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Holistic Approach to Mitigate the Pollution Impacts in the Coastal Ecosystem of Thailand Using the Remote Sensing Techniques

Siddiqui, Z.

School of Civil Engineering, University of Leeds, LS2 9JT, UK

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ABSTRACT: A study of substantial anthropogenic related pollution in the Coastal Samut Prakarn Province (Thailand) was carried out focusing on the Bang Pu Nature Reserve (remnant mangrove wetland) using a remote sensing (geospatial) technique. Statistical regression models were developed between biochemical parameters of sample point and related reflectance data obtained from satellite imagery (Landsat TM). Change detection showed a significant increase in various water bodies over a period of a decade and significant increase in analyzed pollutant levels. The paper highlights the advantages of baseline data obtained and its significance towards a holistic approach to mitigating coastal pollution combining sustainable conservation and enhanced nature education through a significant ecosystem bio-diversification. Within the framework of the approach a buffering zone based on a constructed freshwater-fed wetland is to be introduced to serve as an effective pollution mitigating area serving the local community which is in serious need of such an environmental vehicle.

Key words: Anthropogenic, Change detection, Pollutant levels, Sustainable, Buffering zone

INTRODUCTION

Wetlands constitute a great economic, cultural, and scientific and recreation value loss of which would be difficult to restore (Dierberg and Kiattisimkul, 1996) or rehabilitating in to original conditions (Macintosh and Havanon, 2002). Threats faced by Asia's diverse wetlands include drainage and reclamation for industrial and urban expansion, conversion to salt ponds by shrimp farming, pollution, river diversion and logging (Mahmoudi *et al.*, 2010). These should therefore be preserved and rehabilitated (Dierberg and Kiattisimkul, 1996). Sustainable development is a much accepted approach of conservation now, linking human activities such as nature education, agriculture/ aquaculture with pollution abatement. With nature conservation/bio-diversification the concept of multi-purpose use of ecosystems can be seen as a major way for future development in urban and pre-urban areas (Hamilton and Snedaker, 1984; Stevenson *et al.*, 1999). Though examples are very few, they give very encouraging results. Sites such as the Werribee farm in the Greater Melbourne area (Australia), a Ramsar wetland and the East Kolkata Wetland in India are two examples of wetlands managed according to a multi-purpose approach combining functions of industrial and municipal waste abatement, agriculture/aquaculture and nature conservation (Denny, 1997; Harty, 2004). Using the same multi-approach, The Royal Thai Army and WWF started a project concerning a high profile conservation/education area, the Bang Pu Nature Reserve, located within the boundaries of Greater Bangkok (Samut Prakan, Thailand). A popular destination for recreation/education of inhabitants of Bangkok, it has been recently declared a nature reserve and is under the aegis of WWF and the Royal Thai Army as a significant mangrove-dominated ecosystem. The existing site is recognized as an attraction for migrating birds thereby harboring some 160 species (WWF, 2007) of birds including many globally endangered species. It is currently plagued by a number of serious problems mainly due to its location in the urban and industrial area. The rapid increase in human population and industries coupled with inadequate wastewater management in the area has resulted in severe water pollution in the coastal Greater Bangkok area (NEB, 1992). This strongly influenced the Thai Cabinet to declare Samut Prakarn province a 'pollution control zone' in 1993. Although domestic sewage and industrial waste is being treated effluents still do not meet the environmental standards before being discharged into the coastal areas particularly in the river basin of Chao Phraya (Ketchum, 1970). The environment-related problems further elevate thereby salt and nutrient laden discharges from shrimp farms in to the Chao Phraya river basin causing eutrophication in natural water (Phillips, *et al.*, 1993).

*Corresponding author E-mail: zuhaib80@hotmail.com

This cause an additional threat to the coastal aquatic flora (mangrove forests) and fauna (migrating birds) (Landesman, 1994).

The magnitude of environmental impacts can be predicted through conventional Environmental Impact Assessments (EIAs) such as site visits, field surveys, mathematical modelling and sampling. However, these conventional methods reveal the pollutant concentration data only at a particular location and at a particular time. Such data fails to provide any information about the spatial extent of pollution and its dispersion pattern. The detection of water pollution sources is further exaggerated, if non-point sources are a significant contributor and time required for its accumulation, which leads to a spread of the pollutant over larger areas of water body (Clark, 1993). The geo-spatial EIA process in particular satellite remote sensing data, is a better tool to serve these purposes. The process essentially involves sampling and analysis followed by fitting mathematical models for the spectral reflectance data obtained from satellite imagery (Siddiqui, 2005; Patil *et al.,* 2002; Mahmoudi *et al.,* 2010). Once the mathematical models are ready, these can be applied to detect the extent of pollution across much larger areas and can be used number of times for other satellite images of same study area. The advantage of remote sensing technique is that it provides an augmented view of spatial and temporal variability of water quality and land cover status, which cannot be obtained by conventional measuring techniques. A comprehensive study was undertaken to investigate the environmental changes that have occurred due to pollution from shrimp farms, urban pollution and local industries using geo-spatial techniques (change detection) in the Coastal Areas of Samut Prakarn Province, focussing on Bang Pu Nature Reserve.

