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FLOOD HAZARD MAPPING OF SURMA RIVER BASIN IN SYLHET CITY

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Abstract

As flood is one of the major disasters of Bangladesh and does immense damage to the lives and livelihood of locals living near or in the flood prone zones, it is necessary to study all possible water bodies and their nearby areas. The popularity of using software based data management tools to justify existing vulnerabilities and the overall status of flood and flood hazard in Bangladesh has been observed in recent years while many studies of flood hazard have been found in the literature. It was therefore aimed in this current study to determine the status of flood throughout the years 2006 to 2015 in the district of Sylhet. The discharge capacity of Surma River has been calculated for 25 year return period and a flood hazard map has been generated using GIS which shows the river has not sufficient capacity to carry all the water during peak flow which results in water logging in Sylhet city. Although the overall capacity of the Surma River is much larger than the total yearly discharge and runoff, caution is necessary for a flash flood. At the end, the digital elevation model has been used to understand the elevation of the study area.

Keywords: *flood, geo-statistics, GIS map, hazard, ordinary kriging, Surma River*

Introduction

Floods are one of the highly devastating natural hazards in South-Asia. It is the most common natural disaster of Bangladesh. The country is deltaic in shape and is situated at the Ganges-Brahmaputra-Meghna (GBM) basin which is the third largest fresh water outlet of the world's oceans. The country has to bear the enormous pressure of this flow whereas only 7% of the total catchment of the GBM basin lies within the territory of Bangladesh. This unique geographical feature makes Bangladesh more susceptible to regular flooding. Bangladesh is expected to be one of the most affected countries of global climate change. So, the flood characteristics are likely to be changed with the changing climate. Characteristics study of the flood is fundamental for planning the proper adaptation strategy and effective flood management. Sylhet city is vulnerable to flooding because of having heavy rainfall during the monsoon season. It is located in the north-eastern zone of Bangladesh. The area of Sylhet city is 26.5 km^2 with a population about 479,837 (BBS, 2011). Built out of hilly areas this city is situated in an area that is higher than sea level, from 1 meter to 7 meters (Tanjil, 2016). As the city is on higher land than most another part of the country it has very low chances of long duration flood. But the heavy rainfall throughout the rainy season and most of the year, chances of a flash flood are high. In this manner, flood hazard maps can be of various use. Flood hazard maps are designed to increase awareness of the likelihood of flooding among the public, local authorities and other organizations. They also encourage people living and working in flood-prone areas to find out more about the local flood risk and to take appropriate action (Environment Agency, 2010). Flood hazard maps can be used by developers to determine if an area is at risk of flooding, and by insurers to determine flood insurance premiums in areas where flood insurance exists. The creation of flood maps usually combines topographic data with historic or modeled information on extreme sea levels and wave heights. This allows the determination of the water level at the coast under extreme conditions and shows how this water could flood inland. This is likely to involve the deployment of storm surge and wave models. Geographic Information Systems (GIS) are frequently used to produce flood hazard maps. They provide an effective way of assembling information from different maps and digital elevation models (Sanyal and Lu, 2003). Using GIS, the extent of flooding can be calculated by comparing local elevations with extreme water levels. Flood Hazard maps will give information on the spatial and temporal flood depth and water logging situation at different climate condition.

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Methodology

Selection of study area

The study area is Sylhet city which is the main city of Sylhet district. River Surma, the primary river of Sylhet flows through it. As one of the basic requirements of the study area is a Digital Elevation Model (DEM) and SRTM Digital Elevation Model of the study area, was used in taking the decision of selection of the low laying flood pone area. In a broader sense, the investigated area is lack of any remarkable stream of Bangladesh, but the area is well drained by a network of locally important streams most of which are both structurally lithologically controlled and dendritic in pattern. The relatively major streams are fewer in number and are of perennial type, that is they flow even in the dry season, but during rainy season they flow with their full strength and become able to carry large boulders to distant places whereas the minor streams are large in number and of intermitted type, that is they are seasonal in their flow, and water ceases to flow during the dry spell.

The basic idea is to find out how much water spills out of the river Surma. For that purpose, Data of the annual rainfall, discharge of river Surma and the capacity of the river are necessary.

Water level data

The daily water level data were collected from BWDB for the years 2006 up to 2015 (10 years). This dataset was then converted to monthly water level data by selecting the peak/maximum water level of a month. This gives a better overview of the river Surma water level. These data set then plotted in a graph to show the water level across different time. The Menn-Kendall analysis was also carried out to see if the river showed any trend.

