Faisal et al., J Remote Sensing & GIS 2018, 7:1
DOI: 10.4172/2469-4134.1000236

Journal of Remote Sensing & GIS

Research Article Open Access

Integration of Remote Sensing and GIS Techniques for Flood Monitoring and Damage Assessment: A Case Study of Naogaon District, Bangladesh

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Rec date: March 14, 2018; **Acc date:** March 28, 2018; **Pub date:** March 30, 2018

Abstract

Recording of hydrological parameters of a flood with conventional means often fails due to an extreme event especially in developing countries like Bangladesh. Flood water causes a lot of property damage almost every year and it demands to be controlled for economic growth by water management. The objective of the study is to analyze the damages according to different land uses like urban area (Built-up) or agricultural lands, flood height and thus the percentages of loss in different land use in various corresponding year. Naogaon District has been chosen as the study area for this analysis. Remote Sensing data has been used in this context as remote sensing technology along with Geographic Information System (GIS) has become a key tool for flood monitoring in recent years. Satellite images which have been collected from Landsat 4-5 Thematic Mapper for the year 2004, 2007 and 2012 and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images for the year 2017. In each year images of different times (March and September) of Naogaon district have been analyzed with Geographical Information System (GIS) and ERDAS Imagine software. The analysis demonstrate the variation of land use changes in before and after flood occurrence month from 2004 to 2017 depends on this change. The analysis also describe the relation of the flood in that four observation years as well as the percentages of loss association with the flood spread, flood height, and land uses. The study helps to find out the losses and related relations of flood and thus the importance of water management. The study demonstrates an encouragement to further flood water management studies.

Keywords: Extreme event; Land use change; Satellite image; Remote sensing; Landsat images; GIS; Water management

Introduction

Floods are one of the most common natural disasters leading to economic losses and loss of human lives [1]. As monsoon rain kept on pouring and overflowing the rivers in the country as well as the upstream hilly regions of neighbouring countries, Bangladesh faces flood affecting the northern, north-eastern and central part of the country. Naogaon District is a mostly affected one in northern part [2]. Naogaon district has 10 rivers (Atrai River, Punarbhaba River, Little Jamuna River, Gur River, Dhol River or Dhol Sea, Tulshiganga River, Nagor River, Noor River, Fokinni River, Shiva River) [3]. These rivers overflow and causes flood and damage a huge property. Recently (in 2017) heavy floods have severely damaged properties valued around Tk 300 crore in two upazilas of Naogoan district following the collapse of a flood control embankment at Mirpur area under Atrai upazila in the district. Floods have damaged about 23,000 houses, including 7,000 mud huts, worth around Tk 50 crore in Atrai and Raninagar upazilas and 97 educational institutes have also been damaged in the two upazilas. The recent floods have destroyed about 80 km of roads and 6.50 km of the flood control embankment causing a huge economic loss [4]. Floods in 2017 damaged at least 50,000 acres of crops and washed away fish in almost 1,000 ponds. Water in the Atrai River has been 214 cm above the danger level, while the Chhoto Jamuna's level has been 70 cm above the danger line [5]. So, Naogaon District has bad experiences of flood and that is why Naogaon District has been chosen as the study area.

Land use and floods are closely related; therefore, any changes in the land use, such as urbanization across the catchment's area, may trigger a sequence of flood occurrences and more economic loss [1]. Information on land use/land cover and its changes is very essential for effective management of natural resources [6]. The impact of flood is not only changes the land use, it also affects the community as it destroy the community life [6]. The economic loss due to flood also depends a lot on land uses; flood in urban area causes more loss than the agricultural land. The land use in Naoagaon District has a change with time. A chronological assessment can find out the relation between land use and flood damage. In the study, the changes of the study area has been analyzed from 2002 to 2017. The change detection of land use/land cover is carried out using before and after flood satellite images [7]. In the study, Landsat 4-5 TM, Landsat-8 OLI and MODIS images are classified and analyzed with ERDAS imagine and GIS. The aim of the study is to analyze the damages according to different land uses like Built-up area or agricultural lands and relation between land use and flood helps to analyze the percentages of loss in different land use which will help the future flood management. This study provides an easy, simple and short technique for producing flood inundation maps from various satellite data by using Geographic Information System (GIS) software tools.

Materials and Methods

Study area

Naogoan is a district in northern Bangladesh and a part of the Rajshahi Division. It is situated within the coordinates 24.90°N and

88.75°E. The total study area was 3449.197 sq-km. It is bounded by the West Bengal State of India on the north, Natore and Rajshahi district on the south, Joypurhat, Bogra, and Natore districts on the east, Nawabganj district on the west [8-10] (Figure 1).

