WATER BODIES DELINEATION AND CHANGE DETECTION USING GIS AND REMOTE SENSING WITH MULTITEMPORAL LANDSAT IMAGERY: A CASE STUDY OF TANGUAR HAOR

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Abstract: Tanguar haor, the largest haor of Bangladesh, is situated in Sunamganj district declared as an ecologically critical area in 1999. Nevertheless, the haor has been in a critical situation, decreasing wetland biodiversity in the recent years due to decreasing surface water in the winter seasons. This study aimed to model the spatiotemporal changes of Tanguar haor in the period from 1989 to 2017 using multitemporal Landsat 4-5 TM and Landsat 8-OLI images. In this context, different satellite-derived indices were tested including Normalized Difference Water Index (NDWI), Modified NDWI (MNDWI), Normalized Difference Moisture Index (NDMI), Water Ratio Index (WRI) and Normalized Difference Vegetation Index (NDVI) to extract surface water, but finally, NDWI has been applied to delineate and extract water surface of Tanguar haor. The NDWI is calculated from the different reflectance of water in the two channels of satellite images, channel green and channel near infrared and the equation of NDWI is (GREEN - NIR/GREEN + NIR). Using the mentioned index the water bodies’ change was detected. In the other hands, through change detection authority can take precautionary measures to protect the probable vulnerability of the outcomes. Similarly, Haor authority can take measures to protect the haor bodies that can help to protect wetland biodiversity. The study shows that about 14 percent water surface decreased between 1989 and 1999, 11 percent decreased between 1999 and 2009, 15 percent decreased between 2009 and 2017 and total 41 percent water surface decreased between the period 1989 to 2017 in Tanguar haor.

Keywords: Multitemporal, Spatiotemporal, GIS, Remote Sensing, Modeling, NDWI, MNDWI, NDMI, WRI and NDVI

INTRODUCTION

Bangladesh is a country of the river, lake, wetland, haor, baor, jheel, and beel. Among the totals the haor type wetland ecosystem in Bangladesh is 1.99 million hectares. This accommodated about 19.37 million people (GOB, 2012). There are about 373 haors located in the districts of Sunamganj, Habiganj, Netrakona, Kishoreganj, Sylhet, Maulvibazar and Brahmanbaria. They cover about 859,000 hectares of land, which is

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around 43 percent of the total haor areas. The haors have long been lagged from the mainstream society in respect of economic and social factors. Gradually haors areas have shifted to other activities or have become illegal possession is a common scenario in various areas. The exploitation of the haor ecosystem began due to over expanding the agrarian settlement. Therefore, the government formulated a master plan in 2012 to protect haor land (GOB, 2012). Total biodiversity of the haor areas is now at risk. There has no or little bit research on haor area spatial and temporal change in the last years. Therefore, the changes of haor land should be studied using GIS and remote sensing, especially the Tanguar haor, which is a very important haor of Bangladesh.

AIMS AND OBJECTIVES OF THE STUDY
The study aims at extracting and delineating water bodies and estimating changes during 1989 to 2017 in the winter season using GIS and remote sensing with multi-temporal Landsat data in the Tanguar haor of Sunamganj, Bangladesh. Different surface water extraction techniques were examined and the most suitable technique, NDWI, was used to detect and delineate spatiotemporal changes. The detail objectives are given below:

- To detect and delineate water feature in the Tanguar haor.
- To identify and detect the change of water surface in Tanguar haor.

STUDY AREA
Tanguar haor, located in the Dharmapasha and Tahirpur upazilas of Sunamganj District in Bangladesh, is a unique wetland ecosystem which lies in the Northeastern part of the country between 25°05’35.41”N to 25°11’46.03”N latitude and 90°58’46.36”E to 91°11’05.53”E longitude (Figure 1). There are two spatial boundaries of Tanguar haor, one is assigned by the district administrator and another is assigned by the IUCN and CNRS. In this study the boundary of district administrator has considered as a study area.

