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Evaluation and Monitoring of Water Quantity and Quality of the Buriganga River in Bangladesh using Multi-temporal Landsat Images

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***Abstract**: Buriganga River, the study area, is one of the most polluted and decreasing expeditiously its area in Bangladesh due to rapid urbanization, effluents of industries and factories surrounding the river, sewage disposal from Dhaka City and some anthropogenic activities. The objective of this study is to evaluate and monitor the water quantity and quality of the river using satellite remote sensing techniques. Unsupervised and indices based classification were used to derive and monitor landuse-landcover (LULC), surface water distribution (SWD), land surface temperature(LST) and total suspended material (TSM) using four sets of Landsat TM/ETM+/OLI/TIRS images of the study area from 1989 to 2015. The indices are Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). LULC classification results showed that the water bodies and vegetation decreased and consequently urban as well bared area increased from 1989 to 2015. Results of indices (NDVI and NDWI) analysis are similar to that of unsupervised LULC outputs, that is, the water bodies decreased with increasing urban structures of the study area. The surface water distribution monitoring results from the suitable change detection GIS model indicate that the water bodies have decreased about 31.07% and accretion rate increased rapidly from 1989 to 2015 along the river bank due to urbanization and accretion activity is more prominent in north, northeast, northwest, south, southeast and eastern part. The study also shows that the rate of TSM is sporadically increasing during the study period i.e., the maximum and minimum value of TSM was 56215.53 and 1956 mg/l in 1989 and 14188714.35 mg/l and 333942 mg/l in 2015 respectively; this indicates that the water is harmful for aquatic life. Both the analyzed satellite image outcome and in situ observations reveal that land surface temperature is also increased in some part of the study area. The study results could be used to make policy for upgrading the water quality and to maintain the extent and water quantity for agriculture, navigation and fisheries sectors of the Buriganga River.*

***Keywords**: Water quantity and quality, Landsat image, Buriganga River*

Introduction

Buriganga River, one of the most important rivers of Bangladesh in respect to irrigation, fisheries, transportation, recreational uses and so on, which originated from Dholeshwori near Kalatia passing through west and south of Dhaka city, the capital of Bangladesh (Saifullah et al., 2013). Buriganga plays a very ineluctable role for balancing the environment of Dhaka city. Over the decades, the old Buriganga woefully changed its look. Today, the Buriganga River is annihilated anomalously by the insalubrious problem of pollution. It is regarded as one of the polluted parts of the river system of Bangladesh (Sarker et al., 2015). The water of Buriganga River is enduring incessant changes in terms of quantity and quality (Rahman and Hossain, 2008; Ahmed et al., 2011; Saifullah et al., 2013). The diminution of water quality and reduction of water quantity have exasperated at an alarming rate due to soaring of industrialization, urbanization and development activities (Rahman and Hossain, 2008; Ahmed et al., 2011; Saifullah et al., 2013). The residential and commercial establishments along the river cause reduction of water quantity. Increasing of temperature day by day is also amenable for plummeting the water quantity. As a result of urbanization, the quantity of water has been decreased so rapidly that constitutes a great menace to local people in Buriganga River as well as to the people of Dhaka city. River erosion and accretion is a natural phenomenon in Buriganga River which is also amenable for decreasing water quantity. As most of the industries and factories vigorously textile and garments-cum dying factories situated on the banks of the Buriganga or very close to the river system without dictating waste treatment units during the past decenniums, heavy loads of these venomous industrial wastes are transmitted into the river. The urban sewage of the Dhaka city is also heaving in the Buriganga River.

Buriganga River receives millions of liter of sewage, domestic waste, industrial, tannery and agricultural effluents (Ahmed et al., 2011). Thousands of industrial units and sewerage lines dumping huge volumes of toxic wastes into Buriganga River increasingly polluting the water (Isalm et al., 2006). These changes in water quality by industrial effluents, agricultural pollution and human waste are creating the environment unfavorable for aquatic lives and ecological imbalances (Ali et al., 2008). So, prodigious amount of effluents and solid wastes are annexed with the river water and sediments. Every day more than 60,000 cubic meters (2,100,000 cu ft) of toxic waste, regarding textile dying, printing, washing and pharmaceuticals, are discharged into the main water bodies of Dhaka according to the DOE (Department of the Environment)(Wikipedia 2016).About 12,000 cubic meters (420,000 cu ft) of untreated waste are released into the lake from Tejgaon, Badda and Mohakhali industrial areas every day according to the WASA (Dhaka Water and Sewerage Authority) (Wikipedia 2016).It requires spatial analysis to monitor water quantity and quality to stop loss of water bodies and improve degraded quality of the Buriganga river water continuously. There is not spatial study of water quality and quantity of the Buriganga River using multi-temporal satellite images. Landsat satellite imageries has a long history of spatial analysis of river water quantity and quality of river in the world (Frazier and Page, 2000; Mia et al., 2008; Mia et al., 2014). This study has been done with the processing and interpretation of satellite images of Buriganga River for a period of 26 years and collecting water samples from different locations through field work. One of the prime objective of this study is to investigate and monitor the water quantity of the Buriganga River using multi-spectral Landsat satellite images from 1989 to 2015. The other target is to assess the qualitative parameter of Buriganga River water with support of ground in situ data using 4 sets of multi-satellite images from 1989 to 2015.

