

Drought Risk Mapping in the North-West Region of Bangladesh Using Landsat Time Series Satellite Images



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1 Introduction

Drought is a common hydrometeorological phenomenon [1]. It is regarded as a regional phenomenon whose characteristics vary from one climate region to another [2]. Meteorologically drought can be classified into three different types. They are permanent drought, seasonal drought, and contingent drought. Permanent drought is observed mainly in the arid climate zones where seasonal drought and contingent drought are more common around different parts of the world. Seasonal drought occurs because of the irregularities in rainy and dry seasons and contingent drought is caused by the irregularities in rainfall pattern and intensity. In Bangladesh, seasonal drought and contingent drought are most prominent which are observed mainly in pre-monsoon and post-monsoon periods.

Bangladesh is a disaster-prone country due to its topographic and socioeconomic factors. Various kinds of natural hazards such as floods, cyclones, earthquakes, droughts are quite common here. Though drought is one of the most common natural disasters in Bangladesh, it is the least understood natural hazard in Bangladesh due to its complex and unpredictable nature. It is quite difficult to predict the severity as well as the starting and ending of a drought. Moreover, the effects of drought may build up slowly over a substantial period of time and can last for a prolonged duration which makes it tough to understand the severity and duration of drought [3, 4]. Thus, time-to-time monitoring is necessary in order to be updated with the drought condition and make preparedness for the situation. Drought has become a common phenomenon in some parts of Bangladesh in the past few decades especially in the North-West region of Bangladesh. According to the National Water Management Plan (NWMP), occurrences of drought are considered a major water deficiency related issue in this region. Between 1960 and 1991, about 19 droughts have occurred in Bangladesh [4]. As an agricultural country, the impacts of droughts are detrimental to the economy

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of Bangladesh. It can impose a significant threat on the food and water security of the country. Failure to be acquainted with the up-to-date information about the trend, duration, extent, and intensity of droughts can bring losses of crops, economy, and environment as well as add human sufferings. Moreover, climate change impacts can increase the severity of droughts in the future. In order to combat such a prominent threat, the risk assessment of droughts in this region has no alternative.

Remote sensing techniques have been used in different parts of the world to detect drought in recent times. In a study, drought assessment was done within the Flint Hills of Kansas and Oklahoma, United States, after analyzing MODerate resolution Imaging Spectroradiometer (MODIS), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI) data from 2001 to 2005 [5]. In a recent study, the drought of the southern coastal region in Bangladesh was detected using Landsat time series satellite images [6]. Some efforts were also observed in the north-west region of Bangladesh to identify drought risk areas based on NDVI by using surface reflectance with 250 m resolution from MODIS satellite data [7]. But the main drawbacks of this study are the usage of low-resolution data (250 m), which is not good enough to capture the drought severity at the local level and assessment of drought-prone areas using only one index. Thus, this study attempts to use 30 m Landsat 7 and Landsat 8 satellite images to identify four drought indices NDVI, VCI, NDWI, and MNDWI to identify the extent of drought in the study area. Moreover, the temporal variation of drought in the north-west region of Bangladesh is also shown in this study from 2000 to 2020 with an interval of 5 years.

2 Study Area

This study area was chosen as the north-west region of Bangladesh, which is the most drought-prone area of Bangladesh. The study area covers two important divisions Rajshahi and Rangpur including 16 districts in total with an area of about 32,000 km². This area is located between 26°21 and 24° North latitudes and 88°17 and 89°41 East longitudes. The average seasonal rainfall of this area is about 1000 mm during the five monsoon months (June–October) which is lower than any other part of the country. The study area is shown in (Fig. 1).

3 Methodology

3.1 Data Collection

Landsat 8 and Landsat 7 satellite images were collected from the Earth Explorer database of USGS for this study [8]. Landsat 8 is the most recently launched Landsat satellite that was launched on February 11, 2013. Hence, Landsat 8 images are