According to the Digital Elevation Model (DEM), the range of the Tanguar haor elevation is -02 meters to 16 meters (Figure 2). The mean elevation of the Tanguar haor is 3.96 meters. The contour information shows that there are six types of contour in the study area respectively 0, 3, 6, 9, 12 and 15 meters. The central area of the haor is low land and the height is gradually increasing to the northern and east-southern part of the basin. A large area of the haor is under contour height 0 to 3 meters, those are basically wetland. A substantial portion of the area is under contour height 3 to 6 meters and rest tiny area, those are ordering as above 6 meters (Figure 2). Tanguar is nationally very important due to overexploitation of its natural resources. Recently, it has come into international focus through its ecological condition.
According to secondary information and other literature, there are total 46 villages within the haor area. The area of Tanguar haor is almost 50 km\(^2\) of which, about 2802 hectares are wetland. The Tanguar haor, the northeastern region of the country is characterized by highest rainfall and relatively low temperature compared to the annual average of the country. The average annual rainfall in the region is about 4130 mm which is almost double of the country average. Therefore, in the rainy season the haor area covers maximum water surface and in the winter the water surface decreases to the minimum level. Gradually water surface is decreasing in the winter; as a result, haor biodiversity is under serious threat. The haor has the source of earning for more than 40,000 people. The haor basin plays an important role in the economy through its commercial and ecological importance for its fisheries (Salauddin and Islam, 2011). In 1999, the government of Bangladesh has declared Tanguar haor as an ecologically critical area. Later in 2000, the haor basin was declared a Ramsar site as a wetland of international importance. Through this declaration, the government of Bangladesh is bound to preserve its natural resources, therefore, the government has taken several initiatives to protect this haor, and one of them is the formulation of its master plan.
METHODOLOGY AND MATERIALS

Initially, the problem was understood through literature reviewing and formulated research questions. The aim of the study is to detect and delineate water features changes from 1989 to 2017 of the Tanguar haor. To meet the aims and objectives, the following tasks were performed: Firstly, Landsat satellite data were collected from Landsat 4-5 TM and Landsat 8 OLI-TIRS sensors of USGS GloVis (Figure 3). Table 1, presents the specifications of the Landsat images.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Path/Row</th>
<th>Year/Date</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 4-5</td>
<td>TM</td>
<td>137/43</td>
<td>9 March 1989</td>
<td>30M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5 March 1999</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28 February 2009</td>
<td></td>
</tr>
<tr>
<td>Landsat 8</td>
<td>OLI-TIRS</td>
<td>137/43</td>
<td>18 February 2017</td>
<td></td>
</tr>
</tbody>
</table>

Secondly, collected data were extracted and then image layer were stacked using Erdas Imagine 2014. Thirdly, image preprocessing function radiometric correction like haze reduction, noise reduction and histogram equalization has been performed using Erdas Imagine 2014.
Fourthly, area of interest, the collected base map of Tanguar haor according to district administrator (study area) was extracted from the images. There are several multi-band techniques were used in water extraction purpose, these are NDWI, MNDWI, NDMI, NDVI, WRI, and AWEI. The Normalized Difference Water Index (NDWI) was developed to extract water features from Landsat imagery (McFeeters, 1996). The NDWI is expressed as follows, \( \text{NDWI} = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}} \), Where Green is a green band such as TM band 2, and NIR is a near infrared band such as TM band 4. In 2006, Xu proposed modified NDWI through substituting MIR band for the NIR band (Xu, 2006). The modified NDWI can be expressed as follows, \( \text{MNDWI} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}} \), where MIR is a middle infrared band such as TM band 5. It is referred to that Gao (1996) also named an NDWI for remote sensing but used a different band composite, \( \text{NDWIGao} = \frac{\text{NIR} - \text{MIR}}{\text{NIR} + \text{MIR}} \). Wilson et al. (2002) proposed a Normalized Difference Moisture Index (NDMI), which had an identical band composite with Gao’s NDWI. In addition, Normalized Difference Vegetation Index, NDVI (Rouse, et al., 1973), Water Ratio Index, \( \text{WRI} = \frac{(\text{Green} + \text{Red})}{(\text{NIR} + \text{MIR})} \) (Shen and Li, 2010) and Automated Water Extraction Index, \( \text{AWEI} = 4 \times (\text{Green} - \text{MIR}) - (0.25 \times \text{NIR} + 2.75 \times \text{SWIR}) \) (Feyisa et al., 2014) were used in the surface water extraction and change detection.
Finally, images were analyzed in ArcGIS Image Analysis and Erdas Imagine. In this respect, the NDWI\textsubscript{McFettr} were calculated from Landsat 4-5 TM (1989, 1999, and 2009) and Landsat 8 OLI (2017) images to delineate and extraction of surface water of Tanguar haor. In order so, water features were extracted through using ArcGIS raster calculator and also using Erdas Imagine model maker conditional (Figure 4). Then accuracy assessment was performed using image and other high resolution platform.

