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ASSESSMENT OF WATER QUALITY PARAMETERS IN THE GANGES DELTA USING REMOTE SENSING TECHNIQUES

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ABSTRACT: Monitoring and assessing the quality of surface water are critical for managing and improving its quality. Satellites images provide both spatial and temporal information needed to monitor changes in water quality parameters. Substances in surface water can significantly change the backscattering characteristics of surface water. Remote sensing techniques depend on the ability to measure these changes and relate them to a water quality parameter by empirical or analytical models. The present study attempts to assess the temporal changes of water quality in the Ganges delta during 1989-2009 using remote sensing techniques. The study area is the river networks in the Ganges Delta flowing through the north-west and north-central regions of Bangladesh as well as the adjacent parts of the Meghna estuary and the Bay of Bengal. The study analyzed 3 Landsat scenes of the study area acquired in 1989, 2000 and 2009. Five water quality indices have been estimated in this study: Turbidity, Chlorophyll-a, Secchi Disk Depth (SDD), Total Suspended Material (TSM), and Colored Dissolved Organic Matter (CDOM). It has been found that during 1989-2009 both Chlorophyll-a concentration and Turbidity in the study area increased by 7%, whereas, TSM decreased by 30% and CDOM increased by more than 400%.

Keywords: *chlorophyll-a, landsat, remote sensing, turbidity, water quality*

1. Introduction

Water quality is a general descriptor of water properties in terms of physical, chemical, thermal, and/or biological characteristics. Water quality is affected by materials delivered to a water body from either point or nonpoint sources. Agriculture, industrial, and urban areas are anthropogenic sources of point and nonpoint substances. Polluting substances that lead to deterioration of water quality affects most freshwater and estuarine ecosystems in the world. Monitoring and assessing the quality of surface waters are critical for managing and improving its quality. Remote sensing techniques can be used to monitor water quality parameters. Satellites images provide both spatial and temporal information needed to monitor changes in water quality parameters. Substances in surface water can significantly change the backscattering characteristics of surface water. Remote sensing techniques depend on the ability to measure these changes and relate them to a water quality parameter by empirical or analytical models. The optimal wavelength used to measure a water quality parameter is dependent on the substance being measured, its concentration, and the sensor characteristics.

It is now accepted that some human-induced climate change is unavoidable (Whitehead et al. 2009). Projected climate change is expected to have far-reaching consequences for river regimes, flow velocity, hydraulic characteristics, water levels, inundation patterns, residence times,

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changes in wetted areas and habitat availability, and connectivity across habitats (Brown et al., 2007). More intense rainfall and flooding could result in increased loads of suspended materials (Lane et al., 2007). However, the most immediate reaction to climate change is expected to be in river and lake water temperatures (Hammond & Pryce, 2007). River water temperatures are in close equilibrium with air temperature and, as air temperatures rise, so will river temperatures. Abrupt water temperature rises could have important implications for some aquatic organisms, if species are unable to adapt at the same pace. Most chemical reactions and bacteriological processes run faster at higher temperatures. In addition, temperature controls the growth rates of phytoplankton, macrophytes and epiphytes, making freshwater ecosystems sensitive to rising temperatures (Wade et al., 2002b). Water temperatures also regulate the behavior of aquatic organisms, such as fish migration, and the timing of emergence and abundance of insect populations at different life-cycle stages (Durance & Ormerod, 2007).

The present study attempts to assess the temporal changes of water quality in the Ganges delta during 1989-2009 using remote sensing techniques. The study area is situated between 21^{o}30’00’’N to 23^{o}10’00’’N and 89^{o}10’00”E to 91^{o}00’00”E. It includes the river networks in the Ganges Delta flowing through the north-west and north-central regions of Bangladesh and adjacent part of estuary and the Bay of Bengal (Figure 1). North-west and north-central regions of Bangladesh include the entire Barisal Division and three districts of Khulna Division: Satkhira, Khulna and Bagerhat.