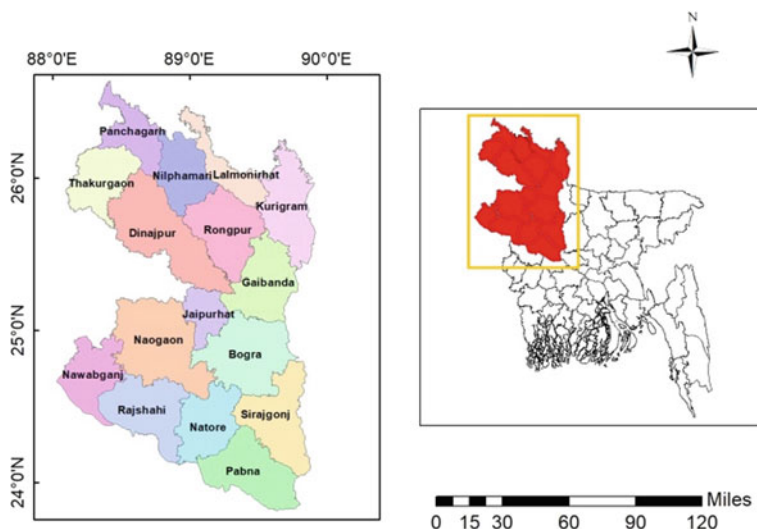


Fig. 1 Study area

Table 1 Details of Satellite images used for the study

Name of Satellite	Path/Row	Spatial Resolution (m)
Landsat 7 ETM + and Landsat 8 OLI and TIRS	138/042	30
	138/043	30
	139/042	30
	139/043	30

available only after 2013. Thus, for analysis of NDVI from 2000 to 2013, Landsat 7 images and from 2014 to 2020, Landsat 8 images of 30 m resolution were used. The scanlines from the images of Landsat 7 were removed using the Landsat Toolbox in ArcGIS. For each year, four scenes of Landsat imagery covering the complete north-west area of Bangladesh were used in this study. Images were primarily collected for the months of October to February to capture the intensity of drought at the dry season. Information about Landsat Images used in this study is given in Table 1.

3.2 Selection of Drought Indices

Different indices can be used to estimate the extent of drought. There are some meteorological drought indices (such as Standardized Precipitation Index (SPI)) which contain information only about rainfall or soil moisture but they do not contain much spatial information where satellite derived drought indices can provide drought related spatial information quite precisely if derived from high-resolution

Table 2 Drought indices

Indices	Remarks
NDVI	This value can vary from -1 to + 1. Usually, healthy vegetation has positive and water bodies have negative values
NDWI	Water bodies usually have positive values and vegetation and soil usually have zero or negative values
MNDWI	The values lie between -1 to + 1. Higher value indicates high vegetation water content
VCI	It is expressed in percentage. Lower values indicate severe cases of drought

satellite data. Moreover, meteorological or climate-based indices depend on data collection methods of different stations. Also, they can be affected by sparsely distributed weather stations in some areas. In this context, satellite-based drought indices are preferable to assess the drought condition. Thus, four satellite derived indices: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI) and Vegetation Condition Index (VCI) are selected for this study to assess the drought condition of North-West region of Bangladesh. These indices are calculated using Eq. (1), (2), (3), (4).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

$$MNDWI = \frac{GREEN - SWIR}{GREEN + SWIR} \quad (3)$$

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (4)$$

The values of these indices indicate different vegetation and drought condition. They are mentioned in Table 2

3.3 Generation of Drought Risk Map

At first, the satellite images need to be georeferenced for any analysis in ArcGIS. As the Landsat satellite images obtained from USGS were already georeferenced and projected in WGS84 UTM zone-46 datum thus, no further georeferencing was required in this case. For each year, four scenes of Landsat images were projected and the indices were calculated for each year. Different tools of ArcGIS such as “Raster Calculator”, “Extraction by mask”, “Spatial analyst tool”, etc., were used for this

analysis. The indices were calculated using different Landsat bands. For NDVI of 2001 to 2013, Landsat 7 Band 3 Visible and Band 4 Near-Infrared spectral band and NDVI of 2014 to 2020, Landsat 8 Band 4 Red and Band 5 Near-Infrared spectral band were used for this purpose. For the calculation of NDWI from 2000 to 2013, Landsat 7 Band 4 Near-Infrared Spectral Band and Band 5 Short-Wave Infrared Band and for NDWI from 2014 to 2020 Landsat 8 Band 5 Near-Infrared Spectral Band and Band 6 Short-Wave Infrared Band were used. In the case of MNDWI calculation, Landsat 7 Band 2 Green and Band 5 Short-Wave Infrared Band were used for the years 2000 to 2014. Similarly, for the years 2014 to 2020, Landsat 8 Band 3 Green and Band 5 Short-Wave Infrared Band were used. Drought risk maps of these four indices are shown in (Fig. 2).

