GEOSPATIAL APPROACH TO WETLAND VULNERABILITY ASSESSMENT FOR NORTHWEST BANGLADESH

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ABSTRACT:

Despite their inestimable environmental significance, wetlands around the world have been disappearing in an alarming way. In the floodplain region like Northwest Bangladesh (NWBD), wetlands are more exposed to numerous pressure factors which have made them susceptible. Assessment of these threats is essential to understand the state of the wetland ecosystem and to develop a suitable management strategy. Exploring different Landsat imageries from 1989 to 2020, the present study has tried to comprehend the physical vulnerability of the wetlands of NWBD. Remote sensing approach of the Modified Normalized Difference Water Index (MNDWI) has been employed to delineate the areal extent and to evaluate the temporal changes of these wetlands in NWBD. The retrieved results have been drawn on to develop the vulnerability index using different statistical manners. Result reveals that between 1989 and 2020 NWBD has lost 57.89% of its total wetland areas which is around 970.34km2. Retrieved results provide a clear trail of individual spatial and temporal wetland areal coverage fluctuations in NWBD. Moreover, the decreasing trends of indicators imply a very unsustainable hydrological condition in NWBD which could be a big threat to the existence of its wetlands in near future. With some area-specific adjustments, this simple method of vulnerability assessment would help the policymakers to conserve, manage, and restore the wetlands in NWBD and other areas as well.

1. INTRODUCTION

Wetlands are considered amongst the earth's most productive ecosystems which provides a very diverse array of decisive ecological functions and values, whilst it covers only 6% of the earth's land surface. However, they are also the most fragile and adaptive systems and susceptible to numerous external stresses(Turner et al., 2000). (Turner et al., 2000). About half of the global wetland losses could be attributed to human activities and natural disaster (X. Yang, Liu, Jia, Liu, & Yu, 2021). With the incessant development and indiscriminate exploitation of natural resources wetland systems have been losing their existence. Wetlands, situated in the developing countries where growth of population is very high, and wetlands' protection is often overlooked by its citizen and the concern authorities have been found more pretentious (Malekmohammadi & Jahanishakib, 2017). NWBD with its vast floodplain lands once was far-famed for its numerous wetlands. However, different external human-induced local stresses including agricultural and built-up lands encroachment onto wetlands, closure of tie channels linking wetlands to rivers, closure of outlet channels, and the excavation of new drainage routes, constructions of road, bridges and culverts, dams etc., ground water extraction have all contributed to the degradation of wetlands in NWBD (Saha & Pal, 2019). Moreover, climate induced phenomenon like changes in precipitation and temperature also have aggravated this situation in the region. Islam et al. (2021) have explored that during the time of their study from 1988 to 2018, around 2058.59 km^2 wetland areas have disappeared from the parts of NWBD. In their study Shopan, Islam, Dey, and Bala (2013) indicated a partial loss of 341.54 km^2 of wetland during 1989 and 2010. Therefore, to minimize the future degradation, it is imperative to quantify the reduction rate of wetlands' areas situated in the NWBD. Remote sensing data at multiple scale combined with geographical information system techniques have brought about a revolution to foster more proactive and effective approaches to resource particularly wetlands management (Copeland et al., 2010). Using the synoptic and moderate to high resolution different satellite imageries, scientist now a days tend to explore micro-level wetland mapping.