Study Area

The Buriganga River flows past the southwest outskirts of Dhaka city, the capital of Bangladesh. Its average depth is 7.6 m (25 ft) and its maximum depth is 18 meter (58 ft), length is 18 km (11 miles) (Wikipedia, 2016). The Buriganga River encompasses the south-western periphery of Dhaka City (Islam, 2005). In the distant past, a course of the Ganges River used to reach the Bay of Bengal through the Dhaleshwari River. When this course gradually shifted and ultimately lost its link with the main channel of the Ganges it was renamed as the Buriganga. The main flow of the Buriganga River comes from the Turag River. The area is surrounded by the residential areas on all of its sides. The study area comprises an area of 1411.47 Hectares. The study area lies between 90°20'09.46"E to 90°26'59.14"E in longitude and 23°37'36.22"N to 23°47'08.27"N in latitude (Figure 1).

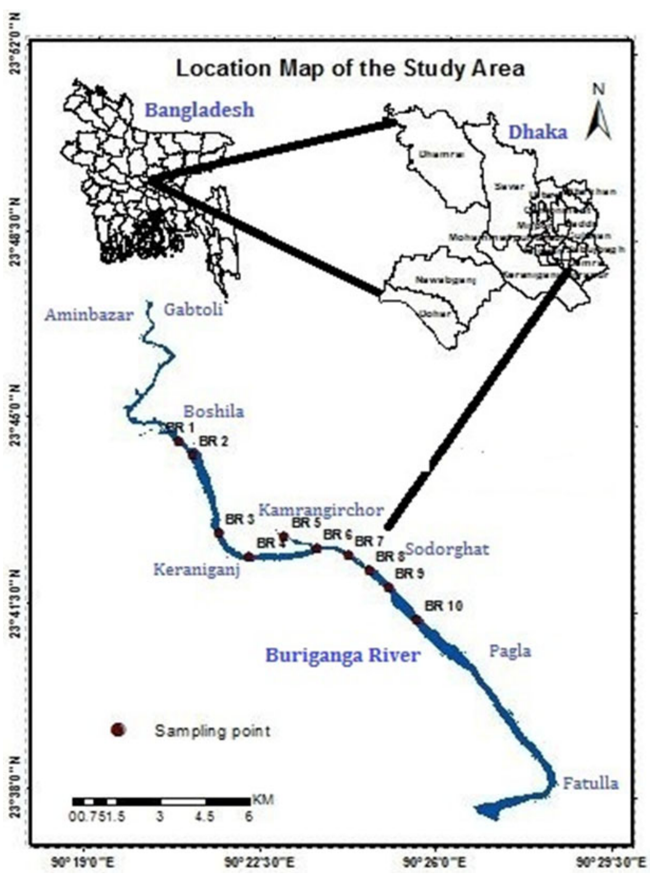

Figure 1: Location of the Study Area

Materials and Methods

Four set of Landsat satellite images from 1989 to 2015 were used for this study i.e., Landsat TM images of February 13, 1989 and February 15, 2010, Landsat

ETM+ image of February 28, 2000 and Landsat 8 OLI/TIRS image of January 28, 2015. The quantitative approaches for the study were to estimate surface water bodies using satellite images based image classification, vegetation and water indices, while the qualitative approaches includes surface water temperature, water samples analysis in laboratory as in the flow chart (Figure 2). After retrieving the water bodies quantitatively using the mentioned three approaches, a change detection model of GIS was applied to monitor the changes of surface water bodies within the Buriganga River from 1989 to 2015 (Mia et al., 2014).

Three classification approaches were used to estimate the quantity or coverage area of water bodies of the Buriganga River from 1989 to 2015 using the four sets of Landsat satellite images such as unsupervised classification, normalized vegetation indices (NDVI) and normalized water indices (NDWI). ISODATA algorithm of unsupervised classification was applied for the landuse-landcover (LULC) map of four classes such as water, urban, vegetation and bared area from the study area of the respective years of study i.e., 1989, 2000, 2010 and 2015. NDVI is an approach for enhancing the near infrared band where the vegetation have maximum value of reflectance. It is a ratio of red and near infrared band of satellite image, ranges +1 to -1, where higher value indicates vegetation and lower value water or bared region of the ground. NDVI can be calculated from the following equation (Rouse et al., 1974).

$$NDVI = (\rho_{nir} - \rho_r) / (\rho_{nir} + \rho_r) \quad (1)$$

Where, ρ_{nir} and ρ_r are the reflectance of near infrared and red band of the Landsat image. Healthy vegetated region shows higher value of NDVI above 0.5, urban region shows as 0.2 to 0.5 and bared region shows lower value less than 0.2 to 0, and water bodies' shows negative value of NDVI.