4 Results and Discussions

One of the prime objectives of this study is to identify the change in drought conditions in the past two decades. Thus, NDVI, NDWI, MNDWI, and VCI maps are generated from 2000–2020 with an interval of 5 years using Landsat 7 and 8 images. In order to capture the change between 2000 and 2020, the maps of different indices from 2000 to 2020 are shown in (Fig. 3).

From the drought risk maps of different indices, it was noticed that six districts of the central, northern, and southwestern parts of the study area: Thakurgaon, Panchagarh, Dinajpur, Nilphamari, Gaibandha, and Nator are most prone to drought. The area covering low, moderate, and high drought risks are listed in Tables 3, 4, 5 and 6 with the help of NDVI, NDWI, MNDWI, and VCI for the north-west zone of Bangladesh from 2000 to 2020. There was some variation observed in the percentage of areas for these indices in different years. This phenomenon was also observed in past studies. In a study on drought analysis of the coastal region of Bangladesh, the authors described this as a result of the difference in accuracy level of different indices where they showed NDVI and VCI give more accurate results than the other indices [6].

Apart from that, the results show similar temporal changes over the past two decades. It was noticed that in the first half of the decade the drought severity was more than the second half. In the first 5 years of the time period, the overall drought condition was quite severe especially the worst drought condition was seen in the year 2005 where in 2015 an overall low drought condition was observed in comparison to the other years.

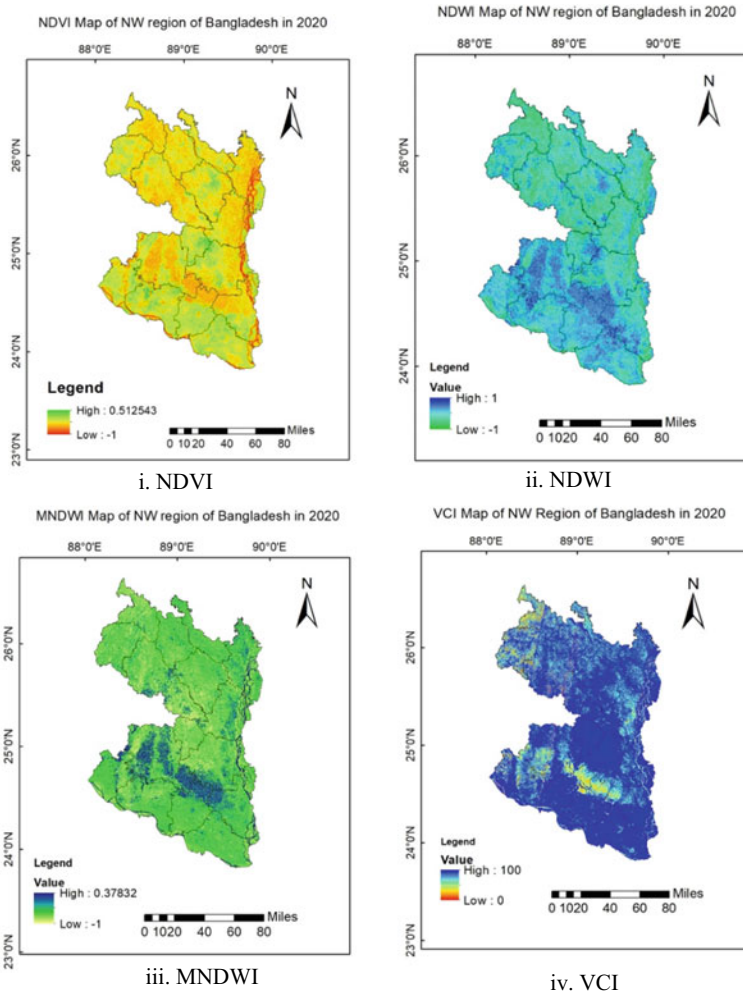


Fig. 2 Drought risk maps of various indices

5 Conclusion

Drought is one of the most common natural disasters of Bangladesh and accurate identification of drought-prone areas is a first step to build resilience against it. In this study, remote sensing and GIS application have been used to detect the spatio-temporal change in drought condition of the north-west region which is the most drought-prone area of Bangladesh. Four satellite-derived drought indices were estimated from Landsat 7 and 8 satellite images for identifying drought risk in the study area for the past two decades. The study reveals that six districts of the central,