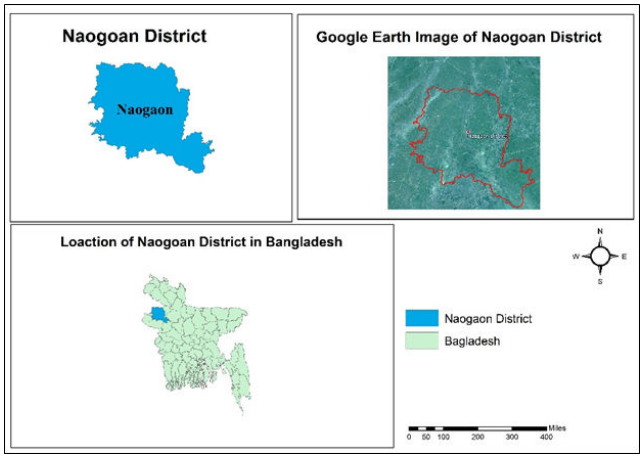

Figure 1: Location and Google earth image of Naogoan district.

Data used and its pre-processing

Landsat 4-5 TM, Landsat-8 OLI images (in the form of both surface reflectance) and NDVI at 30 m spatial resolution are freely available in United States Geological Survey (USGS) websites [11,12]. For this study, these images covering the study area and within the time frame of 2004 to 2017 have been collected. The image collection considers two different times (i) in the flood happening month (July to September) and (ii) when the flood is not occurring (December to May). These images were acquired with a combination of path-row 138-43 as this cover the study area. Upon acquiring all the required datasets, we performed the following set of pre-processing steps to both Landsat 4-5 TM and Landsat-8 OLI. Those included: (i) re-projecting the images into Universal Traverse Mercator (UTM) Zone 46 N with World Geodetic System 1984 (WGS84) datum, (ii) clipping the images to represent the study area (iii) Supervised classification before and after flood occurrence months and (iv) Watershed creation during flood months.

Methodology

The processing of data for evaluation has three major components: (i) mapping of Naogaon area before and during the flood using Landsat 4-5 TM and Landsat-8 OLI images (ii) determining the percentage of land use damaged like (urban area or Agriculture land) in the study area during the flood from 2004-2017 upon combining the outcomes from the first two components through matrix union in ERDAS imagine.

In order to map the pre and during flood period using Landsat 4-5 TM and Landsat-8 OLI a number of steps have been performed. Firstly, a supervised classification has been to classify the larger extent of heterogeneous landscapes (includes various vegetation types). Secondly, it has been intended to generate four major land cover classes (i)Urban area, (ii)Agriculture land and Vegetation, (iii)Bare soil and (iv)Water Body using 16-18 signatures for every image and recode them into four classes using recode techniques in ERDAS imagine. After getting two classified map from before and during the flood occurring period finally matrix union has been conducted between the two maps to identify the damaged area using pixel value of two different maps.

Results and Discussion

Flood mapping assessment in Naogaon district

The study area has experienced a huge amount of changes due to flood during the year between 2004-2017. For the year of 2004, two Landsat images are taken for analysis purpose. Figure 2 shows the land use changes for two months in year 2004. In the figure, the image of (a) March 25, 2004 which is taken for showing the land use conditions before occurring flood and the image of (b) October 19, 2004 is taken for showing the lands use conditions of during flood.

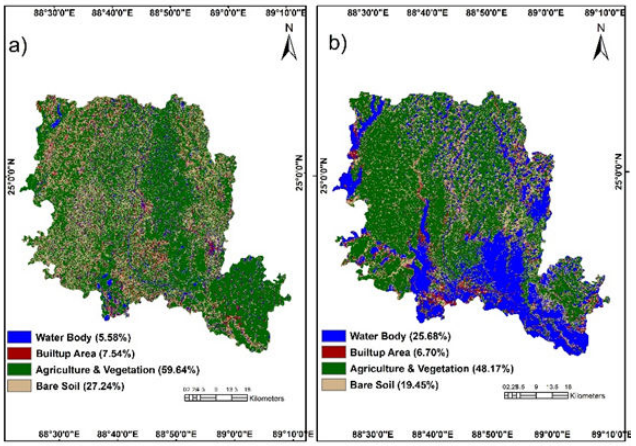

Figure 2: a) Land use map before occurring flood (March 25, 2004) and b) Land use map during flood (October 19, 2004).