NDWI is a spectral rationing technique used to evaluate the water bodies or water content of leaves using near infrared and short wave infrared region of electromagnetic range of the remote sensing (Gao, 1996). NDWI is widely used as for water content, wetland mapping and environmental change monitoring (Gao, 1996; Ouma and Tateishi, 2006). It ranges from +1 to -1. NDWI can be defined as follows:

$$NDWI = (\rho_{nir} - \rho_{swir}) / (\rho_{nir} + \rho_{swir}) \quad (2)$$

Where, ρ_{nir} and ρ_{swir} are the reflectance of the near infrared and short wave infrared bands of the Landsat images. Positive value of NDWI indicates water content or bodies and negative value indicates ground or land of the study area.

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. An equation was to estimate TSM from Landsat imagery analysis established by the following equation (Brezonik et al., 2005; Zhou et al., 2006; Schiebe et al., 1992).

$$TSM\ (mg/l) = 92.4 - (516*band\ 2) + (135.8*band\ 3) + (955.3*band4) \quad (3)$$

Surface water temperature is one of the important qualitative parameter for the ecosystem of the Buriganga River. The effluent from surrounding industries, air temperature, ground water, upstream surface water flow, turbidity and solar radiation are the components of maintaining the temperature of the surface water bodies in this river. Landsat thermal infrared data used in this study to estimate surface water temperature of the Buriganga River using effective satellite sensor or brightness temperature techniques by the following equation (Mia et al., 2017).

$$L_\lambda = (Lmax_\lambda - Lmin_\lambda) / (Qcal_{max} - Qcal_{min}) * (Qcal - Qcal_{min}) + Lmin_\lambda \quad (4)$$

$$T_b = K_2 / \ln((K_1/L_\lambda) + 1) \quad (5)$$

Where, L_λ= Spectral radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$), $Lmax_\lambda$=maximum radiance value of the corresponding bands, $Lmin_\lambda$=Minimum radiance values of the corresponding bands, $Qcal_{max}$ = Quantized calibrated maximum value of the corresponding bands, $Qcal_{min}$= Quantized calibrated minimum value of the corresponding bands, $Qcal$ =Quantized calibrated value of the band which is expected to be converted into radiance value, K_1= First calibration constant ($Wm^{-2}sr^{-1}$), K_2= Second calibration constant (K), T_b = Effective at satellite temperature (K). All these parameters were taken from the metadata of each Landat images.

Field verification process was done with an extensive field work of 10 sample points within the study area with sophisticated instruments such as handheld GPS, HANNA Pocket pH and thermometer. Field works were conducted for the in situ water quality parameters and finally graphs were prepared and some of the parameters were spatially mapped using ArcGIS software (Figure 2).