The study area is located geographically between E 67°33’41", N 15°39’65" to E 68°4’, N 15° 32’55" and covers the Coastal Samut Prakarn Province of Thailand with the Bang Pu Nature Reserve, as a focal point. Study area was picked out from similar seasonal ortho-rectified Landsat TM and ETM+ images (path 129; Row 051) by EarthSat of years 2004 and 1994. False color composition with bands 432 (Near infra red, red and green) are shown in Fig.1a &1b. Reliability of the corrected satellite data was appreciable, after examining in-situ co-ordinates (significant sampling points) observed by GPS (Garmin V) so called geo-referencing. Later both satellite data were processed using modified Patil et al. (2002) in Environment for Visualizing Images (ENVI) software and later analyzed in Arc View software discussed below. A pollution monitoring program was conducted diurnally, focusing different seasonal conditions (rainy and dry season) during May 2004 – March 2005, on such a day that the first date of sampling coincides with the satellite acquisition. Before starting sampling, previous year’s rainfall data was collected from Station: 455301 Bang Na, Climatology Division, Meteorological Department Thailand and demonstrated that the rainy season fell between March-October. Twenty-four critical sampling locations were selected: rehabilitated ponds, existing shrimp ponds, water channels, local municipal (residential and market) wastewater, seawater and mudflats (Fig.2) during August 2004 – March 2005. Analytical data of numerous parameters (dissolved and suspended solids, nutrients, microalgae *etc*) comprising both organic and inorganic pollutants were analyzed following American Public Health Association (APHA, 1998) methods and were compared with the National Environmental Board of Thailand (NEB, 1992) (Table 1).

Table 1. Baseline conditions to be maintained in the Bang Pu Nature Reserve in terms of concentrations to be maintained related to different pollution parameters

Water quality parameters	Unit	Concentration	Reference
pH	-	6.5 - 8.5	NEB. (1992)
Dissolved oxygen (DO)	mg/L;(gr/gal)	> 4 (0.23)	NEB. (1992)
Total suspended solids (TSS)	mg/L;(gr/gal)	< 30 (1.75)	NEB. (1992)
Salinity	ppt ;(gr/gal)	29.0 – 35.0 (1,693.6 – 2,044)	NEB. (1992)
Biochemical oxygen demand (BOD)	mg/L;(gr/gal)	< 20 (1.168)	NEB. (1992)
Total nitrogen	µg/L;(µgr/gal)	< 260 (15.184)	Wattanamongkol, S. (2002)
Total phosphorus	µg/L;(µgr/gal)	< 10 (0.584)	Wattanamongkol, S. (2002)
Chlorophyll *a* (Chl *a*)	µg/L;(µgr/gal)	< 1 (0.0584)	Wattanamongkol, S. (2002)
Cadmium (Cd)	mg/L;(µgr/gal)	< 0.005 (0.292)	NEB. (1992)
Chromium (Cr)	mg/L;(µgr/gal)	< 0.005 (0.292)	NEB. (1992)
Copper (Cu)	mg/L;(µgr/gal)	< 0.005 (0.292)	NEB. (1992)
Zinc (Zn)	mg/L;(µgr/gal)	< 0.1 (5.84)	NEB. (1992)

Fig. 1(a). Landsat TM image of study area in year 2004 (432)

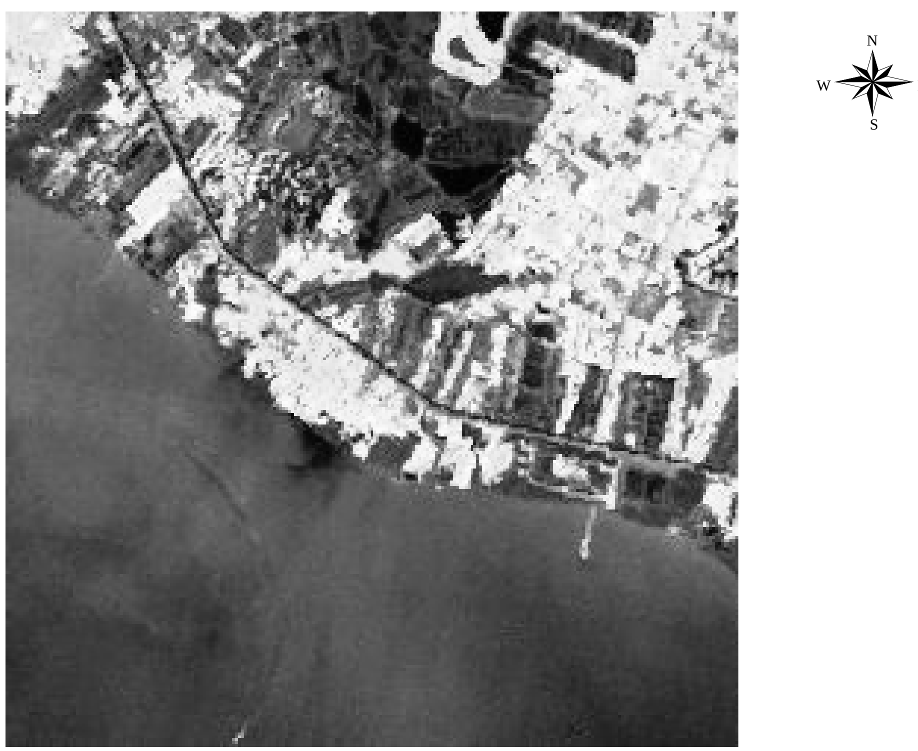


Fig. 1(b). Landsat TM image of study area in year 1994 (432)