Maps of vulnerability can be employed to formulate priority-based policies pertaining to wetlands. Vulnerability of wetlands is determined by its relationship between the exposer and risk of a particular event, the impact of the event on the wetlands, and their ability to deal with the impacts or minimize the impact of the event. Magnitude of vulnerability and its nature highly vary in different spatio-temporal scale (Gitay, Finlayson, & Davidson, 2011; Saha & Pal, 2019). The components, therefore, diverge and require minor to significant adjustments with the change of geographical areas. A landscape-scale geospatial assessment of wetlands in Wyoming has been carried out by Copeland et al. (2010). When physical vulnerability of the wetlands of Atreyee river basin has been explored by Saha and Pal (2019) using logistic regression, and fuzzy logic approach for both pre and post dam periods. Stratford, Acreman, and Rees (2011) have developed a methodology using three wetland sites in Nepal which provides a structure to data collection and analysis and guide the users to produce a vulnerability assessment of wetlands. However, a model to evaluate the ecological environment vulnerability of the Jixi National Wetland Park using remote sensing image, digital elevation model, and environmental quality interpolation process was established by X. Yang et al. (2021). Malekmohammadi and Jahanishakib (2017) developed a systematic methodology for assessing wetland vulnerability in a social-ecological approach applying broad-scale ecosystem services and vulnerability functions combining the hydro-geomorphic approach with DPSIR analysis. Most of these works tried to address the wetland vulnerability in terms of ecosystem health, water qualities, exotic species invasion, wastewater disposal etc.

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(Erwin, 2009; Saha & Pal, 2019) . However, the physical vulnerability assessment of wetland in a simple but effective manner has found scarce. Inter-annual variation for surface water extent of wetlands indicates the hydrological variability when landscape indicators are used to accomplish change analysis. These vulnerability assessments provide better understanding of wetland condition where spatial wetland extent is highly dynamic and numerous pressure factors are prevailing. Human and climate induced physical vulnerability of the wetlands in NWBD has been found very persuasive. Therefore, considering the needs and challenges present study contemplates on assessing the physical vulnerability of wetlands in NWBD in a simple but effective geospatial approach.

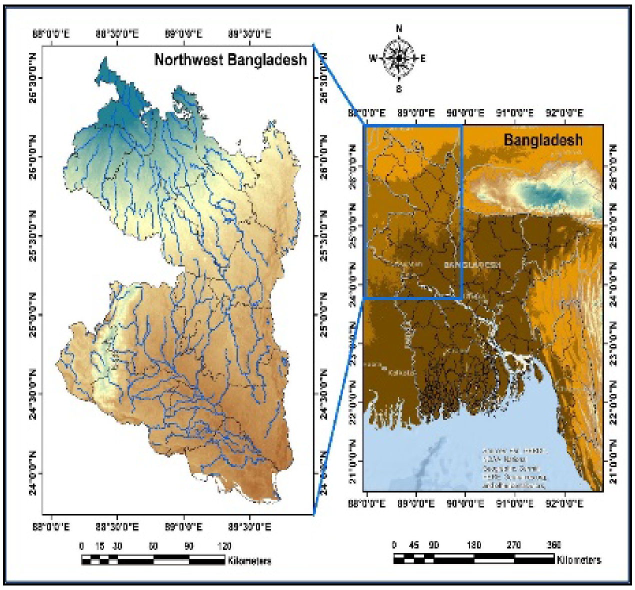

Figure 1. Northwest Bangladesh

2. STUDY AREA

The northwest Bangladesh comprises with two divisions namely: Rajshahi and Rangpur. It has an area of 34, 513 km^2 having a total population of 29,992,955 (2011 census). The region is a part of Ganges-Brahmaputra rivers system- a flat alluvial basin which is completely separated by these river systems from the rest parts of the country. More than hundreds of rivers including tributaries and distributaries flow through the northwest region constituting a network of interlinked waterways. The region elongates latitudinally between 23^0 48′ and 26^0 37′ N, and longitudinally between $88^0$01′ and $89^0$48′ E (Islam 1991). It has a vast area of flat land having several depressions which created a vast number of natural freshwater wetlands in this region. The region has got the tropical monsoon climate characterized by wide seasonal variation in rainfall (1200mm-5000mm), high temperature (ranges from 7^0C-40^0C) and humidity (45%-92%). This diversified physiography along with climate extremes have made this region distinctive compared to the other regions of the country. Figure 1 illustrate the study area.