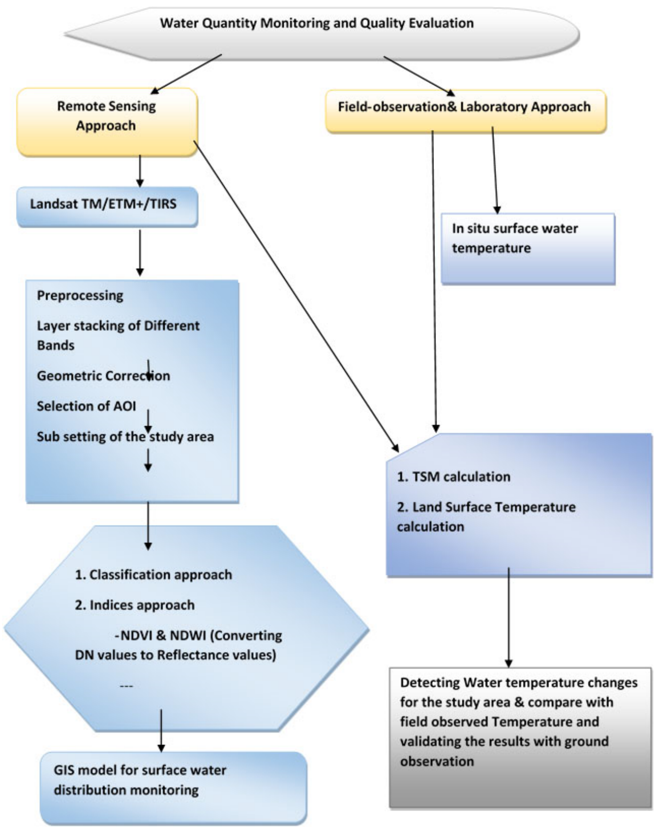

Figure 2: Flow Chart of the Study

Results and Discussion

Four sets of Landsat images were classified using unsupervised classification method into four landuse-landcover (LULC) types such as water body, mixed land, urban and bared region of the study area in the year of 1989, 2000, 2010 and 2015(Figure 3). Unsupervised classification has been quite successful in identifying the water bodies over the study area. From the derived LULC map, the spatial and temporal change of water body over this area has been detected. The area coverage of water bodies are about 48.88% (685.26 ha), 43.02% (607.23 ha), (40.5% (571.41ha) and 38.85% (548.28 ha) respectively in the year of 1989, 2000, 2010 and 2015, (Figure 6A). The total decrease of water bodies is about 10% (136.98 ha) of the study area over the period. Considering the growth of urban areas, the changes were very significant and had a positive correlation between the urban growth and water body reduction has been identified (Figure 6A). Towards southeast and surrounding areas have lost significant amount of water body. Towards northeast, southwest and surrounding areas, water bodies have been lost significantly due to real estate development going on for housing. The densely populated areas of old part of the city has also expanded rapidly and engulfed some part of the Buriganga river over the study period (Figure 3). A rapid degradation of vegetated lands was detected in the study area over those years (Figure 3). The areas covering vegetation were 25.47% (359.55 ha), 19.65% (277.56 ha), 17% (239.76 ha) and 13.03% (183.87 ha) of the study area respectively in 1989, 2000, 2010 and 2015 (Figure 6A). Total loss of vegetation is about 175.68 ha or 48.86% over 26 years of this study due to different housing projects have been extended on these areas (Figure 6A). The identified urban structured areas were 23.08% (325.8 ha), 28.58% (403.38 ha), 34.9% (476.46 ha), 38.62% (545.04 ha) of the total study area in the year of 1989, 2000, 2010 and 2015 respectively (Figure 3; Figure 6A). The increasing rate of urbanization is responsible for the degradation of water bodies and vegetation in and around the Buriganga River. The urban area has increased about 219.24 ha or 67.3% over the study period in the Buriganga river. It has been also identified that the urban growth was in the Southwest part of the river as industrialization in 1989, and then, the urban growth has been expanded towards North and South of the Buriganga River. In 2015, the urbanization has been reached to the furthest Northern part of the Buriganga River with development of many industries. The identified bared areas were 40.86 ha, 123.3 ha, 116.73 ha, 134.28 ha respectively which were 2.90%, 8.75%, 8.3% and 9.51% of the study area (Figure 3; Figure 6A). Bared area is increasing because of destruction of cultivable or vegetated land for construction urban structure and industries. The area is increasing more towards northern part of the study area.

Two indices such as NDVI and NDWI were used to classify the major landcovers (LC) of the study area using four sets of Landsat images from 1989 to 2015. The purpose of NDVI calculation was to identify the vegetation cover changes over the study area. NDVI mapping was successful in identifying the “greenery” or vegetation over the study area. Three types of LC such as water body (NDVI<0), mixed land and urban area (NDVI =0-0.5), vegetation (NDVI>0.5) were demarcated using NDVI method (Figure 4). From the

NDVI analysis, a gradual decrease of vegetation cover has been observed from the year of 1989 to 2000. Vegetation coverage was about 5.57% (78.57 ha), 1.51% (21.15 ha), 2.04% (28.71 ha) and 2.34% (33.038 ha) of the total study area respectively in the year of 1989, 2000, 2010 and 2015 (Figure 4). The water body coverage also decreased about 22.48% (203.14 ha) of the study area (Figure 6B). On the other hand, the mixed land and urban area increased rapidly about 57.96% (248.77 ha) of the study area during the studied 26 years from 1989 to 2015 (Figure 6B).

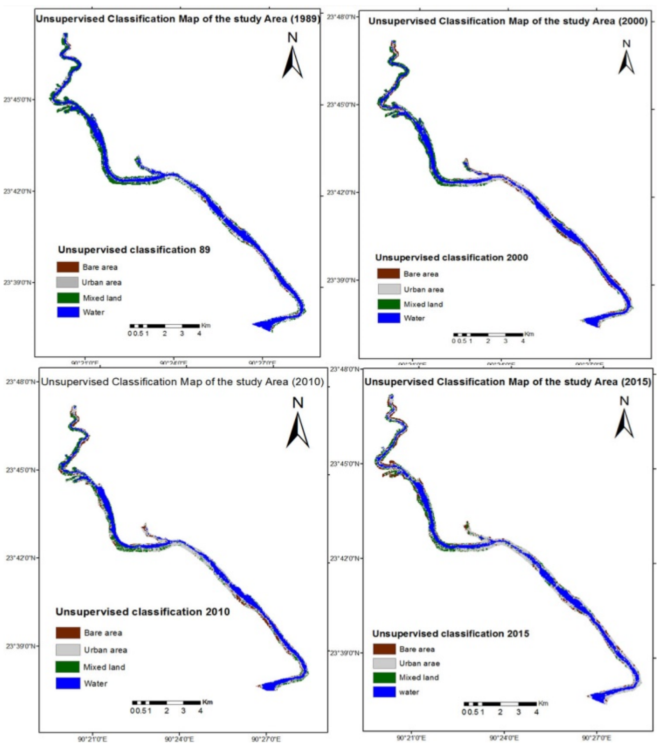

Figure 3: Landuse-landcover of the Study Area, Prepared Using Landsat Images With the Unsupervised Classification Method from 1989 to 2015

