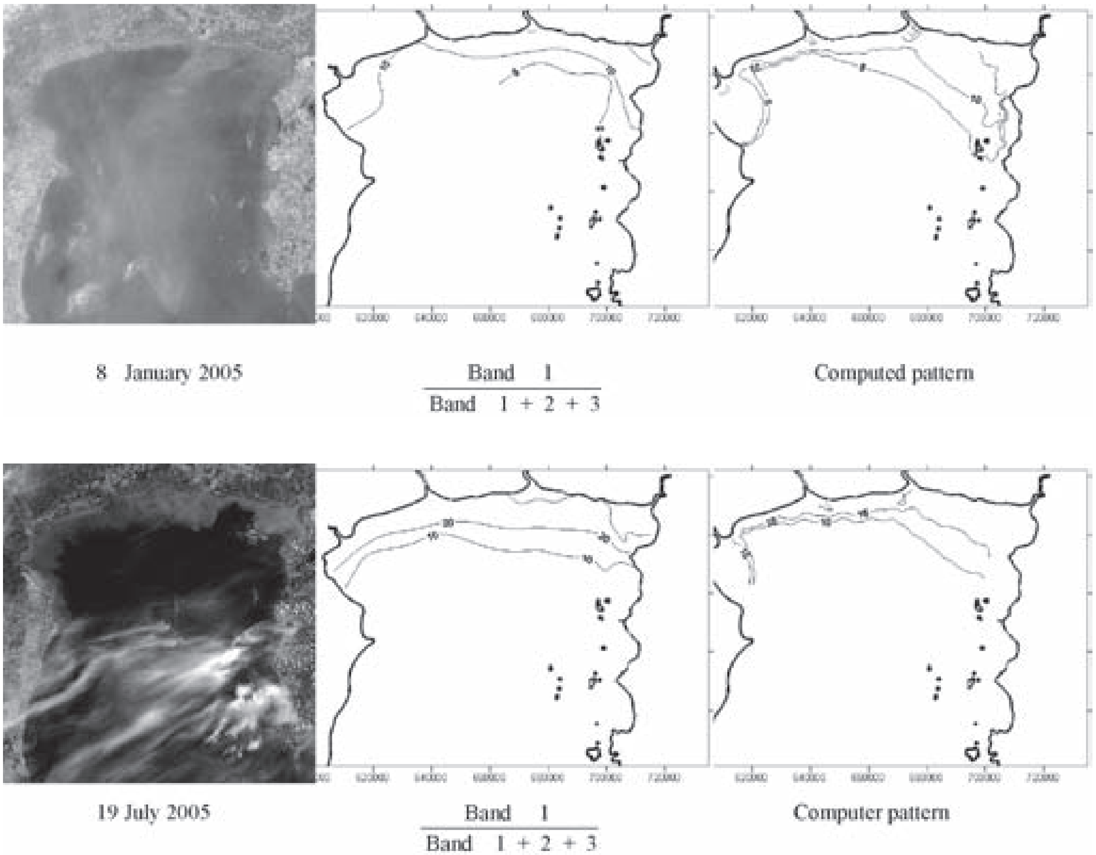

Figure 3 The comparison of LANDSAT image with the TSS (mg/l) distribution of reflectance ratio of band 1, 2, 3 and TSS distribution by TSS model.

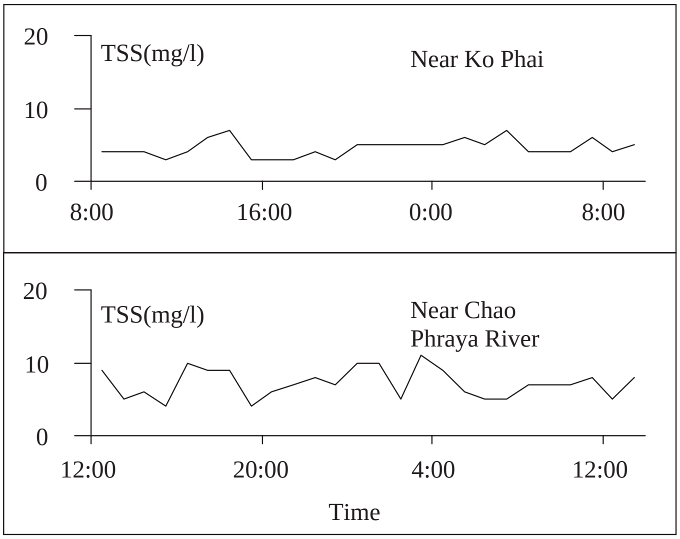

Figure 4 The variations of TSS (mg/l) near Ko Phai and Chao Phraya River mouth by on 26th -27th January and 27th -28th January 2005, respectively.

concentration was abundant near the river mouth and coastal area. TSS in the coastal zone was about 10-15 mg/l. It was decreased in offshore area. The reports of Vashrangsi (1978) which were studied around the eastern coast of the Gulf of Thailand from Khlong Dan to Bang Lamung, showed that the quantity of TSS had been about 8-226±164 mg/l.

CONCLUSION

TSS in the Upper Gulf of Thailand was abundant near the river mouth and coastal area and decreased in the offshore area. TSS dispersion model was used to study the TSS concentration fields in the immediate vicinity of the rivers mouth and in the Upper Gulf of Thailand. Verification had been done by comparing the predicted diffusion patterns with the satellite image. It showed similar trend in the diffusion pattern between observed and simulated results.

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