![Flow chart of research methodology](image)

**Figure 4: Flow chart of research methodology**

**Results and Discussions**

Different satellite-derived indices together with NDWI, NDVI, MNDWI, NDMI, WRI and AWEI were tested to extract water surface from Landsat 4-5 TM and Landsat 8 OLI-TIRS in the Tanguar haor for the years 1989, 1999, 2009 and 2017. The absolute errors, overall accuracy and Kappa coefficient were examined to assess the accuracy of the calculated results. According to different examinations the results shows that NDVI, MNDWI, NDMI, WRI and AWEI were inapplicable to surface water delineatein the Taguar haor because of omission/commission of water pixels around the Haor areas.
The examinations show that only NDWI_{McFeeter} has provided highest accuracy to delineate surface water in the Tanguar haor, therefore, accuracy to delineate surface water in the Tanguar haor, therefore, NDWI_{McFeeter} is used to calculate and model the spatiotemporal changes of surface water in the haor area.

At present NDWI is widely used to delineate water surface and spectral change of water. The results of NDWI are shown in the table 2 and figure 5. The NDWI_{McFeeter} reflectance result is \pm 1, which has been counted as pixel. Like NDVI, the negative values of NDWI_{McFeeter} shows up water reflectance. The land-water threshold has been identified through using NDWI and CIR (Color Infrared) images in Erdas Imagine Link Views with Inquire tool. Then the haor surface area was extracted through the classification of NDWI images using image specific thresholds in Erdas Imagine model maker in each year. According to classification the land-water threshold was -0.19 in 1989, -0.07 in 1999, -0.19 in 2009 and -0.04 in 2017 (table 2). According to NDWI images there are areal decrease of water surface in the Tanguar haor as well as there is a significant change in the depth of watersurface (Figure 5).

![Figure 5: NDWI Classified image of the area from 1989 to 2017](Source: Satellite image)
The reflectance of water and land histogram has been shown in figure 6 and table 2, which gives directions that water surface in the area is decreasing as linear rate, $R^2 = 0.997$ and land area is increasing as a linear rate $R^2 = 0.977$. To ensure overall accuracy of the analysis results the accuracy assessment analyses are shown in table 3.

Table 2: Evaluation of surface water using satellite-derived NDWI index

<table>
<thead>
<tr>
<th>Year</th>
<th>Land-water threshold</th>
<th>Histogram count</th>
<th>Surface water area (in hectares)</th>
<th>Land area (in hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water</td>
<td>Land</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>-0.19</td>
<td>20892</td>
<td>33821</td>
<td>1880.28</td>
</tr>
<tr>
<td>1999</td>
<td>-0.07</td>
<td>17954</td>
<td>36753</td>
<td>1615.86</td>
</tr>
<tr>
<td>2009</td>
<td>-0.19</td>
<td>15545</td>
<td>39168</td>
<td>1399.05</td>
</tr>
<tr>
<td>2017</td>
<td>-0.04</td>
<td>12318</td>
<td>42395</td>
<td>1108.62</td>
</tr>
</tbody>
</table>