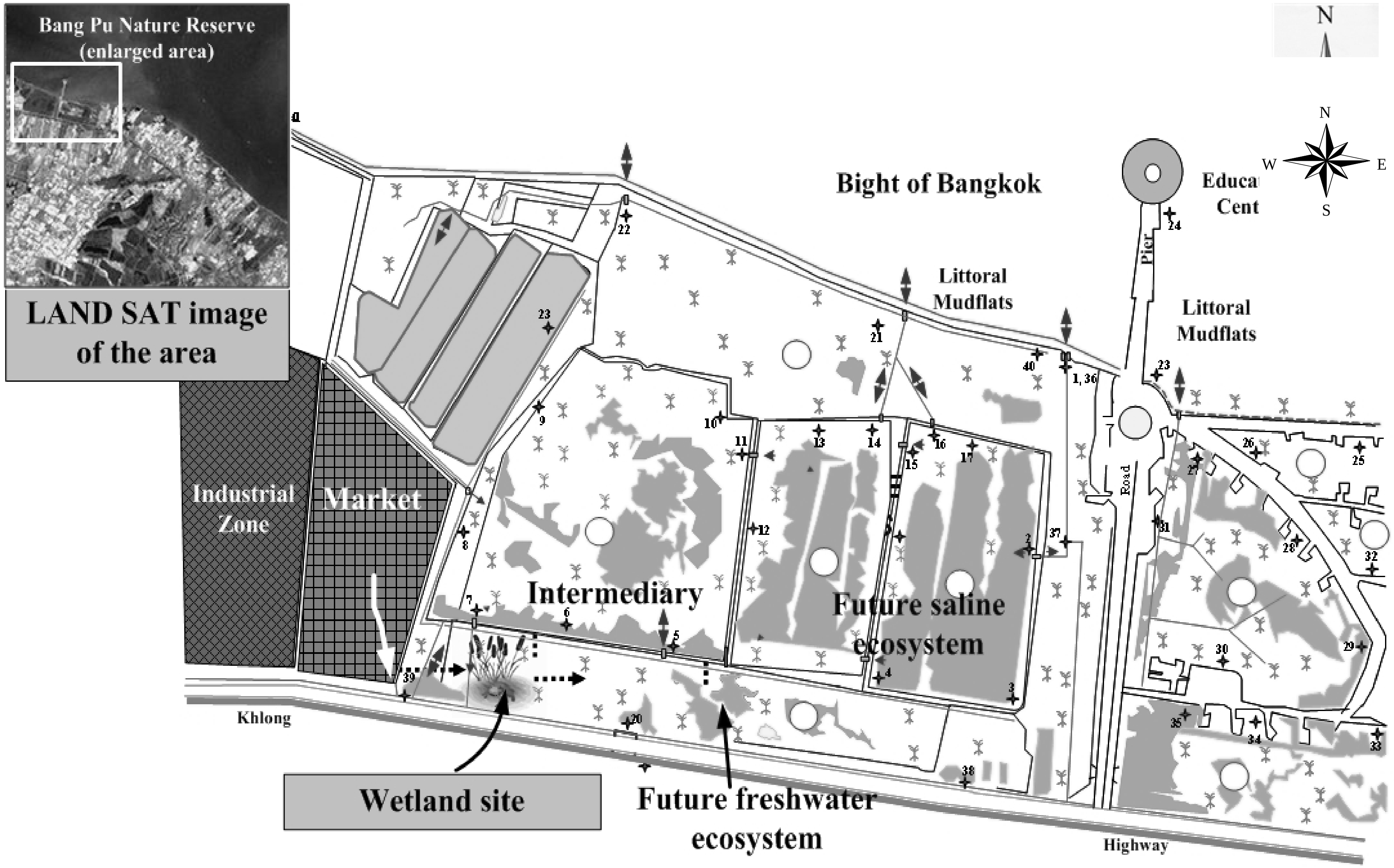


Fig. 2. Layout of the Bang Pu Nature Reserve: locations of the sampling points, freshwater wetland as a buffering zone for wastewater. Note three new ecosystems to be introduced in lieu of the existing "Saline mangrove wetland ecosystem": Freshwater, intermediary saline/freshwater and saline wetland ecosystems

MATERIALS & METHODS

A water pollution scenario in terms of total dissolved solids (TDS), total suspended solids (TSS), ammonium nitrogen (NH_4-N), phosphate phosphorus (PO_4-P) and chlorophyll *a* (Chl-*a*) was predicted modifying Patil et al. (2002) methodology. A mean square regression analysis curves available in Microsoft Excel 2003 (linear, exponential, power, logarithmic and polynomial fits of second degree were tried between average pollutant levels analyzed during three scheduled sampling monitoring programme and optical property (spectral reflectance) changed due to pollutant levels. A band provided the highest coefficient of correlation was selected as empirical models (Table 2). The empirical model equations were verified using t Stats An and Kim (2003). Verified empirical models were used to map the pollutant extent using the math band function available in ENVI. A gray scale image was produced consists only water bodies available in the study thereby avoiding interferences caused due by non-water bodies. Satellite data of year 1994 was radiometrically normalized to avoid errors; during this root mean square (RMS) was appreciable. The pollution map was acquired in following the same methodology as 2004 Landsat data. A classified image was prepared using color code to define the water pollution scenario in the coastal area of Samut Prakarn Province. After enhancement final classified classes were clumped using Arc View utility and converted to a vector file (Fig.3&7).