The interpretation of Landsat image (a) represents that the study area was 5.58% of the water body, 7.54% of the built-up area, 59.64% of agricultural and vegetation land and 27.24% bare soil of 3449.197 sq-km area. The data shows only 5.58% of water body existed before an overflow of water. But after increasing the overflow of water in the month of October 2004, the percentage of water body represents a massive change. The Figure 2b shows the massive changes of water body during the flood which affected all other land uses. The figure represents that the percentage of water body converted from 5.58% to 25.68% which impacts on all other land uses. Due to an increase of water body, the percentage of built-up area was also shifted from 7.54% to 6.70%. Similarly, increasing of water body also effects on agricultural and vegetation land and the percentage was shifted from 59.64% to 48.17% of 3449.197 sq-km lands. The percentage of bare soil also decreased from 27.24% to 19.45%. The results indicate that, due to the overflow of water most vegetation and agricultural land were flooded which washed out most of the agricultural crops and causes negative impacts on rural people as well as economy. In addition, 0.84% of the built-up area was also flooded because of occurring flood and people became homeless. The most underlying finding of the analysis of the flood of 2004 is, the flood covers most of the land about 692.3052 sq-km area of Naogoan District and washed out a huge amount of agricultural crops and built-up areas.

Another analysis is taken place of the year of 2007 in Naogoan District. Figure 3 represents the land use changes where the image of (a) March 18, 2007 which is taken for showing the land use conditions before occurring flood and the image of (b) August 7, 2007 is taken for showing the lands use conditions of during flood. The comparison of the two images gives the information about the land use changes and by why the changes occurred. If anyone concentrates the water body changes of the year of different months, then the percentage of flood damage will be clarified. The Figure 3b shows the conditions during the flood where the percentage of water body was 16.83% which was converted from 5.78%. The amount of and flooded was 380.8071 sq-km of 3449.197 sq-km. Due to an increase of water body, the percentage of built-up area was also shifted from 10.2% to 8.69%. Similarly, increasing of water body also effects on agricultural and vegetation land and the percentage was shifted from 51.80% to 45.68% of 3449.197 sq-km lands and bare soil land was shifted from 32% to 28.81% due to flood. The result indicates that, due to the overflow of water most vegetation and agricultural land were flooded which washed out most of the agricultural crops and causes negative impacts on rural people as well as economy. In addition, 1.33% of the built-up area was also flooded because of occurring flood and people became homeless.

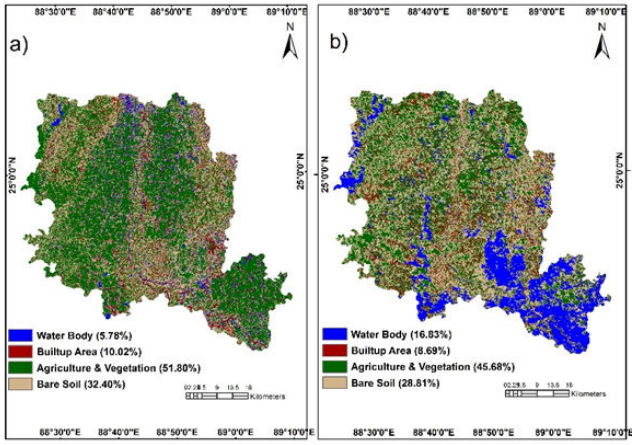

Figure 3: a) Land use map before occurring flood (March 18, 2007) and b) Land use map during flood (August 7, 2007).

Figure 4 shows the land use changes where the image of March 18, 2012 (a) which is taken for showing the land use conditions before occurring flood and the image of June 30, 20012 (b) is taken for showing the lands use conditions of during flood.

The interpretation of both images represents the geographic descriptions of the flood. In April there was only 9.60% of water body but after occurring flood, it raised to 33.02%. The percentage shows the deadliest effects of the flood that not only affected by water body but also affected all other land uses. The flood washed away 2.63% of the built-up area which caused a huge amount of economic losses as well as made the victims homeless. It also washed away the extensive amount of agricultural and vegetation lands where percentage fall down from 41.81% to 34.00%.

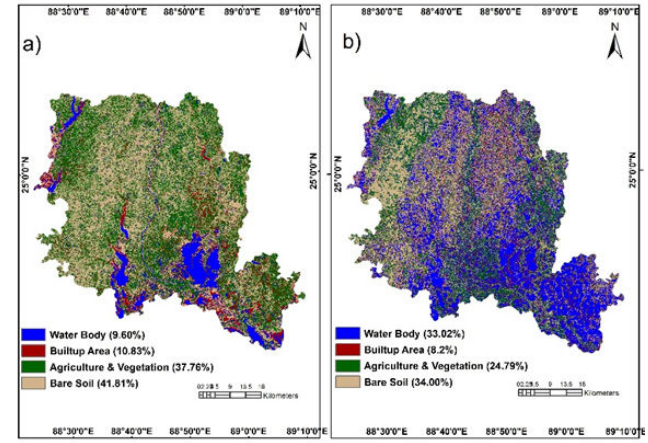

Figure 4: a) Land use map before occurring flood (March 18, 2012) and b) Land use map during flood (June 30, 20012).