3. MATERIALS AND METHODS

3.1 Materials

Multispectral bands in Landsat (TM, ETM+, and OLI) imageries brings about the enhanced aptitudes to derive Land Cover (LC) information from the imageries (Roy et al., 2020). Moreover, its broader swath (185km), higher spatial and temporal (30m, and 16 days respectively) resolution, and free availability of long-term historical data have made Landsat data popular among the researchers (Tang & Di, 2019). Several studies have successfully used remote sensing Landsat satellite data for wetland change detection(Kumar & Arya, 2021; L. Yang et al., 2020), wetland vulnerability assessment (Akumu et al., 2018; Boyden, Wurm, Joyce, & Boggs, 2018; Ghosh & Das, 2019; Jensen et al., 2022; X. Yang et al., 2021).Therefore, considering all these through literature review, Landsat series of different sensor data (TM, ETM+, and OLI) have been used in this study. All these images have been obtained from the United States Geological Survey (USGS)'s official website https://glovis.usgs.gov. The limitation of these image data is that these images were not acquired on the same date. However, near date of February and March (as alternative) month for each year has been used considering the minimum cloud cover and maximum availability of long-term historical data. The detailed specification of the employed images has been described in Table 1.

Table 1. Details of used Landsat data.

Sensor Type	*Path*	*Row*	*Acquisition Date*	*Spatial Resolution*
Landsat TM5	138	42,43	28/02/'89 24/02/'05 06/02/'10	30m
	139	42,43	23/02/'89 15/02/'05 13/02/'10	
Landsat ETM$^+$7	138	42,43	19/02/'00	30m
	139	42 43	26/02/'00 29/03/00	
Landsat8 OLI	138	42,43	04/02/'15 02/02/'20	30m
	139	42,43	11/02/'15 09/02/'20	

3.2 Data pre-processing and processing

Selected data were reprojected to Universal Traverse Mercator Coordinate system zone 43N, using GCS_WGS_1984 datum. To improve the interpretability and quality of the selected satellite data, radiometric calibration and atmospheric correction using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) atmospheric correction module has been performed using Envi 5.3 software to convert digital numbers (DN) to reflectance and to filter the interference from the path radiation, such as aerosol, dust particles, and water vapor.

3.3 Identifying wetland areas

Over the past few years, several spectral index-based approaches have been developed and successfully employed to delineating surface water features. Among them, substituting the middle wave infrared (MIR)/ short wave infrared (SWIR1) band for near-infrared (NIR) Xu (2006) proposed MNDWI which has been perceived prevalent among the scientist as it can enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise. MNDWI can be expresses as follows Eq(1):

$$MNDWI = \frac{Green - MIR}{Green + MIR} \text{............ Eq(1).}$$

The resulting values range from -1 to +1; among which the positive values represent the water bodies because of their higher reflectance in the green band compared to those of the MIR band (Nath, Ni-Meister, & Choudhury, 2021). Therefore, remote sensing based spectral indices, MNDWI has been employed using Landsat imageries in an Envi 5.3 and ArcGIS 10.3 environment to characterise the two-land cover types of viz landmass, and water to explore the wetland changes in NWBD.

3.4 Method

The spectral index, MNDWI has been employed to extract the two-land cover types of namely landmass and water. A prudent threshold has been set for individual image after a long trail and error practice to categorize the landmass from waterbodies by suppressing the irrigated lands. At the end, a Shapefile has been prepared and transferred to ArcGIS environment. In ArcGIS, firstly, from the two types of landforms (Water & Landmass), landmass has been deleted keeping the waterbodies only (Which contains wetland & River). Finally, the linear shaped rivers have been removed from the images keeping only the wetlands. Thus, the area of wetlands for individual year has been computed. The retrieved results have been employed to assess the wetland vulnerabilities using statistical analyses.

Accuracy assessment for each land cover types was performed by uploading 150 points taken from each image to Google Earth Pro to compare their similarity. Overall Accuracy, Producer's Accuracy, User's Accuracy, and Kappa co-efficient index were produced to evaluate the classification accuracy. Table 2 describes the details of accuracy results.

Table 2. Accuracy chart for image classification.