RESULTS & DISCUSSION

Expanding numbers of shrimp farming, industries and urban population along the coastal areas (Chao Phraya River) poses a drastic impact on the local mangroves. A significant increase of TSS (208 – 560 mg/L or 12.15 – 32.7 grain(gr)/gallon (gal)), dissolved solids (7,100 – 43,500 mg/L or 414.64 – 2,540.4 g/gal), ammonium nitrogen (0.1 – 12.2 µg/L or 0.006 – 0.712 µg/gal), PO_4-P (0.9 – 23 µg/L or 0.053 – 1.343 µg/gal), chlorophyll *a* (0 – 40 µg/L or 0 – 2.336 µg/gal) and reduction of mangrove cover was observed in the study area. Myo (2005) analyzed concentration of various heavy metals and found Cd (0.0 – 0.03 mg/L or 0.0 – 0.0018 µg/gal), Cu (0.01 –0.05 mg/L or 0.0006 – 0.0018 µgr/gal), Ni (0.01 – 0.05 mg/L or 0.0006 – 0.0018 µg/gal) and Zn (0.01 – 0.07 mg/L or 0.0006 – 0.0041 µg/gal). No significant changes in these pollutant levels were observed diurnally due to the character of the hydraulic management of the Reserve affected through installed control water gates, which were closed during low tides to prevent water from leaving the internal water bodies in the seaward direction. Concentrations of different pollution components, both organic and inorganic, were lower in the rainy season (May-October) in comparison to dry season (November-March), apparently due to precipitation-induced dilution. Elevation of ammonium N and phosphate may be caused by continuous use of nearby the natural coastal wetlands for shrimp farming. Enrichment of PO_4-P may potentially lead to serious algal bloom problems and classified the reserve as mesotrophic in the dry season and oligotrophic in the rainy season.

The rapid increase in human population and industries coupled with inadequate wastewater management in the area has resulted in severe water pollution in the coastal Bangkok area. Several thousand local industries discharge wastewater into the Chao Phraya River and the Bight of Bangkok

Table 2. Coefficients of correlation for empirical relations achieved using twenty-four sampling points

Parameters	Spectral Bands	Coefficients of correlation				
		Linear	Exponential	Logarithmic	Power	Polynomial
Total Suspended Solids	5	0.682	0.552	0.535	0.448	0.682
Total Dissolved Solids	5	0.43	0.65	0.32	0.41	0.49
Ammonium nitrogen	5	0.231	0.415	0.262	0.662	0.448
Phosphate phosphorus	3	0.411	0.392	0.211	0.234	0.452
Chlorophyll *a*	5	0.243	0.124	0.552	0.244	0.311

Parameters	Empirical relationship
Total Suspended Solids	$Y = 0.6761x + 29.78$
Total Dissolved Solids	$Y = 7724.3\ e^{0.0158x}$
Ammonium nitrogen	$Y = 123100\ x^{-2.3211}$
Phosphate phosphorus	$Y = 0.0034\ x^2 - 0.4394\ x + 22.699$
Chlorophyll *a*	$Y = -2.029 \ln x + 18.023$

Where: Y = spectral reflectance of sampling point
x = Concentration of environmental parameter of sampling point

making the Samut Prakarn coastal area one of the most polluted provinces in Thailand (WWF, 2007). Although the sewage and industrial wastes are often treated, the effluents do not meet the environmental standards before being discharged into the local water bodies closely linked to the Bang Pu conservation area. As a result, remnant biodiversity has dramatically decreased over the last decade (Siddiqui *et al.*, 2003) and is presently under stress. In turn this leads to a situation when numerous biodiversity components, including globally endangered species of birds which inhabited or migrate through the regional coastal ecosystems, are now threatened with extinction. Hence a major challenge for the local conservation is to rehabilitate and diversify the environment while shifting the focus of the government policy towards more prudent and sustainable development of the remnant urban ecosystems.

The initial data may serve as a foundation for future informed guidelines for the rehabilitation of the ecosystems of the Bang Pu Nature Reserve, in particular, and Samut Prakarn Province, in general, with a view to rehabilitating and enhancing local biodiversity. The Nature Reserve has high risk of hyper-eutrophication due to which habitat diversity and species diversity within the nature reserve can be significantly affected. To avoid a risk of hyper-eutrophication an enhanced careful management of salinity levels and fresh water and organics inputs from the adjacent areas is required so as to bring the pollution level with reference to Table 1.

It is deemed necessary to introduce a buffering zone in the Reserve adjacent to the polluted area (Fig.2). It is obvious from the results quantifying organic and inorganic pollutants that this zone can be based on a constructed freshwater-fed reeds wetland which will prevent heavy metals finding their way into the reserve while it will still feed stimulating nutrients (C, N and P). Thereby the nature reserve will not only work for nature conservation but will be an effective pollution mitigation area serving the local community badly in need of such a facility. Eventually these measures will substantially enhance the biodiversity value of the area through attraction of a wider variety of birds which will in turn significantly increase educational value of the reserve.

Similar trends were also observed retrospectively while utilizing remote sensing when results were evaluated as a result of processing of Land Sat TM satellite images from the year 2004 and 1994. The empirical relations were developed between optical properties of water (spectral reflectance directly from satellite data) and water quality (critical pollution parameters) at specified locations (Clark, 1993; Siddiqui,2005; Patil *et al.*, 2002). These empirical relationships were simulated (Table 2) under field conditions by developing pollution enhanced maps which also helped trace the extent of local organic and inorganic pollution. The concentration of the total dissolved solids, total suspended solids, ammonium nitrogen and PO_4-P profiles showed a remarkable increase in 2004 in comparison to 1994. These empirical relationships can be utilized to trace the extent of surface pollution in future using new satellite data. An increasing trend in TSS from 100 – 300 mg/L (5.84 – 17.52 gr/gal) was observed in estuarine area between grids (A, 6) to (G, 3) and wetlands between grid (A, 7) to (G, 7) in years 2004 and 1994 (Fig.3a &3b).