Rainfall data

The daily rainfall data was collected from BWDB for the year's 2006 up to 2015 (10years). This dataset was then converted to monthly rainfall data by selecting the peak/maximum rainfall of a month. This gives a better overview of the Sylhet city rainfall. Then the data was converted into a format (.xlsx) suitable for use in the Arc map software. Rainfall was then converted to Runoff and was used for Kriging in the Arc map software.

Runoff calculation

The expected volume of monthly runoff for 50% probability was estimated for Surma river using the total Table 1) monthly rainfall depth in Sylhet station for the period (2006-2015)

Table 1. Expected runoff depth of monthly rainfall for 50% possibility

Probability	Monthly Rainfall (mm)	Monthly Rainfall (MCM)	Monthly Runoff* (MCM)	Equivalent Runoff depth (mm)
50%	210	87.15	40.96	98.7

*Using runoff coefficient method

R=k P Eq. (1)

Where,

R = runoff depth (mm)

K = coefficient of runoff (Sogreah, 1978)

P = Rainfall depth (mm)

Runoff volume calculation

Runoff volume is the total rainfall depth of a catchment area. Therefore, runoff volume is obtained by the following formula:

V= R * A Eq. (2)

Where A is the catchment area and V is the runoff volume.

The study area had a catchment area about 1 km^2 and the runoff depth was calculated in mm. To simplify, the following was obtained with the unit (m^3)

$$V = \frac{R}{1000} * 1 * 1000 * 1000 = 1000R$$

Digital Elevation Model (DEM)

Digital Elevation Model is one of the essential data for flood study of an area. DEM data of the study area were collected from the NASA Shuttle Radar Topographic Mission (SRTM). The NASA Shuttle Radar Topographic Mission (SRTM) digital elevation data (DEMs) were downloaded from the SRTM FTP server (ftp://e0srp01u.ecs.nasa.gov/srtm/version2/) for the study area. The resolution of DEM is 90 meter. The DEM data were further processed using ArcGIS 10.0 to fill in the no-data voids or cells. The processing involved the production of vector contours and the re-interpolation of these derived contours back into a raster DEM using ILWIS contour interpolation tool. DEM was used to develop flood inundation maps and land types classification. Difference between water level data obtained from the interpolated water level surface of different return periods and land surface values have been considered as inundation depth in the study area. The DEM is also used for the preparation of a vulnerability map for different flood risk elements.

Discharge data

The daily discharge data were collected from BWDB for the year, 2006 upto 2015 (9years). This dataset was then converted to monthly discharge data by selecting the peak/maximum Discharge of a month. This gives a better overview of the river Surma discharge. Then the data was converted into a format (.xlsx) suitable for use in the Arc map software.

Reservoir capacity calculation

In order to understand the total capacity of River Surma, calculation of the total volume of the study area is necessary. Calculating the reservoir capacity requires estimating the shape of the reservoir. As the reservoirs are irregular both in cross sections and in long sections it is not easy to calculate. In many cases reservoirs are estimated from the reservoir width, the throwback and maximum impounded water depth (Lawrence and Cascio, 2004). The formula is based on the equation below with different values for the two constants.

$$C = k_1 * k_2 * D * W * T \quad \text{Eq. (3)}$$

Where, C = Capacity, D = Depth, W = Width, T = Throwback

And k_1 k_2 are constants that have different values based on the shape of the reservoir

Following formula is used from the dam design manual (Lawrence and Cascio, 2004).

$$C = 0.25*1*D*W*T$$

(Fowler, 1977), where $k_1 = 0.25$ and $k_2 = 1$, for valley cross section shapes.

The study area has a roughly estimated 11.3km throwback which was later reduced to 10km for the calculation of capacity. This provides a marginal volume left out of calculation which gives a better safety check.

The formula was then simplified as below with the unit m^3

$$C = [0.25 * 1 * D * W * T(= 10) * 1000] = 2500DW$$

Width and depth (cross section) of the river was obtained from BWDB for 3 stations, namely S#29 (Sheikhghat), S#30 (Mendibag) and S#33 (Kanaighat). Among these, the width in the S#30 station was almost double compared to the other two which increased the over-all capacity of the study area.

Geostatic analysis steps

The methodology of this study begins with the selection of the study area. The Discharge data of the Surma river and the Rainfall data of Sylhet city were obtained from BWDB. This data was then processed into the monthly maximum dataset. The geostatic analysis is done under the kriging method using Arc GIS platform. Various kriging methods were used to find better visual representation.