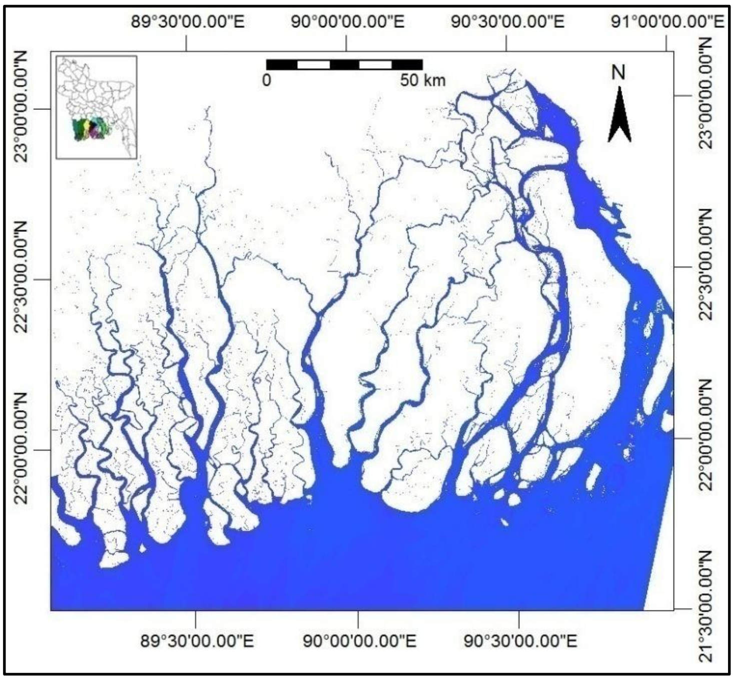

Figure 1: Study Area

2. Water Quality Indices

Five water quality indices have been estimated in this study: Chlorophyll-a (Chl-a), Turbidity (T_{NTU}), Total Suspended Material (TSM), Colored Dissolved Organic Matter (CDOM) and Secchi Disk Depth (SDD). A brief description of these indices is provided below.

Chlorophyll-a is the main green photosynthetic pigment found in all plants including phytoplanktonic algae. Phytoplanktons are the source of food for most marine animals. Chlorophyll-a concentration in estuarine, coastal or marine waters is used as an indicator of photosynthetic plankton biomass. It is a commonly used measure of water quality (as a surrogate of nutrient availability) with low levels suggesting good condition. However, high levels are not necessarily bad; it is the long-term persistence of high levels that is a problem (NLWRA, 2008).

Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. The units of turbidity from a calibrated nephelometer are called Nephelometric Turbidity Units (NTU). Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid. Turbidity in open water may be caused by growth of phytoplankton. Human activities that disturb land, such as construction, mining and agriculture, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff. Areas prone to high bank erosion rates as well as urbanized areas also contribute large amounts of turbidity to nearby waters, through stormwater pollution from paved surfaces such as roads, bridges and parking lots. In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths, which can inhibit growth of submerged aquatic plants and consequently affect species which are dependent on them, such as fish and shellfish. High turbidity levels can also affect the ability of fish gills to absorb dissolved oxygen (USEPA, 2005).

Total Suspended Material (TSM) can include a wide variety of material such as silt, decaying plant and animal matter, and industrial waste. As the amount of suspended material increases, the appearance of the water becomes cloudier as more light is scattered by particles within the water column. As TSM levels increase, light penetration decreases adversely affecting photosynthesis by primary producers. Suspended solids can clog fish gills, either killing them or reducing their growth rate (Ocean Optics, 2014).

Colored dissolved organic matter (CDOM) is the optically measurable component of the dissolved organic matter in water (Hoge et al., 1995). CDOM occurs naturally in aquatic environments primarily as a result of tannins released from decaying detritus. CDOM most strongly absorbs short wavelength light ranging from blue to ultraviolet, whereas pure water absorbs longer wavelength red light. Therefore, non-turbid water with little or no CDOM appears blue. The color of water will range through green, yellow-green, and brown as CDOM increases. CDOM can have a significant effect on biological activity in aquatic systems. CDOM diminishes light as it penetrates water. This has a limiting effect on photosynthesis and can inhibit the growth of phytoplankton populations, which form the basis of oceanic food chains and are a primary source of atmospheric oxygen. CDOM also absorbs harmful UVA/B radiation, protecting organisms from DNA damage.

The Secchi disk, as created in 1865 by Angelo Secchi, is a plain white, circular disk (30 cm in diameter) used to measure water transparency in bodies of water. The disc is mounted on a pole or line, and lowered slowly down in the water. The depth at which the disk is no longer visible is taken as a measure of the transparency of the water. This measure is known as the Secchi disk depth and is related to water turbidity. Since its invention the disk has also been used in a modified, smaller 20 cm diameter, black and white design to measure freshwater transparency.