NDWI method was used to identify LCs as Land (NDWI < 0) & Water body (NDWI >0). From the NDWI analysis, it has been identified that the area of water bodies were about 58.97% (832.32 ha), 50.07% (706.77 ha), 48.57% (658.53 ha) and 45.44% (641.23 ha) of the total study area in the year of 1989, 2000, 2010 and 2015 respectively (Figure 5). So, a gradual decrease of water body has been observed from the year of 1989 to 2015. The decrease of the water body during the four years was supposed to cause by the rapid urbanization. The change of water body is about 191.09 ha (22.96%) from the year of 1989 to 2015 and the rate of decrease is 7.40 ha per year (Figure 6C). In considering the areal coverage of water body towards central, north, southwest and southeast have been decreased due to urbanization. The land coverage area has been increased about 198 ha and percentage of increase is 34% and rate of increase is 7.62 ha from 1989 to 2015 within the study area (Figure 5). Overall, the results showed that the water body is decreasing in all classification approaches and the trend is quite similar in all classification (Figure 6D). Due to rapid urbanization, the area coverage of water is decreasing day by day and the reduction of area is about 177.07 ha, the percentage of reduction is 21.8% and the reduction rate per year is 6.83 ha on an average from the three classifications (Figure 6). It seems that different housing projects have been extended surrounding the Buriganag River. This kind of unplanned urbanization has greatly degraded the living condition. As a result, the river is dying one.

Monitoring of surface water bodies of the study area indicates the distributional change of water bodies within the river from 1989 to 2015 using the GIS change detection. Erosion-accretion along riverbanks is the major cause of distributional changes in surface water distribution in the study area (Figure 7). Conditional change detection GIS model based surface water body distributional change have been monitored from 1989 to 2015 using four satellite images in this study area by ERDAS Imagine 9.1 software (Mia et al., 2008).

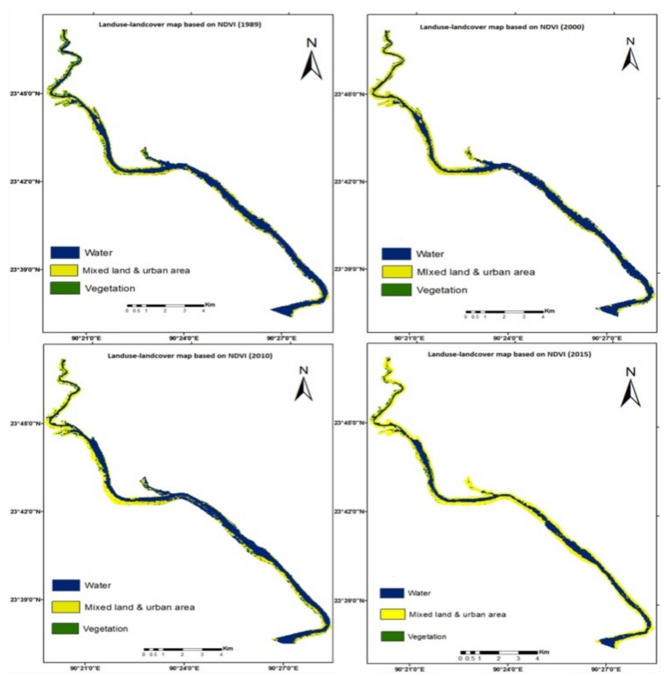

Figure 4: Landcover Map the Study Area Prepared Using NDVI Indices from 1989 to 2015

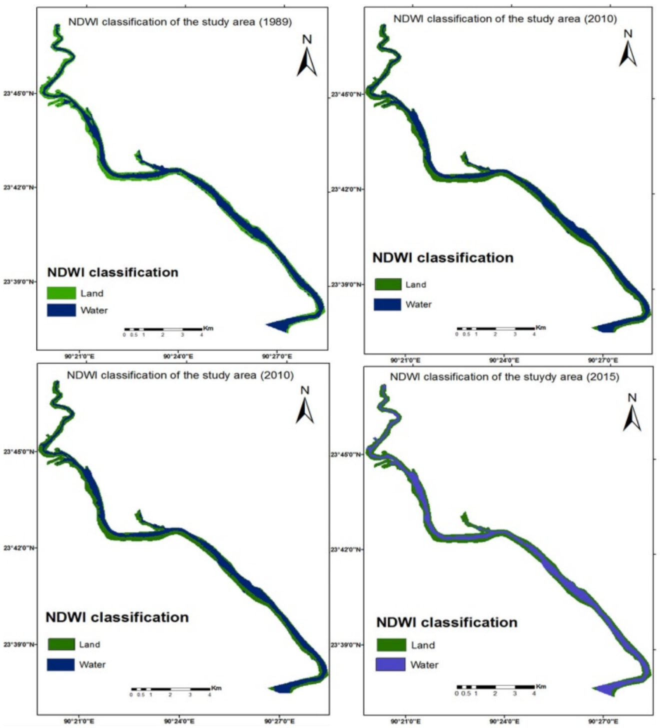

Figure 5: NDWI Based Landcover Classification of the Study Area from 1989 to 2015