Source: Satellite image analysis

Figure 6: Land and water surface trend in different year

Source: NDWI analysis result

**ACCURACY ASSESSMENT**

According to the analysis in 1989, there was 0.67 percent absolute error, which was 32.83 hectare of the haor area at 99.33 percent accuracy level with a Kappa coefficient 0.99 (table 3). While in 1999, there was 0.33 percent absolute error, which was 16.41 hectare of the haor area at 99.67 percent accuracy level with a Kappa coefficient 0.99. In 2009, the absolute error was 1.00 percent, which was 49.24 hectare of the haor area at 99 percent accuracy level with a Kappa coefficient 0.98. Finally, in 2017, there was 1.33
percent absolute error, which was 65.66 hectare of haor area at 98.67 percent accuracy level with a Kappa coefficient 0.97 (table 3). The accuracy assessment analyses show that the NDWI\textsubscript{McFeeter} method is applicable in delineating surface water and also change detection in the Tanguar haor.

Table 3: Accuracy assessment analysis of NDWI method

<table>
<thead>
<tr>
<th>Year</th>
<th>Absolute Errors (%)</th>
<th>Absolute Errors (in Hectares)</th>
<th>Overall Accuracy (%)</th>
<th>Kappa Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>0.67</td>
<td>32.83</td>
<td>99.33</td>
<td>0.99</td>
</tr>
<tr>
<td>1999</td>
<td>0.33</td>
<td>16.41</td>
<td>99.67</td>
<td>0.99</td>
</tr>
<tr>
<td>2009</td>
<td>1.00</td>
<td>49.24</td>
<td>99.00</td>
<td>0.98</td>
</tr>
<tr>
<td>2017</td>
<td>1.33</td>
<td>65.66</td>
<td>98.67</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Source: Satellite image and Google Earth Pro

Figure 7: Delineation of surface water and land in the Tanguar haor during 1989-2017

Source: Landsat image analysis result
Delineation of Surface Water in the Tanguar Haor between 1989 and 2017

The spatial pattern of water surface change in Tanguar haor for the year 1989, 1999, 2009 and 2017 is shown in figure 7. It is revealed that in 1989, the haor area dominated by water body, but in 1999, the northern and the south-eastern part of the haor have lost it surface water. Similarly, in 2009, the Tanguar haor continuously loses its surface water at the same direction, but the central and the north-western part covered water surface. Finally, in 2017, the haor has lost its maximum water surface, which was at north-western part and from the central part of the haor area (Figure 7). The statistical results of the NDWI index are shown in table 4. According to the table 4, it is revealed that the haor water surface area was about 1880 hectares in 1989, 1615 hectares in 1999, 1399 hectares in 2009 and 1108 hectares in 2017 (table 4, Figure 7). The results further show that haor water surface area changes about 264 hectares (14 percent) between the year 1989 and 1999. Similarly, haor water surface area changes about 216 hectares (11.53 percent) between 1999 and 2009. Between 2009 and 2017 the haor water surface area changes about 290 hectares (15.45 percent). Finally, about 771 hectares (41 percent) water surface of Tanguar haor has been changed between 1989 and 2017 (Figure 7).