Geo-statistics

The theory of Geo-statistics has been expressed in many textbooks, including those of Issaks and Srivastava (1989) and Goovaerts (1977). Here a brief discussion of the geo-static methods that were used in the study is presented. In geo-statics, a semi-variogram is used to quantify the differences between sampled data values as a function of their separation distance, h. In practice, the experimental semi-variogram *(h), is calculated as follows

$$y * h = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - Z(x_i + h)]^2 \quad \text{Eq. (4)}$$

Where, N(h) is the number of sample pairs that are separated by a vector h, and Z(x) and $z(x_i+h)$ are the values of the variable z at locations of x_i

and x_i+h, respectively. However, for kriging analysis, an appropriate theoretical model should be used to fit the experimental data. The most widely used models include the spherical, exponential and Gaussian models. The spherical model used in the study is defined as follows:

$$y(h) = C_0 + C[\frac{3h}{2a} - \frac{1}{2}(\frac{h}{a})^3] \text{ where, } h \leq a; \quad \text{Eq. (5)}$$

$$y(h) = C_0 + C \text{ when, } h > a; \quad \text{Eq. (6)}$$

Where, C_0 is the y-axis intercept (the nugget effect), $C_0 + C$ is the "sill", which is near the sample variance, and a represents the range of influence.

Among many kriging procedures, Ordinary Kriging was chosen due to the lack of sufficient data.

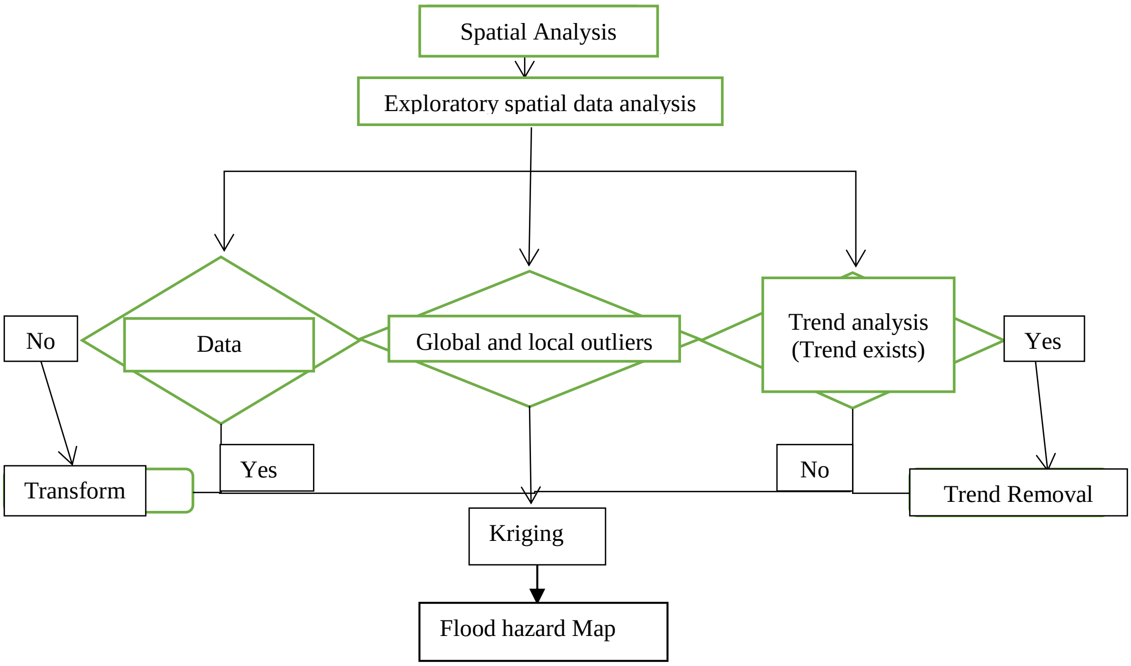

Fig. 1. Flow chart of the geo-static analysis steps

Ordinary Kriging (OK)

OK assumes that the mean is stationary but unknown. In addition, the OK estimator is known as the best linear unbiased estimator (BLUE) and is defined as follows (Journel and Huijbregts, 1978)

$$z^*(x_0) = \sum_{i=1}^{n(u)} \lambda_i z(x_i) \text{ with } \sum_{i=1}^{n(u)} \lambda_i = 1 \quad \text{Eq. (7)}$$

Where $z^*(x_0)$ is the OK estimator at location x_0, $z(x_i)$ is the observed value of of the variable at location x_i, λ_i is the weight assigned to the known values near the location to be estimated and n(u) is the number of neighboring observations. The values of λ_i are weighted to obtain a sum of unity, and the error variance is minimized as follows:

$$\left\{\sum_{j=1}^{n(u)} \lambda_i \gamma\left(x_i, x_j\right) - \mu = \gamma\left(x_i, x_j\right)\right\} \quad j = 1, \ldots, n(u) \sum_{j=1}^{n(u)} \lambda_j = 1 \quad \text{Eq. (8)}$$