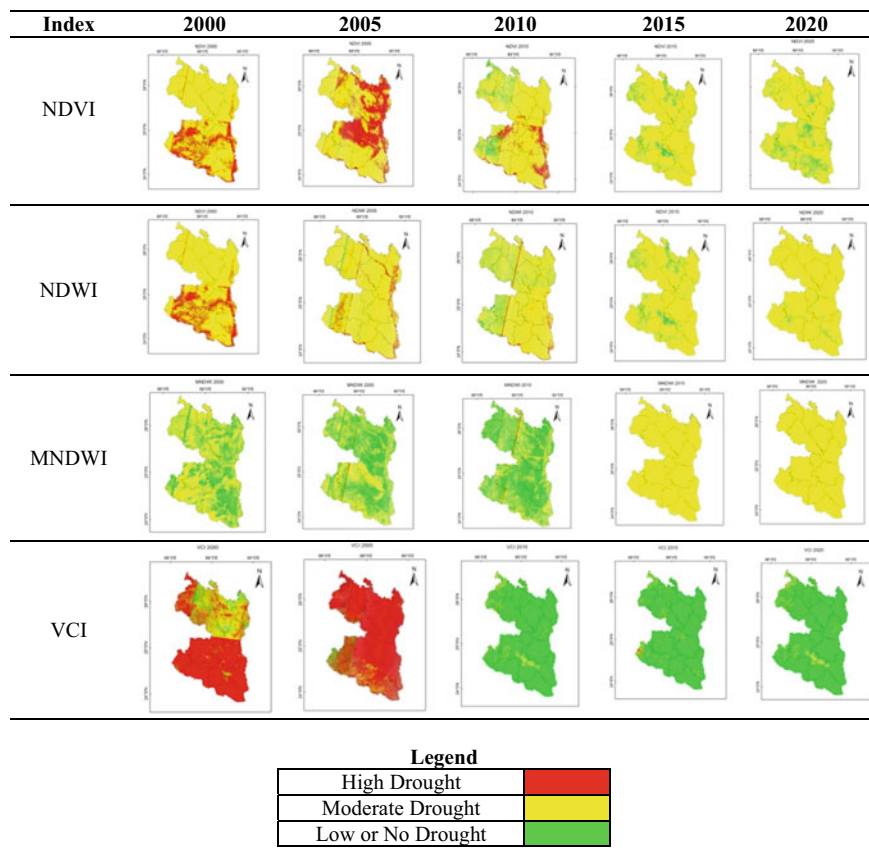


Fig. 3 Drought risk maps from 2000–2020

Table 3 Amount of area in different NDVI ranges over the past two decades

Classification	NDVI value	Area at 2000 (%)	Area at 2005 (%)	Area at 2010 (%)	Area at 2015 (%)	Area at 2020 (%)
High	-1 to -0.3	15.68	33.28	9.19	0	0.003
Moderate	-0.3 to 0.3	84.29	66.11	84.74	95.11	92.21
Low	0.3 to 1	0.03	0.61	6.07	4.89	7.79

northern, and southwestern parts of the study area-Thakurgaon, Panchagarh, Dinajpur, Nilphamari, Gaibandha, and Nator are most susceptible to drought. Apart from that, the temporal analysis indicates the first half of the decade experienced drought severity more than the second half. It was also found that the most severe drought was experienced in 2005 and the lowest drought severity was observed in 2015.

Table 4 Amount of area in different NDWI ranges over the past two decades

Classification	NDWI value	Area at 2000 (%)	Area at 2005 (%)	Area at 2010 (%)	Area at 2015 (%)	Area at 2020 (%)
High	-1 to -0.3	3.45	6.97	3.72	0.002	0.004
Moderate	-0.3 to 0.3	94.36	90.74	87.7	99.96	99.17
Low	0.3 to 1	2.20	2.29	8.58	0.034	0.83

Table 5 Amount of area in different MNDWI ranges over the past two decades

Classification	MNDWI value	Area at 2000 (%)	Area at 2005 (%)	Area at 2010 (%)	Area at 2015 (%)	Area at 2020 (%)
High	-1 to -0.3	0.02	1.90	2.27	0.003	0.003
Moderate	-0.3 to 0.3	71.55	54.99	42.44	99.95	99.96
Low	0.3 to 1	28.43	43.11	55.29	0.044	0.037

Table 6 Amount of area in different VCI ranges over the past two decades

Classification	VCI value	Area at 2000 (%)	Area at 2005 (%)	Area at 2010 (%)	Area at 2015 (%)	Area at 2020 (%)
High	0-33	64.88	88.32	2.69	1.03	1.07
Moderate	33-67	28.64	8.22	16.53	9.37	11.70
Low	67-100	6.48	3.46	80.78	89.60	87.23

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