Table 4: Variation in areal extent of the water surface area of Tanguar haor in the period of 1989-2017

<table>
<thead>
<tr>
<th>Year</th>
<th>Haor water surface area (in hectares)</th>
<th>Haor water surface area decrease (in hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>1880.28</td>
<td>-264.42</td>
</tr>
<tr>
<td>1999</td>
<td>1615.86</td>
<td>-216.81</td>
</tr>
<tr>
<td>2009</td>
<td>1399.05</td>
<td>-290.43</td>
</tr>
<tr>
<td>2017</td>
<td>1108.62</td>
<td></td>
</tr>
</tbody>
</table>

Source: Lantsat satellite image analysis

Water Surface Area Changing Model in the Tanguar Haor between 1989 and 2017

The statistical results of the analysis show that in the period of 1989 to 1999 the water surface of the haor area has been increased 159 hectares and decreased 423 hectares and about 1444 hectares area has remained as common (Figure 8 and table 5). In this period, the edges of the water surface have been changed by filling, perhaps it occurred from the upstream sedimentation and the changing direction in the north-eastern to the south-western. On the other hand, between 1999 and 2009 the water surface of the haor area has been increased about 242 hectares and decreased about 458 hectares and has remained common about 1144 hectares. The trend is more or less common during 1999-2009. Subsequently, during 2009-2017 the haor surface water has been decreased to 587 hectares and increased about 297 hectares and about 800 hectares has remained common in this period. In this time, haor bordering water surface especially the north-eastern part and the north-western part has totally been decreased as a continuation of the previous
Finally, between 1989 and 2017 there has been about 177 hectares water surface area increased and 949 hectares water surface area decreased and has remained common area about 918 hectares (Table 5). The model shows that the common water surface area has always been declining during 1989-2017. The trend of common water surface (fixed) area is decreasing, as a linear rate of $R^2 = -0.998$. On the other hand, the water surface decreasing trend is upward as a linear rate of $R^2 = 0.902$ (Figure 9). According to the analysis, it is very much clear that the haor area water surface is gradually decreasing, which is alarming for the ecologically critical area, Tanguar haor.

![Changing pattern of water surface in Tanguar haor during 1989-2017](image)

**Figure 8:** Changing pattern of water surface in Tanguar haor during 1989-2017

**Table 5: Model statistics of Tanguar Haor water surface area changing**

<table>
<thead>
<tr>
<th>Time Duration</th>
<th>Water surface area increase (in hectares)</th>
<th>Water surface area decrease (in hectares)</th>
<th>Net decrease of water surface area (in hectares)</th>
<th>Common water surface area (in hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989 to 1999</td>
<td>159.07</td>
<td>423.49</td>
<td>264.42</td>
<td>1444.81</td>
</tr>
<tr>
<td>1999 to 2009</td>
<td>242.14</td>
<td>458.95</td>
<td>216.81</td>
<td>1144.41</td>
</tr>
<tr>
<td>2009 to 2017</td>
<td>297.19</td>
<td>587.62</td>
<td>290.43</td>
<td>800.68</td>
</tr>
<tr>
<td>1989 to 2017</td>
<td>177.96</td>
<td>949.62</td>
<td>771.66</td>
<td>918.68</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>($R^2 = 0.902$)</td>
<td>($R^2 = -0.998$)</td>
<td>Source: Change detection from image analysis</td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSIONS

The study aimed at modeling the spatio-temporal changes of Tanguar haor water surface in the winter between 1989 and 2017. The aim has been fulfilled using NDWI. The results reveal that there is a sharp declining trend of the surface water in the Tanguar haor and 41 percent of water surface area has declined between 1989 and 2017. If this trend continues, it is likely that Tanguar haor will have no water in the winter in the near future. It is very critical because the haor provides an important role in fish production as it functions as a ‘mother fishery’ for the country. Every winter the haor is home to about 200 types of migratory birds, which will be at risk. Society at large and the population living in the surrounding in particular will be in trouble for its declining trend. Therefore, appropriate measures need to be taken by the policy makers to protect Tangura haor water surface to protect biodiversity of the haor area. The outcomes of community-based sustainable management of Tanguar haor should go in favour of haor natural cover, especially water surface. Otherwise, the life of the haor, freshwater will be exhausted and Tanguar will lose its international significance as a freshwater habitat. Besides, regular monitoring of surface water must be arranged institutionally.

REFERENCES


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