Where, μ is the Lagrance co-efficient for minimizing the OK estimation variance, $\gamma(x_i, x_j)$ is the average semivariogram value between the observed values and $\gamma(x_i, x_j)$ represents the average semivariogram value between the location x_i and the location to be estimated. The OK estimation variance (or standard deviation) can be used as a measure of the estimation uncertainty as follows:

$$\sigma^{2*}(x_0) = \sum_{i=1}^{n(u)} \lambda_i \gamma (x_i , x_0) + \mu \qquad \text{Eq. (9)}$$

Results and discussion

There are several statistical tests available for testing stationary-ness of time series (Hirsch Et Al 1993). In the present study, the regression test for linear trend has been carried out for the annual water level series from 2006 to 2014 at Kanaighat SW-266 station, Sylhet SW-267 station of Surma-Meghna River and Islampur SW-332 station of Dhala River. These tests start from a null hypothesis (H0) that the observations are samples from a stationary process. The likelihood of this hypothesis is evaluated based on the value of a test statistic, a property of the data set. A large deviation of the test statistic from the stationary value is unlikely to be coincidental. The P-value is the probability that the deviation of the test statistic from the homogeneous case is coincidental. If the p value is less than the significance level α (alpha) = 0.05, H0 is rejected. Rejecting H0 indicates that there is a trend in the time series while accepting H0 indicates no trend was detected. The p-value is a percentage. It tells you how likely it is that the coefficient for that independent variable emerged by chance and does not describe a real relationship. A p-value of .05 means that there is a 5% chance that the relationship emerged randomly and a 95% certainty that there is indeed a positive trend. This is the "Significance F" value in Excel; some other statistical programs call it by other names. This measures the likelihood that the model as a whole describes a relationship that emerged at random, rather than a real relationship. As with the p-value, the lower the significance F-value, the greater the chance that the relationships in the model are real.

Arc-Map analysis

Results were produced in the form of maps. These maps include Capacity of Surma river, Discharge pattern in Surma river, Rainfall affecting the existing flow and Digital Elevation Model (DEM) of the study area.

River capacity: From the equation, the corresponding capacity at that point of river Surma in m^3 can be obtained and plot them in the arc map software. After that, Geostatic analysis was carried out with Kriging which gave the following map (Fig. 2)

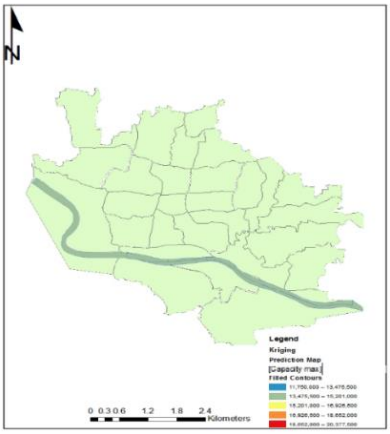

Fig. 2. The average capacity of Surma River

Here we can see that on an average, the river has a capacity of about 15 thousand m^3 with a maximum of about 20 thousand m^3 in the Machimpur region.

Water discharge through River Surma

Originating from the Barak River of eastern India, Surma river's discharge data of three different stations are featured in the following Fig. 3, where discharge rate decreases from east to north-west.

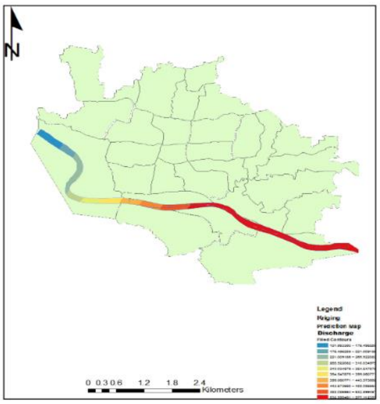

Fig. 3. Water discharge (2006-14) pattern in the River Surma.

Discharge of the river with additional rainfall water

Rain water runoff has been induced in the following Fig. 4 along with discharge. Here the total discharge is lessened by the rainfall.