Turbidity levels were found significantly higher than the standard value of 30 mg/L (1.752 gr/gal) (Patil *et al.*, 2002) which are due to municipal and industrial discharge in the Chao Phraya River. Considerable increase of salinity (10,000 mg/L or 584 gr/gal) in terms of TDS was observed in seawater between gird (A, 5) to (G, 0) in years 2004 and 1994 (Fig.4a & 4b). It is probable that this is due to salt laden discharge from shrimp farms in to the Chao Phraya River and less availability of discharge of freshwater from upstream. Siddiqui et al. (2003) found retrospective results in the estuarine area due to insufficient discharge from downstream of Kotri Barrage in the River Indus that increased TDS level.

Increase in nutrients (ammonium nitrogen and phosphate) over a decade was high. Ammonium nitrogen increased from 20 µg/L (1.168 µgr/gal) to 40-80 µg/L (2.336-4.672 µgr/gal) (Fig.5a & 5b) between grid (A, 6) to (G, 2) and other water body at (E, 7). Phosphate increased from (10-15 µg/L or 0.584-0.876 µgr/gal) to (> 20 µg/L or 1.168 µgr/gal) between grid (A, 7) to (G, 0) and other water body at (E, 7) (Fig.6a & 6b). Frequent disposal of municipal wastewater to the Nature Reserve with high level of nutrients: ammonium nitrogen (62,800 µg/L or 3.67 gr/gal) and phosphate phosphorus (>20µg/L or 1.168 µgr/gal) caused a high risk of algal bloom (NEB, 1992; An and Kim, 2003; Wattanamongkol, 2002). It is evident from the change of eutrophic state from oligotrophic to mesotrophic in a decade. No subsequent change was observed in chlorophyll *a* level (> 30 µg/L or 1.752 µgr/gal) during 1994 and 2004 (Fig.7a &7b).

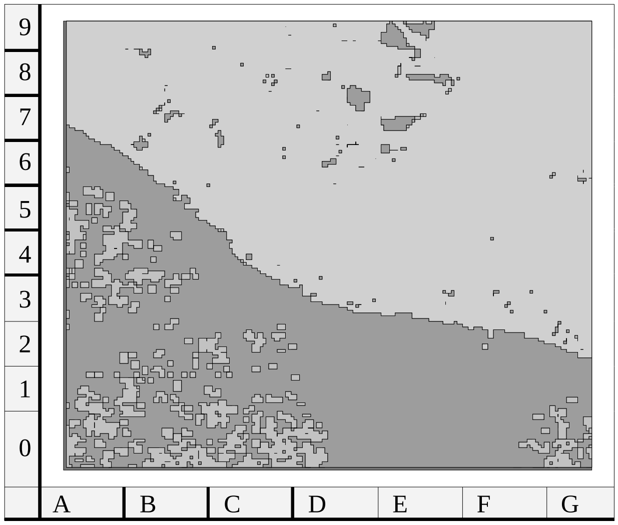


Fig. 3(a). Concentration of TSS of the study area in year 2004

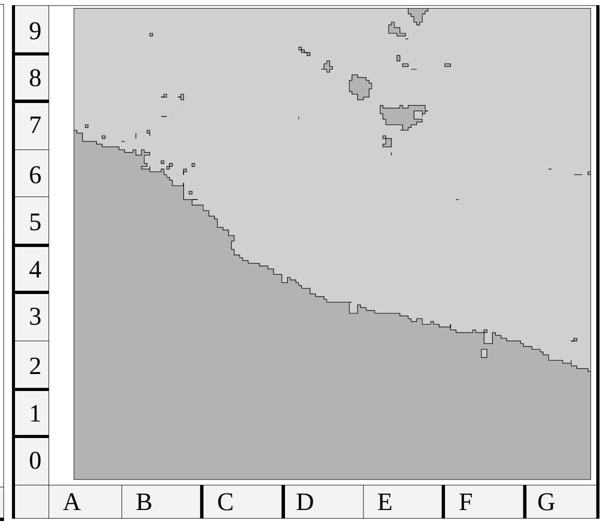


Fig. 3(b). Concentration of TSS of the study area in year 1994

Legend

- Nil
- 0-100 mg/L (0-5.84 g /gal)
- 100-200 mg/L (5.84-11.68 g /gal)
- 200-300 mg/L (11.68-17.52g /gal)
- > 300mg/L (17.52 g /gal)