3. Methodology

The study analyzed 3 Landsat scenes of the study area acquired in 1989, 2000 and 2009. The images have been collected from the webpage of United States Geological Survey (www.earthexplorer.usgs.gov). These images are taken at four tiles: Path of 137 with Row of 44, Path of 137 with Row of 45, Path of 138 with Row of 44 and Path of 138 with Row of 45, which cover the entire study area. The images represent dry season of Bangladesh as all of them have been captured in the month of January. It is assumed that temporal changes of water bodies remain insignificant over this period.

Properties of the images are presented in Table 1. It should be mentioned that the TM (Thematic Mapper) sensor has a spatial resolution of 30 m for the visible, near-IR, and mid-IR wavelengths and a spatial resolution of 120 m for the thermal-IR band. The ETM+ (Enhanced Thematic Mapper Plus) has spectral bands which are similar to those of TM, except that the thermal band (band 6) has an improved resolution of 60 m. However, all TM/ETM+ images are now resampled to 30 m resolution by the production system.

Table 1: Properties of Landsat satellite images

Image No.	Acquisition Date	Satellite	Sensor	Spatial Resolution (m)
2	January, 1989	Landsat 4	TM	30
3	January, 2000	Landsat 7	ETM+	30
4	January, 2009	Landsat 5	TM	30

The satellite images have been analyzed using ILWIS 3.4 (ILWIS, 2014). An NDVI (Normalized Difference Vegetation Index) map is prepared and the pixels with negative values have been separated and recognized as water. Water bodies other than rivers, estuary and the Bay of Bengal have been removed using polygons. NDVI is calculated on a per-pixel basis as the normalized difference between the red and near infrared bands from an image using equation 1.

$$NDVI = (NIR-RED)/(NIR+RED) \quad \ldots\ldots.(1)$$

There are many algorithms which make correlation with spectral bands and water quality parameters. For example, Brezonic et al. (2005), Zhou et al. (2006) and Schiebe et al. (1992) established several equations to estimate different water quality indices from Landsat imagery analyses. In this study, the water quality indices are assessed by applying the following equations (Eqn. 2-6) selected from those studies based on their given accuracy levels.

$$ln(Chl\text{-}a) = 6.71+(0.0537*band\ 1)-(1.559*(band\ 1/band\ 3)) \quad \ldots\ldots(2)$$

$$ln(CDOM) = 23.65-(0.3528*band\ 1)-(0.657*band\ 2) \quad \ldots\ldots(3)$$

$$ln(SDD) = -2.663-(0.03191*band\ 1)+(1.1030*(band\ 1/band\ 3)) \quad \ldots\ldots(4)$$

$$T_{NTU} = 0.545*Chl\_a \quad \ldots\ldots(5)$$

$$TSM = 92.4-(516*band\ 2)+(135.8*band\ 3)+(955.3*band\ 4) \quad \ldots\ldots(6)$$

4. Results and Discussions

Figure 2 shows the spatial and temporal variations of Chlorophyll-a, Turbidity, Total Suspended Material (TSM), Colored Dissolved Organic Matter (CDOM) and Secchi Disk Depth (SDD) at the study area in 1989, 2000 and 2009. Table 2 represents the mean value of these indices at different years. It has been found that during 1989-2009 both Chlorophyll-a concentration and Turbidity in the study area increased by 7%, whereas, TSM decreased by 30% and CDOM increased by more than 400%. The results indicate that concentration or growth rate of planktons and microorganisms have increased in the study area during 1989-2009 which can be attributed to the increase in water temperature as a result of climate change.