Recently the deadliest flood occurred recently all over Bangladesh especially in the northern portion of the country. As Naogoan is situated in the northern portion of Bangladesh, that's why the district was a direct victim of the action of the flood. For analysis purpose two Landsat images are taken which is shown in Figure 5. In the figure, represents the land use changes during the year of 2017. In the figure, the image of April 14, 2017 (a) which is taken for showing the land use conditions before occurring flood and the image of August 5, 2017 (b) is taken for showing the lands use conditions of during flood.

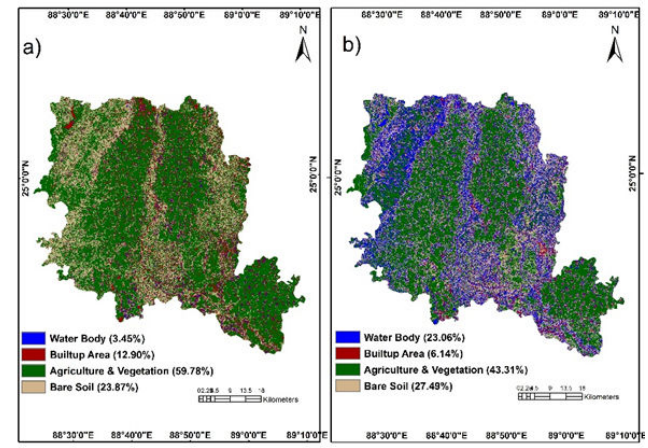

Figure 5: a) Land use map before occurring flood (April, 2017) and b) Land use map during flood (August, 2017).

The result shows that, the percentage of water body increased because of the overflow of water from 3.45% to 2.06% of 3449.197 sq-km. It indicates that the increasing water affected all other land uses mostly in agricultural and vegetation lands. The land uses such as built-up area was shifted from 12.90% to 6.14%, agriculture and vegetation lands were shifted from 37.76% to 24.79%.

Flood level change assessment

Figure 6 represents the flooded area with respect to their corresponding year. In 2004 693.31 sq-km land was flooded and in 2007 the total under water land area was decreased to 38.81 sq.-km. But in 2012, another flood acted in Naogoan District and the total flooded area was increased to 807.89 sq.-km and recently in 2007 the total flooded area was 676.34 sq-km.

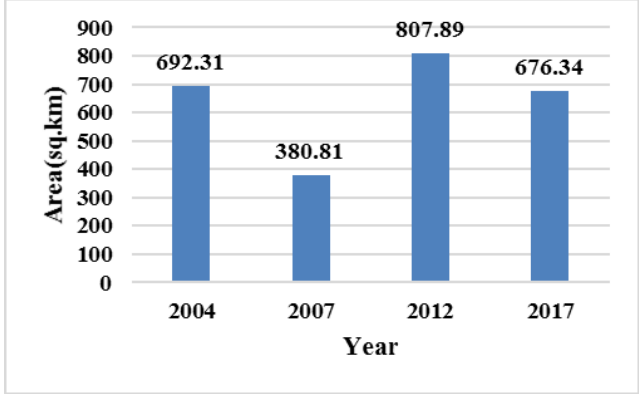

Figure 6: Area (sq.km) under Water during Flood.

Figure 7 shows the percentages of the water body at flood occurring moths. The line shows that, in 2004 the percentage of water body increased to 25.68% due to flood. Similarly, due to flood, the percentage of water body increased in 2007, 2012 and 2017 to 16.83%, 33.02% and 23.06%. The key finding of the analysis is, the percentage of a water body can be increased more than 30% and if it will, then the extensive area of valuable land would go under water and would create a physical and economic loss of Naogoan District.