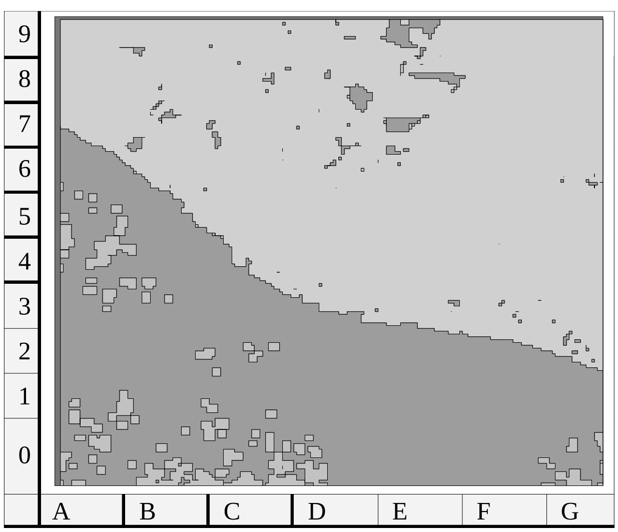


Fig. 4(a). Concentration of TDS of the study area in year 2004

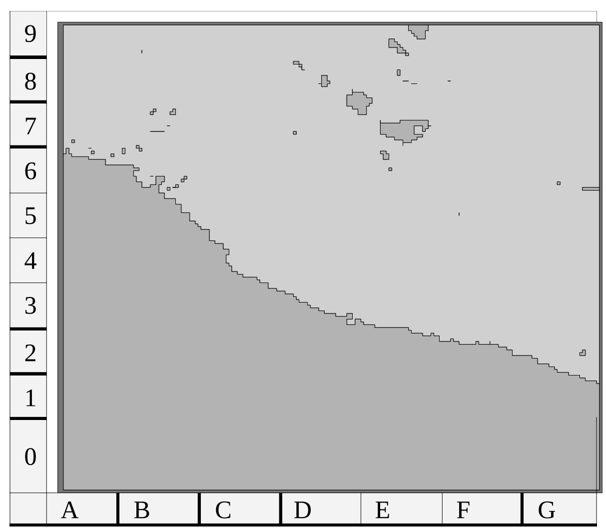


Fig. 4(b). Concentration of TDS of the study area in year 1994

Legend

- Nil
- 0-10,000 mg/L (0-584 g /gal)
- 10,000-20,000 mg/L (584-1,168g /gal)
- 20,000-30,000 mg/L (1,168-1,752 g /gal)
- > 30,000mg/L (1,752 g /gal)

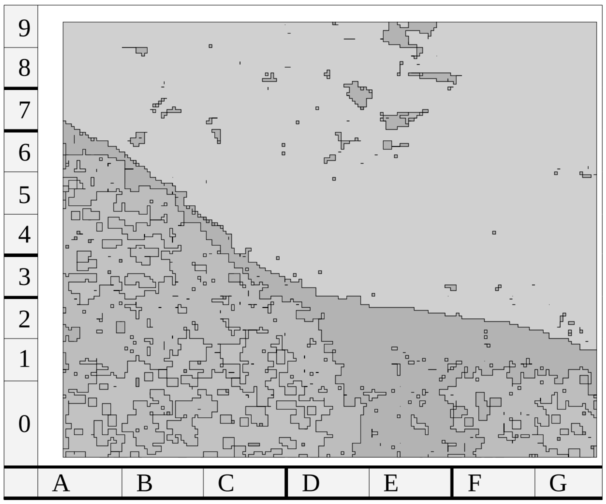


Fig. 5(a). Concentration of ammonium nitrogen of the study area in year 2004

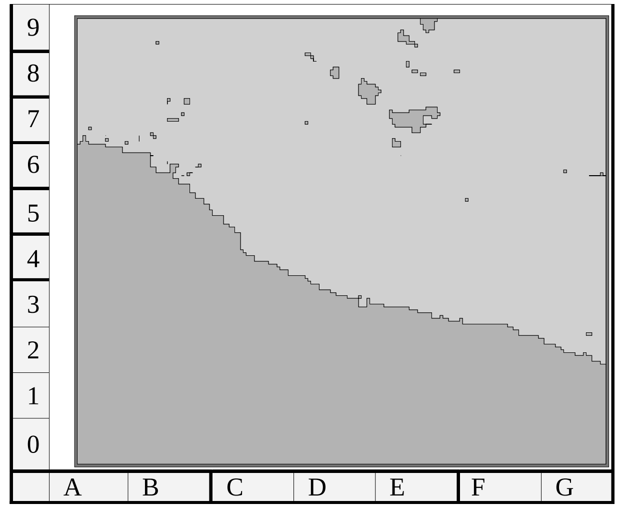
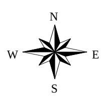


Fig. 5(b). Concentration of ammonium nitrogen of the study area in year 1994

Legend



- Nil
- 0-20 µg/L (0-1.168 µg /gal)
- 20-40 µg/L (1.168-2.336 µg /gal)
- 40-80 µg/L (2.336-4.672 µg /gal)
- > 80 µg/L (4.672 µg /gal)