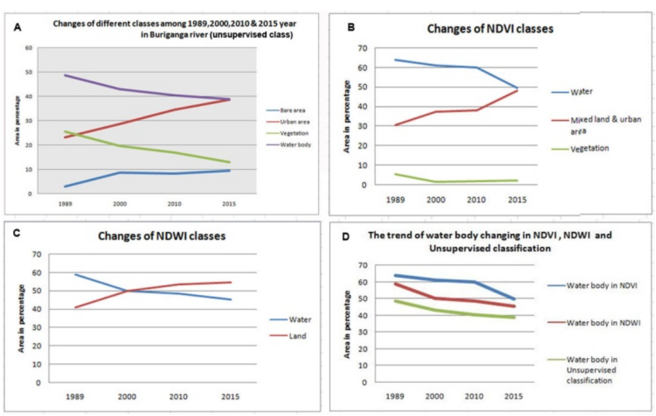

Figure 6: Compares the Area of Landcover Classes of the Study. Area of Unsupervised Classes Shown in 'A', NDVI in 'B' and NDWI in 'C'. Water Bodies changes With Time from 1989 to 2015 shown in 'D'

Water body distributional change map between 1989 and 2000 shows that the area covered by water bodies between these two years occupied about 540.09 hectares (about 72.75%) of the study area (Figure 7A, 7E). The total water covered areas at 1989 were about 685.26 hectares, of them, about 145.17 hectares area was accreted as land or riverbank at 2000 of this study area (Figure 7E). The total water covered areas at 2000 was about 607.23 hectares, of them, about 57.14 hectares area was land or riverbank at 1989 (Figure 7A, 7E). Accretion activities from 1989 to 2000 were more than erosion in the study area (Figure 7A). Total 7.70% of the study area was eroded and 19.55% area accreted from 1989 to 2000. Erosion activities were dominated at the northwest and accretion phenomenon were found at the northwest, southeast and eastern part of that study area from 1989 to 2000 probably due to rapid urbanization and construction and increasing of land surface temperature (Figure 7A, 7E).

Study of the water body distributional change map between 1989 and 2010 shows that the area covered by water bodies between these two years occupies about 465.03 hectares (about 58.74%) of the study area (Figure 7B). The total water covered areas were about 685.26 hectares at 1989, of them, about 220.03 hectares area was accreted as land or riverbank at 2010 of this study area (Figure 7F). The total water covered areas at 2010 was about 571.41 hectares of these about 106.38 hectares area was land or riverbank at 1989. Accretion activities from 1989 to 2010 were more than erosion in the study area (Figure 7B, 7F). Total 13.44% of the study area was eroded and 27.82% area accreted from 1989 to 2010. Erosion activities were found at the northwest , eastern part and accretion phenomenon were dominated at the north, northwest, west, southwest, southeast and eastern part of that study area from 1989 to 2010 probably due to rapid urbanization and construction and drying up of river for increasing of land surface temperature (Figure 7B, 7F).

Finally, the result shows from the water body distributional change map between 1989 and 2015, that the area covered by water between these two years occupies about 453.03 hectares (about 60.61%) of the study area (Figure 7C). The total water covered areas were about 685.26 hectares in 1989, of them, about 232.23 hectares area was accreted as land or riverbank at 2015 of this study area (Figure 7G). The total water covered areas at 2015 was about 548.28 hectares of these about 62.19 hectares area was land or riverbank at 1989. Accretion activities from 1989 to 2015 were more than erosion in the study area (Figure 7C, 7G). Total 8.32% of the study area was eroded and 31.07% area accreted from 1989 to 2015. Erosion activities were found at the northwest , southwest part and accretion phenomenon were dominated at the north, northwest, northeast, south, southeast and eastern part of that study area from 1989 to 2015 probably due to rapid urbanization and construction and drying up of river for increasing of land surface temperature (Figure 7C).