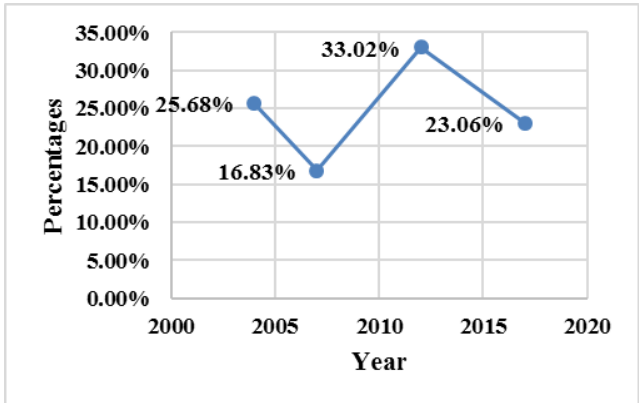

Figure 7: Percentage of Water Body at Flood Occurring Months.

Damage assessment of agricultural land and buildup area during flood

Figures 8 and 9 shows the total percentage of loss during flood with their corresponding year. The figure represents that percentage of damage to built-up area was increasing year after year, that means due to increasing of urbanization, built-up area damages was increasing from 0.84% to 6.76%. In the year 2017, people of Naogoan District suffered most because of losing their household due to food.

In addition, the figure also represents the total percentage of agricultural and vegetable damaged land with its corresponding year. The percentage fluctuated in a different year. In 2004, the percentage was 11.47% but in 2007 the percentage decreased to 6.12%. After 2007, the damage of agricultural and vegetation land was increased and turned to 16.47% in 2017. The most underlying key point is that, day-by-day due to flood, property as well as agricultural and vegetation lands are destroyed most and therefore the economic loss is increasing constantly which adversely affect the country's economic condition.

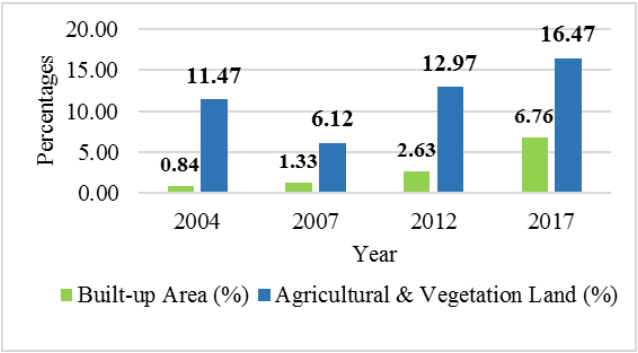

Figure 8: Percentage of Built-up and Agricultural and vegetation land damage.

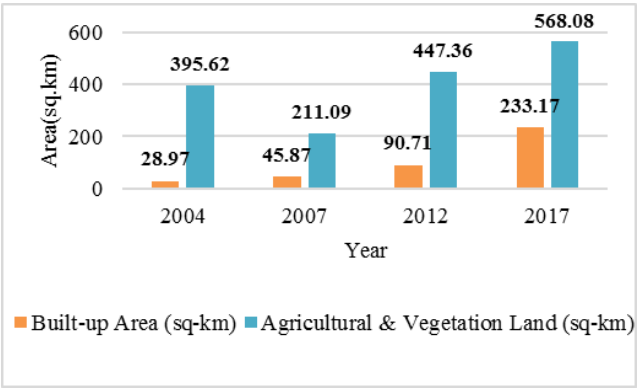

Figure 9: Built-up and Agricultural and vegetation land damage area (sq.km).

Conclusion

The research presented in this article formulates an efficient methodology to accurately delineate the flooded areas with the help of remote sensing data and GIS tools in Naogoan District, Bangladesh. Flash flood is a natural hazard that poses a risk to both populations, structures and agriculture land within the affected areas. There are several factors that affect the amount of runoff which help determine the intensity of flooding. Therefore, physical characteristics such as impervious surfaces, the hydraulic rating of soil, and flow accumulation of water were combined with demographic characteristics to create a composite flood hazard index. In this paper

some applications of ArcMap are used to calculate the flooded area using LANDSAT Images. It is estimated that the LANDSAT data could help to map the flooded area with an accuracy of 73–81% depending on various indices used. From the analysis of flood damaged area from 2004 to 2017 most damages happen in the agricultural and vegetation lands and in every five years interval its keep raising from 3.95.62 sq.km (11.47%) to 16.47% area. The maps can help the decision makers to identify the flood risk zones. It also helps the decision makers for planning residential, urban and land use system of a catchment area. It also provides the useful information to the town planners to use relocation, mitigation, modernization, flood protection and flood management system to reduce the properties and live losses. The study also suggests the further use of the remote sensing data and GIS tools for flood risk zones mapping. The study shows that Naogoan District area comes under high risk due to low gradient and slope watershed and surrounded by numerous small and large rivers and here needs proper flood management by accurate flood mapping.

Acknowledgement

The authors would like to thank US Geological Survey (USGS) for Landsat archives.

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