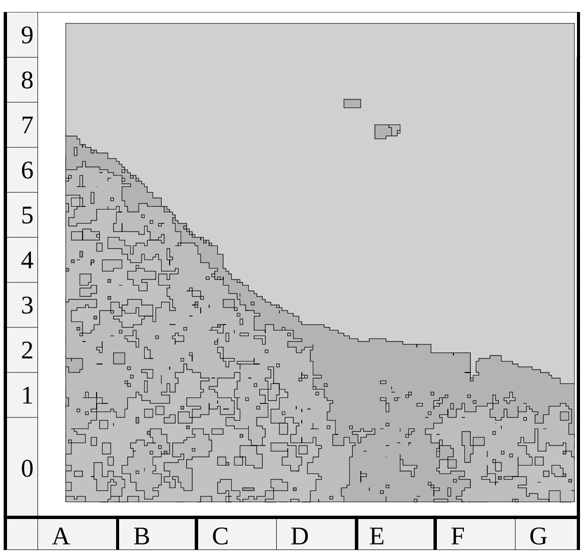


Fig. 6(a). Concentration of PO_4-P of the study area in year 2004

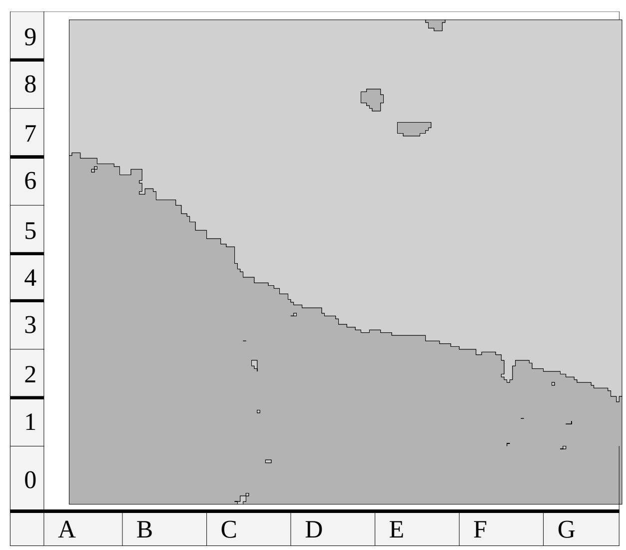


Fig. 6(b). Concentration of PO_4-P of the study area in year 1994

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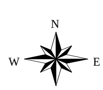


- Nil
- 0-10 µg/L (0-0.584µg /gal)
- 10-15 µg/L (0.584-0.876 µg /gal)
- 15-20 µg/L (0.876-1.168 µg /gal)
- > 20 µg/L (1.168 µg /gal)

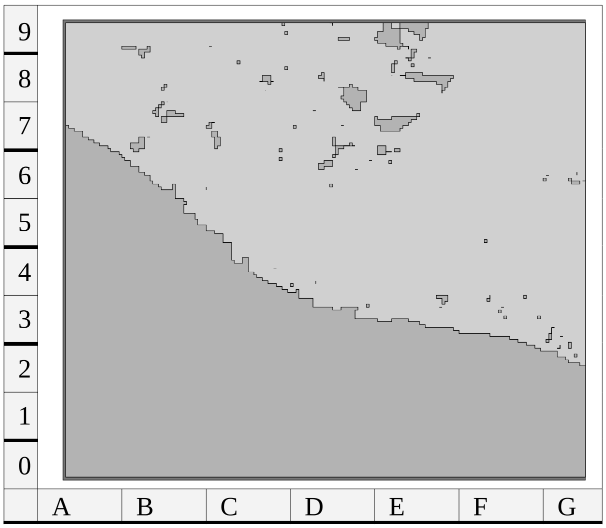


Fig. 7(a). Concentration of Chl *a* of the study area in year 2004

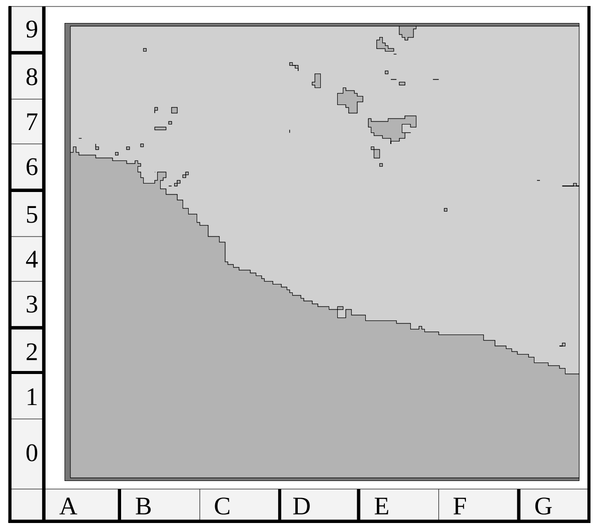
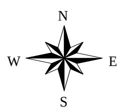


Fig. 7(b). Concentration of Chl *a* of the study area in year 1994

Legend



- Nil
- 0-20 µg/L (0-1.168 µg /gal)
- > 30 µg/L (1.168 µg /gal)

CONCLUSION

It was conclusively shown that water bodies (sea, mangrove mudflats, ponds, wetlands and channels) of the area, and those of the Reserve in particular, sustain synergistic impact of pollution from both municipal (market and residential) and industrial point and non-point sources.

Concentrations of different pollutant components, both organic and inorganic, were lower in the rainy season (May-October 2004) as compared to the dry season (November 2004-March 2005), apparently due to precipitation-induced dilution.

It was established through the analyzed numerous parameters (dissolved and suspended solids, nutrients, microalgae etc) comprising both organic and inorganic pollutants and there comparison with the National Environmental Board, 1994 and other guidelines that the area should be classified as mesotrophic in dry season and oligotrophic in rainy season. Nevertheless results still showed the coastal ecosystem appears to be in a healthy state. Water pollution enhanced maps showed significant increases in levels of total dissolved solids, total suspended solids, ammonium nitrogen and PO_4-P in 2004 compared to 1994. These empirical relationships can be utilized to trace extent of surface pollution in future using new satellite data.