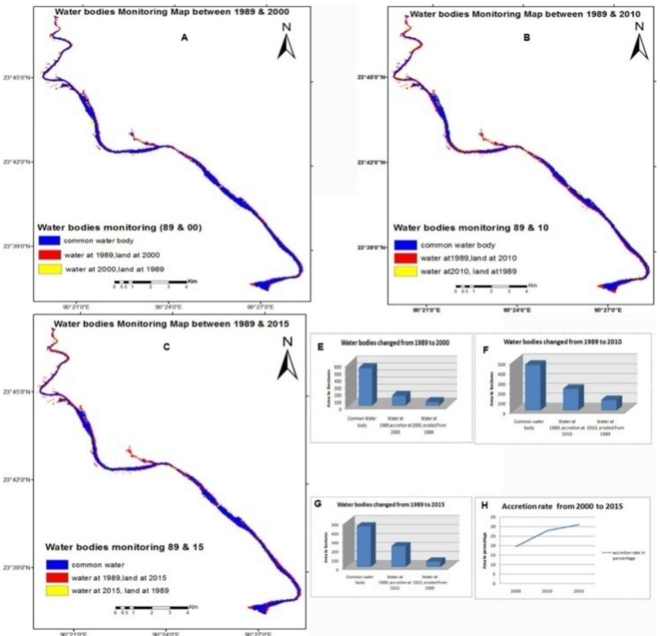

Figure 7: Surface water changes monitoring with land erosion-accretion along the bank of the Buriganga River from 1989 to 2015

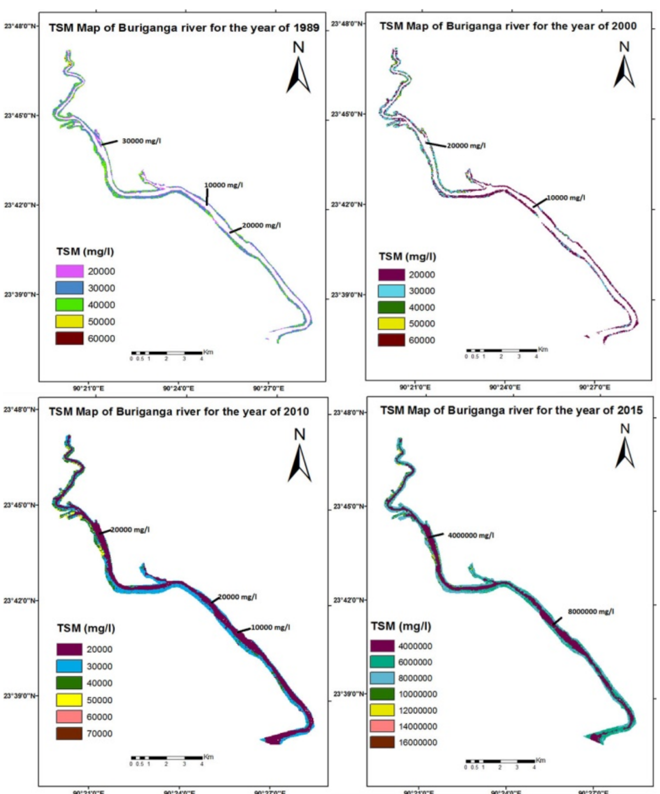

Figure 8: Total Suspended Materials of the Buriganga River, Prepared Using Landsat Images from 1989 to 2015

In case of water quality, two methods were applied in this study - one for total suspended materials (TSM) and another for land surface temperature (LST) using four sets of Landsat images in the year of 1989, 2000, 2010 and 2015. The maximum TSM values obtained from the Buriganga River water were about 56215.91 mg/l, 56278.53mg/l, 65480.18mg/l, and 14188714.35mg/l and the minimum ones were about 1956mg/l, 3682mg/l, 10650mg/l, and 333942mg/l respectively in the year of 1989, 2000, 2010 and 2015 (Figure 8). Number of tanneries and textile industries very close to the Buriganga discharge substantial amount of industrial wastes , raw organic substances and heavy metals into the river that increases the amount of silt and suspended materials. As TSM levels increase, light penetration decreases adversely affecting photosynthesis by primary producers. As a result, clog fish gills, either killing them or reducing their growth rate. In Bangladesh the TSS standard of Tannery and textile effluents are 150 mg/l. The study shows that the obtained TSM value much higher that is harmful for aquatic life in the river and it is deteriorating the water quality.