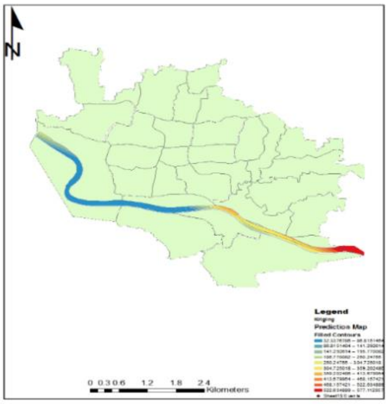

Fig. 4. Water discharge with rainfall (2006-2014) induced pattern in the river Surma

The following map (Fig. 5) contains information about the elevation of the study area with respect to mean sea level. As the study area is mostly in between -101inch to 291inch or -3 meters to 7.5 meters. It is comparatively on higher land than the rest of the country, which helps in flushing out the excess discharge through the river or through the smaller water ways in the study area.

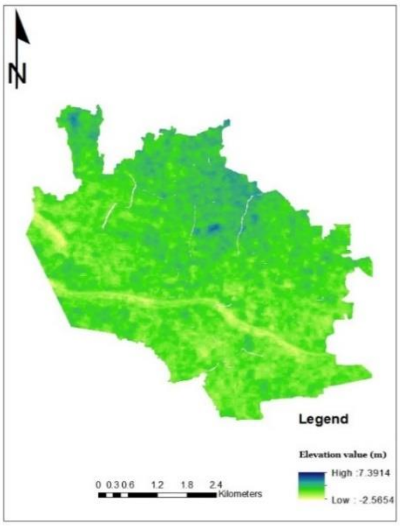

Fig. 5. DEM of the study area

Again Fig. 6 shows a comparison between the models created in the Arc map with the DEM. It can be noted that there are low lying areas quite next to the river.

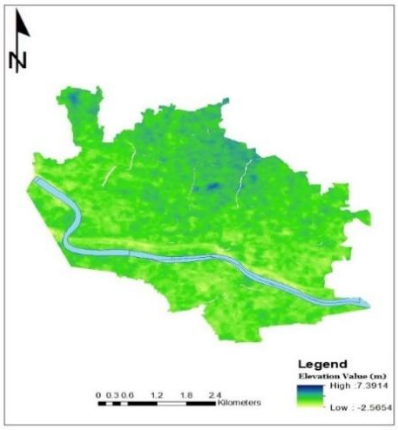

Fig. 6. DEM compared with the study area of Surma River

Flood hazard mapping

The total maximum peak discharge through Surma River at Sylhet City Corppration (SCC) is calculated as 321.35 m^3/s. Based on discharge a flood hazard map (for 25 year return period) has been generated using GIS (Fig. 7)

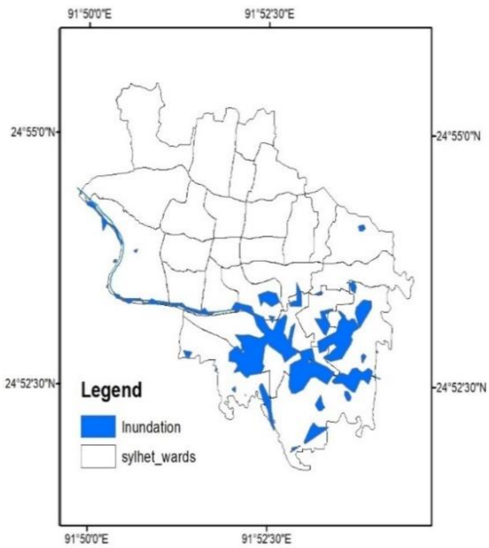

Fig. 7. Flood hazard map for Sylhet City

Conclusion

There is a decreasing trend of water level in Islampur SW332 station and there is no linear trend that could be detected at the 5% significance level in Kanaighat SW 266 and Sylhet SW267 stations. River capacity is sufficiently large enough to keep the flow within the channel throughout most of the year.

Rainfall increases overall precipitation count in the river throughout the year. A hypothetical ten times the regular rainfall induced map shows a significant rise in the precipitation count of the river which shows that the river is quite sufficiently large to support the excess water.

The tri-yearly analysis shows the discharge trend changes in recent years. The years 2006-08 shows the high discharge near the Eastern region of the study area. The years 2009-11 follows a similar trend with slight shifting to the western part. The years 2012-14 drastically shifted toward the west and to the middle region of the study area as well as the heart of the city. From the DEM, low lying lands near the study area are in the primary risk of flash floods.

From flood inundation mapping it is clear that the water bodies in SCC are not sufficient enough to carry all the water during the peak flow in near future. So, water logging will be a major suffering to the people. Moreover, some parts of the city will be inundated due to flooding of Surma River. Taking some flood control management and designing a proper storm water drainage system facility in all across Sylhet City Corporation must be done in order to get rid of these vicious sufferings.

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