Accuracy Parameter	1989	2000	2005	2010	2015	2020
Overall Accuracy	87.5	90.18	90.18	92.04	89.38	89.61
User's Accuracy						
Wetlands	81.58	94.59	96.00	88.10	84.78	91.67
Landmass	83.33	93.75	82.69	95.29	97.06	90.00
Producer's Accuracy						
Wetlands	88.57	97.22	85.71	92.50	97.50	89.19
Landmass	88.89	97.30	87.18	86.84	93.55	87.80
Kappa Coefficient	0.81	0.85	0.85	0.89	0.84	0.83

4. RESULT AND DISCUSSION

4.1 Wetland change evaluation

Spatiotemporal wetland maps of the Northwest region of Bangladesh for the years of 1989, 2000, 2005, 2010, 2015, and 2020 were produced from the Landsat series of satellite images for the comprehensive evaluation of its spatiotemporal changes. Table3 illustrates the spatiotemporal wetlands areal coverage of the Northwest region of Bangladesh from 1989 to 2020 in selected time spans. The total area of the Northwest region estimated from the Landsat imageries is about 34437.39 km^2. It is observed that overall wetland areas have been decreasing during the whole study time. In 1989, initially the total wetland area was 1676.12 km^2 occupying 4.87% of the total area of the region, which was the highest during this study period. Gradually, it starts declining and continues at a disquieting rate, though the rate of loss was very inconsistent throughout the study time. In the final state in 2020, it is seen that the declining wetland area has dropped down to 705.78 km^2, which was 2.05% of the total study area. Figure 2 portrays the decline trends of wetlands area from 1989 to 2020 in Northwest region of Bangladesh. The R^2 value of 0.9515 indicates a very significant declining correlation of wetlands with the time.

Table 3. Areal coverage of wetlands in NWBD

Year	Wetlands Area (Km2)	% Of Total Area
1989	1676.12	4.87
2000	1289.31	3.74
2005	1009.92	2.93
2010	838.14	2.43
2015	811.92	2.36
2020	705.78	2.05

In the initial state in 1989, wetlands were well distributed among all the five districts of the study area. High concentric distribution of wetlands has been found in the northeast and the middle part of the study area, befalling in the district of Rangpur, Bogura, and Rajshahi, respectively. However, throughout the study area, an inconsistent wetland area loss has been observed on the following years after 1989. In 2000, wetland areas were seen to increase in the Dinajpur districts, however, in Bogura and Rajshahi districts, the areas were found to be decreased.

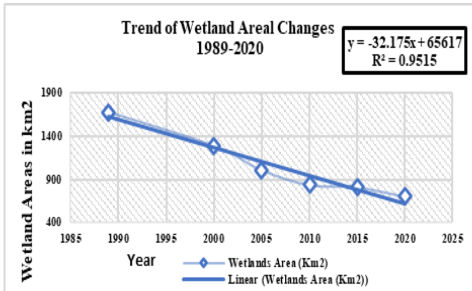

Figure 2. Wetland change trends in NW Bangladesh.

In 2005, enormous decrease of wetlands areas had been noticed in Rangpur and Rajshahi districts. After 2005, massive decrease of wetlands has been perceived in all most all the districts and all the following years. Yet some areas revealed their indiscriminate increase of wetlands, especially in 2015 and 2020. It might be mentioned that man-made artificial small and medium size ponds/tanks for fish culture contribute a lot to rise the total wetland areal coverage in some districts in the region. However, due to the spatial resolution of the Landsat imageries, all these micro level expansions or changes of wetland areas cannot be evaluated very accurately. Figure 3 delineates the details of spatiotemporal wetland distribution and table 4 explains the wetland change scenario in NWBD. Previous several studies indicate that different anthropogenic factors like huge population growth, extensive expansion agriculture, economic and social developments have contributed to these changes of wetland areas (Faruque et al., 2022; Hoque, Islam, Ahmed, Hasan, & Prodhan, 2022; Sarkar et al., 2021). Table 5 depicts the district wise temporal wetland distribution in NWBD.