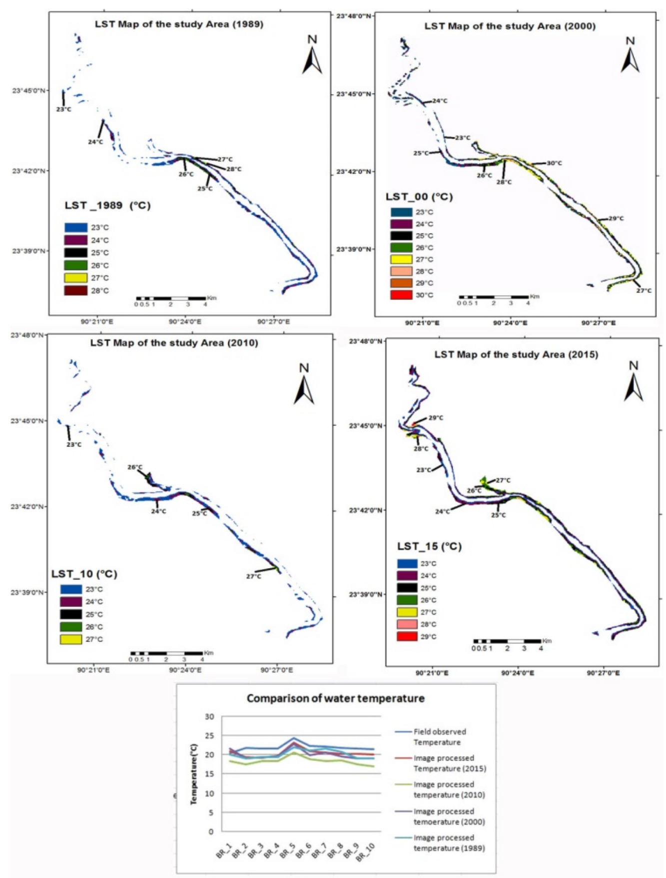

Figure 9: Land Surface Temperature of the Study Area from 1989 to 2015. Compares of Image Derived LST and In Situ Surface Temperature of the Study

LST was estimated using the thermal band of Landsat images of the study area in the year of 1989, 2000, 2010 and 2015 (Fig. 9). The highest LST was

28°C,30°C,27°C and 29°C, and lowest LST about 17°C, 20°C, 18°C, and20°C respectively in 1989, 2000, 2010 and 2015 of the study area. The highest temperature covered area of 0.09 hectares was observed towards eastern part near to Sodorghat port of the study areas as it is urban region in 1989. The highest temperature covered an area of 2.79 hectares has been observed towards Northeast, northwest part near to Sodorghat, Kamrangirchor, Zinzira in 2000. The highest temperature covered an area of 1.53 hectares observed towards southwest near to Bashundhara city road in 2010. The highest temperature covered an area of 3.33 hectares found towards northeast near to Boshila road. Water temperature is an important parameter in assessing the water environment. The water temperature plays a profound impact on the chemical, physiochemical characteristics of water body. Water samples were collected from 10 locations and measured temperature of each water samples. Here field measured values were tried to compare with all satellite images for the year of 2015, 2010, 2000 and 1989 on that same points (Figure 9). From the graph it is found that the in situ water temperature was highest (24.4°C) in 2016 near to Kamrangirchor Bridge and lowest (17.01°C) in 2010 near to Postogola Bridge. In 2010, the temperature was much lower than other years due to meterological fact, less solar radiation, less cooling operations for manufacturing of products using Buriganga's water and error of image processing. But in other years the results are different. From the study it is observed that temperature is increasing day by day. According to EQS (1997) the standard temperature of fisheries for Bangladesh is 25°C. The highest water temperature (24.4°C) observed from field in 2016 indicates that temperature values are in range for fisheries. The reason of higher temperature in Buriganga River is a result of meteorological fact and solar radiation. Beside this, there are many mills and factories constructed in the both bank of Buriganga River and use Buriganga's water for the cooling purposes in different steps of manufacturing of their products. After cooling operations, they are draining out their effluents into the Buriganga River which increases the Temperature. The water of Buriganga River was dark in color and turbid. More heat content captured by turbid water than clean water which is another reason of increasing temperature .So day by day the temperature is increasing. We also know that cool water is generally more palatable than warm water and temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth of micro-organisms and may increase problems related to taste, odor, color and corrosion.

Conclusion

The Buriganga River is the main river flowing beside Dhaka, the capital of Bangladesh. City dwellers largely depend on the Buriganga's water for drinking, fishing and carrying merchandise. The effect of changing of water quantity and quality is more vulnerable in overpopulated Dhaka and Narayanganj areas. The landuse-landcover characteristics of the study area have not been studied using satellite images in the past. Detail land use-land cover map prepared using satellite image could be an important prerequisite for the development of infrastructure and socio-economic growth of a nation. The study has been successful in identifying the landuse-landcover especially the water body and urban area. Three classification approaches were used for mapping the study area for the year of 1989, 2000, 2010 and 2015 and from these three classes it is depicted that the water body is decreasing day by day. The average reduction area of the water body is 177.07 hectares from1989 to 2015 and the percentage is 21.8% and the rate of reduction per year is 6.83 hectares. By change detection model it is found that erosion-accretion activities are prominent in the study area especially accretion towards north, northwest, northeast, south, southeast and eastern part of Buriganga river due to rapid urbanization and construction. Total suspended materials increased alarmingly over the study period in the Buriganga River. We also observed increased LST both from satellite image analysis result and field in situ data. This study indicates that the water of Buriganga is decreasing rapidly day by day and the quantity is deteriorating from its surrounding point and non-point sources which include discharges from tannery industries, sewage and municipal wastewater. Identification of water bodies and detection the changes of distribution of water bodies of this study area using satellite images would be useful to quantify the water bodies which can be helpful for the city dwellers and the policy makers and also utilized toward proper planning and sustainable development of agriculture, fisheries and navigation in this area.

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