The Reserve requires a higher degree of ecosystem rehabilitation as it was a shrimp farming zone for a long time. Examples from some countries (e.g. Werribee wastewater treatment facility/ International nature reserve in Melbourne, Australia) show that the biodiversity and ecosystem productivity can still be significantly enhanced while incoming waste nutrients are carefully managed. It is proposed to gradually reinstate a lost freshwater habitat in the currently saline water nature reserve. Monitoring of the process will allow obtaining critical information on behavior of nutrient-rich ecosystem performing waste mitigating function while undergoing bio-diversification. The reinstatement (rehabilitation) is expected to bring additional freshwater-related biodiversity (through the food chain starting with microalgae and ending with birds and mammals). A freshwater ecosystem is to be created by an introduced low cost reed-based constructed wetland into which freshwater rich in nutrients is pumped at empirically established rates. Thereby in addition to being treated and abated waste nutrients, C, N, P (otherwise causing pollution in the area) will serve the important function of increasing ecological productivity of the Reserve and, hence, bringing a new socially important benefit.

The bio-diversification project is intended to serve as a model for other South East Asian cities. The model ecosystem will work for the Bangkok community in two ways: conserve/enhance biodiversity and its educational/recreational value (a) while performing mitigation of rampant water pollution (b). The model ecosystem will involve a sustainable combined multi-faceted management of urban environment: (i) nature conservation of the high profile coastal ecosystem based on simultaneous water pollution mitigation (ii), enhancement of ecosystem productivity through additional nutrients originating from local wastewater (iii) and concomitant diversification of the ecosystem (iv), dramatically increasing its educational and recreational potential. Such multi-faceted management will increase the Reserve's educational and recreational potential for the sake of the people of Bangkok. An important example will be set for Thailand and the Strategic Environmental Impact Assessment (SEA) region at large with a view to promoting socially and economically sustainable approach to urban environment enhancing international image of the Reserve which will undoubtedly serve as an inspiration for further regional and global promotion of this holistic approach. Taking into account the high visibility of the Reserve in Thailand an impetus will be given to the establishment of appropriate international pollution legislation and funding for international and national sustainable wetland development programme.

REFERENCES

APHA, (1998). Standard methods for the examination of water and wastewater. 20th edition. Washington DC, USA.

An, K. G. and Kim, D. S. (2003). Response of reservoir water quality to nutrient inputs from streams and in-lake fish farms. Water, Air and Soil Pollution, **149**, 7-49.

Clark, C. D. (1993). Satellite and remote sensing of marine pollution. Intl. J. Remote Sensing. **14**, 2985-3004.

Denny, P. (1997). Implementation of constructed wetlands in developing countries. Water Sci. Tech., **35**, 27-34.

Dierberg, F. E. and Kiattisimkul, W. (1996). Impact and implications of shrimp farming of shrimp aquaculture. Enval. Manag., **20**, 649-666.

Hamilton, L. S. and Snedaker, S. C. (1984). Handbook for mangrove area management. IUCN Thailand.

Harty, C. (2004). Planning strategies for mangrove and saltmarsh changes in Southeast Australia. Coastal Manag., **32**, 405-415.

Ketchum, H. (1970). Eutrophication of estuaries. Proceeding of the Symposium on Eutrophication: Causes, consequences, correctives. Washington, DC.

Landesman, L. (1994). Negative impacts of coastal aquaculture development. World Aquac. **25,** 12–17.

Macintosh, D. J., Ashton, E. C. and Havanon, S. (2002). Mangrove rehabilitation and interdial biodiversity. A study in the Ranong mangrove ecosystem, Thailand. Estaurine, Coastal and Shelf Science, **55**, 331-345.

Mahmoudi, B. Bakhtiari, F., Hamidifar, M. and Danehkar, A. (2010). Effects of land use change and erosion on physical and chemical properties of waster (Karkhe watershed). Intl. J. Environ. Res., **4**, 217-228.

Myo, A. N. (2005). Impact of pollution on water quality of the coastal ecosystem of Samut Prakarn Province (Thailand) with a focus on the Bang Pu Nature Reserve. Dissertation. Asian Institute of Technology, Thailand.

National Environmental Board NEB. (1992). Enhancement and Conservation of National Environmental Quality Act B.E.2535. Royal Government Gazette, Thailand.

Patil, A.A, Annachhatre, A.P. and Tripathi, N.K. (2002). Comparisons of conventional andgeospatial EIA: A shrimp farming case study. Environmental Impact Assessment Review, 22, 361-375.

Phillips, M. J., Lin, C. K. and Bereridge, M. C. M. (1993). Shrimp culture and environment lessons from world's most rapidly expanding warm water aquaculture sector. Conference Proceedings of Enval. and Aquaculture in Development Countries (Eds.). I.C Larm. **31**, 71-197.

Siddiqui, Z. (2005). Impact of pollution on water quality if the coastal Samut Prakarn Province (Thailand) with a focus on the Bang Pu Nature Reserve. Dissertation. Asian Institute of Technology, Thailand.

Siddiqui, Z., Channa, A. R., Khahro, N. A, Memon, S. A. and Kandhir, A. W. (2003). Study of sea intrusion and its environmental impacts on Ghorabari Taluka, District Thatta. Dissertation. Mehran University of Engineering and Technology, Jamshoro, Pakistan.

Stevenson, N. J., Lewis, R. R. and Burbridge, P. R. (1999). Disused Shrimp ponds and mangrove rehabilitation. In An International Perspective on Wetland Rehabilitation (Streever W., ed.). 277-297. Kluwer Academic Publishers.

Wattanamongkol, S. (2002). Validating eutrophication model for coastal Samut Prakarn Outfall. Dissertation. Asian Institute of Technology, Thailand..

WWF, (2007). Thailand together with the Royal Thai Army opens Bang Pu Nature Education Centre. WWF, Thailand.