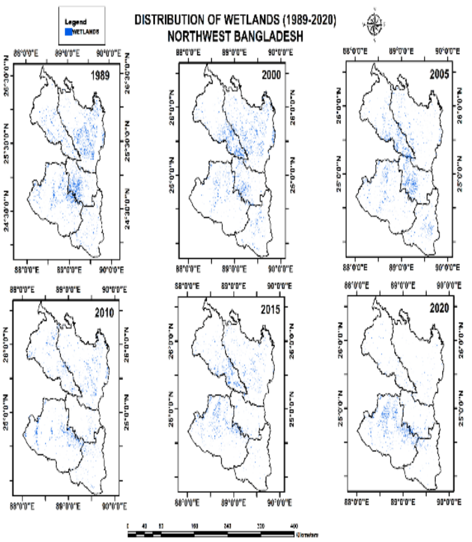

Figure 3. Spatiotemporal distribution of wetlands in NW Bangladesh.

Table 4. Wetland areal coverage changes in Northwest Bangladesh (1989-2020)

Time Period					
From	To	Interval	Wetland Change (km^2)	Change in Percentage (%)	Wetland Change/Year (km^2)
1989	*2000*	*11*	*386.81*	*23.08*	*35.16*
2000	*2005*	*5*	*279.39*	*21.67*	*55.88*
2005	*2010*	*5*	*171.78*	*17.01*	*34.36*
2010	*2015*	*5*	*26.22*	*3.13*	*5.24*
2015	*2020*	*5*	*106.14*	*13.07*	*21.23*
1989	*2020*	*31*	*970.34*	*57.89*	*31.30*

4.2 Wetland vulnerability assessment

The retrieved results have been employed to evaluate the vulnerabilities for these wetlands with help of statistical analyses A landscape indicator chart for wetlands sustainability is also developed in this regard.

Table 5. Districts wise wetland distribution in NW BD (1989-2020)

	Bogura		Dinajpur		Rajshahi		Rangpur		Pabna	
Year	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
1989	402.76	10.43	186.3	2.81	453.61	4.82	580.22	5.99	92.37	1.90
2000	190.37	4.93	353.3	5.34	231.8	2.46	446.15	4.61	79.37	1.64
2005	282.43	7.31	243.54	3.68	220.16	2.34	170.14	1.76	102.52	2.11
2010	59.54	1.54	158.45	2.39	318.7	3.38	251.03	2.59	57.42	1.18
2015	51.84	1.34	228.02	3.45	321	3.41	193.87	2.00	22.45	0.46
2020	90.5	2.34	47.08	0.71	508.35	5.40	33.93	0.35	41.57	0.86

4.2.1 The inter-annual variation of wetlands

The inter-annual variation for surface water extent of wetlands for individual district, and the NWBD as a whole have been examined using the Coefficient of Variation (CV%). The CV% (Eq. 2) is a statistical indication of inter-annual variation for the variables (Dettinger & Diaz, 2000). High value of CV% indicates more variability (i.e., extreme variability in wetland water surface areal fluctuations) and low CV% indicates less variability (i.e., constant water surface and minimal fluctuations) on a period-to-period basis.

Coefficient of Variation % (CV%) = σ/μ…… Eq(2) here σ = standard deviation, and μ= Mean.

Table 6. Coefficient of variation (%) in wetland areal coverage

Name of Area	Mean	Maximum	Minimum	Std.Dev	C.V (%)
Northwest BD	1069.80	1715.26	721.43	376.38	35.18
Bogura	179.57	402.76	51.84	140.83	78.43
Dinajpur	202.78	353.3	47.08	101.42	50.02
Rajshahi	342.27	508.35	220.16	116.71	34.10
Rangpur	279.22	580.22	33.93	199.30	71.38
Pabna	65.95	102.52	22.45	30.90	46.86