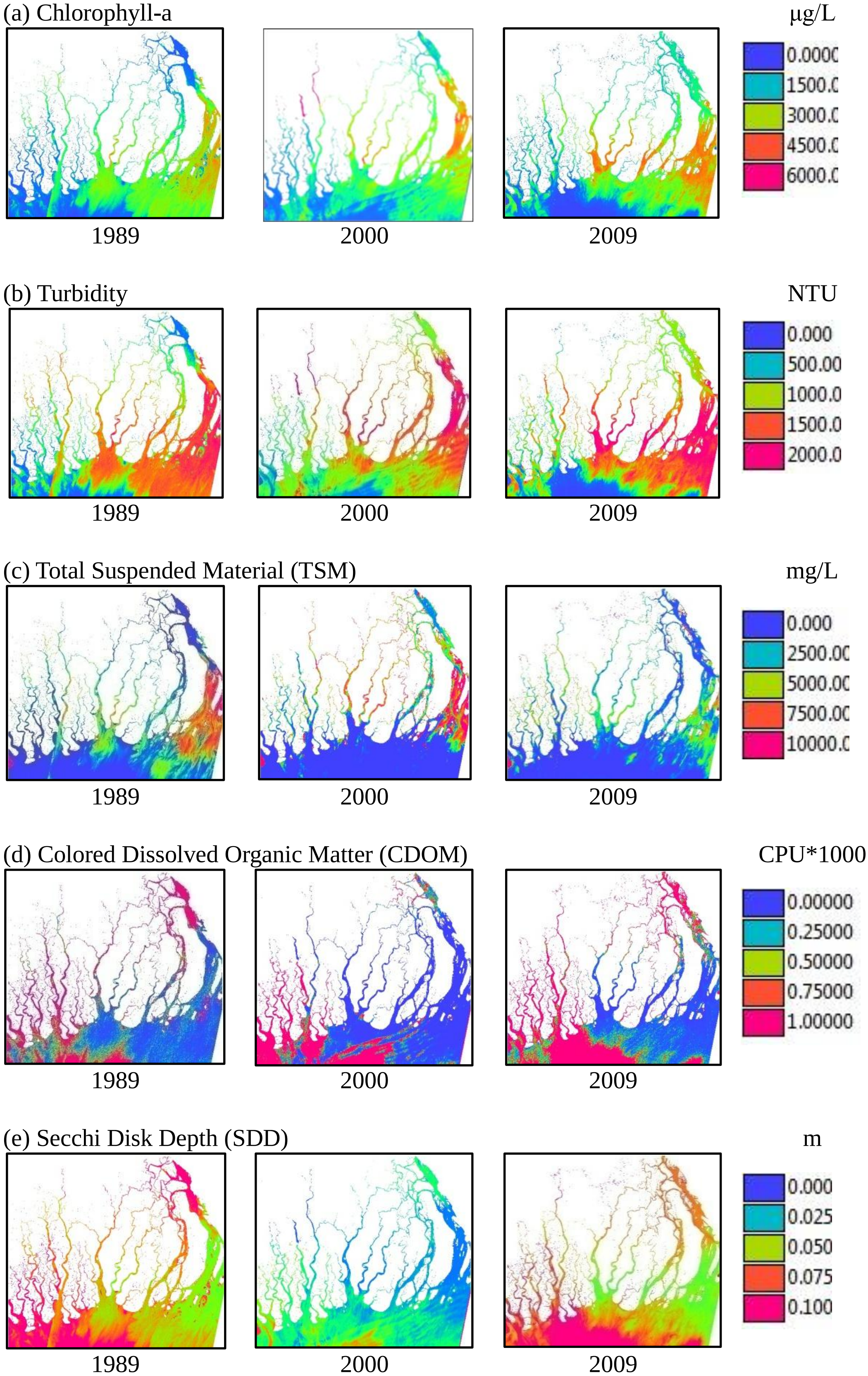

Figure 2: Spatial and Temporal Variations of (a) Chlorophyll-a (b) Turbidity (c) Total Suspended Material (TSM) (d) Colored Dissolved Organic Matter (CDOM) and (e) Secchi Disk Depth (SDD)

Table 2: Temporal Changes in the mean value of Water Quality Indices

Water Quality Index	Unit of Measurement	Mean Value			Change (%)		
		1989	2000	2009	1989-2000	2000-2009	1989-2009
Chl-a	µg/L	1977	2010	2113	2%	5%	7%
T_{NTU}	NTU	1078	1095	1152	2%	5%	7%
TSM	mg/L	2317	1348	1620	-42%	20%	-30%
CDOM	CPU*1000	0.18	0.17	0.94	-6%	453%	422%
SDD	m	0.09	0.06	0.08	-33%	33%	11%

5. Conclusion

The study demonstrated the use of remote sensing techniques in estimating different water quality indices and attempted to relate it to possible climate change impact. Further research works incorporating comparison with ground measurements would help determine the accuracy of such analyses. The results should also be linked to the current climate change scenarios and changes in ecosystem services in order to get a more clear view of the correlations between these variables.

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