*Unit in km^2

The wetland areal coverage of individual district extracted from the Landsat imageries has been used to calculate the CV% for the period 1989-2020. Table 6 illustrates CV% for whole NW region along with its 5 districts. The overall result of CV% of NW region was 35.18% which indicates relatively low degree of variability during the study period. In contrast, the CV% for individual districts' wetland system presents more detail of the variability of wetland areal coverage. The result reveals CV% ranges from 78.43% for Bogura district (high variability) to 34.10% for Rajshahi district (moderate variability). In case of individual CV%, Bogura and Rangpur districts (78.43% and 71.8% correspondingly) exhibit a very high fluctuations of wetland areal coverage, when other three districts namely Rajshahi, Pabna, and Dinajpur (34.10%, 46.86%, and 50.02% correspondingly) reveal mild to moderate variability. This range of variability suggests that wetland areal coverage in some districts can double or halve in size seasonally or from period-to-period. These MNDWI retrieved results provide a clear trail of individual spatial and temporal wetland areal coverage fluctuations in NWBD.

4.2.2 Landscape indicators

Landscape indicators are used to accomplish landscape change analysis. To assess the change on wetland sustainability in NWBD, landscape change analysis has been executed using the landscape indicators: Landmass area, total wet area, wet area density, wet area/landmass, wetland areas, wetland density, average wetland area size, wetland/landmass, river areas, river density, river/wetland, and wet/non-wet area. In Table 7 the details have been explicated. The analysis result of landscape indictors from 1989 to 2020 reveal that among the 12 indicators only landmass areas exhibit increasing trends, when all other 11 indicators are showing declining trends. Here, landmass indicates the built-up areas along with non-water areas like agriculture fields, fallow lands, forests etc. However, these decreasing trends of indicators imply a very unsustainable hydrological condition in NWBD which could be a big threat for existence of wetlands in near future.

Table 7. Landscape indicators for wetland sustainability in NWBD

Assessment Area	1989	2000	2005	2010	2015	2020
Landmass Areas km^2	31824.9	32614.7	32710.1	33044.5	33083.5	33210.9
Total Wet Areas (km^2)	2612.47	1822.68	1727.29	1392.93	1353.85	1226.45
Wet Areas Density	0.075861	0.052927	0.050157	0.040448	0.039313	0.035614
Wet areas/Landmass	0.082089	0.055885	0.052806	0.042153	0.040922	0.036929
Wetland Areas	1676.12	1289.31	1009.92	838.14	811.93	705.78

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Wetland Density	0.048672	0.037439	0.029326	0.024338	0.023577	0.020495
Average Wetland Area Size	0.009578	0.005379	0.005538	0.0054	0.004916	0.005836
Wetland/Landmass	0.052667	0.039532	0.030875	0.025364	0.024542	0.021251
River Areas	936.35	533.37	717.37	554.79	541.92	520.67
River Density	0.02719	0.015488	0.020831	0.01611	0.015736	0.015119
River/Wetland	1.790057	2.41729	1.407809	1.510734	1.498247	1.355523
Wet/Non-Wet Areas	0.08209	0.05589	0.05281	0.04215	0.04092	0.03693

5. CONCLUSSION

Present study evaluated the physical vulnerability of wetlands in NWBD. The employed methods reveal mass destruction of wetlands has been taking place in NWBD since 1989 till 2020. Within these 31 years of time, at a rate of 31.30km^2/year 57.89% of the total wetland areas have been disappeared from study area which is around 9700.34km^2 in areal extent. District of Rangpur, Bogura, and Dinajpur have lost the highest areas of wetlands respectively. However, Bogura was found most vulnerable, followed by Rangpur, and Dinajpur districts. Agriculture as a dominant phenomenon, has been apprehending and changing the land use and landcover types in the area. The huge growth of population, rapid urbanization along with its economic growth has aggravated the condition. Considering the threats and the value of wetlands it now very imperative to take necessary measures for the conservation of the existing wetlands of NWBD. Though within the scope of this study few parameters have been considered, however, it is expected that this study would help the government organizations and the policymakers to develop a national standard vulnerability assessment strategy adding more required parameters.

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