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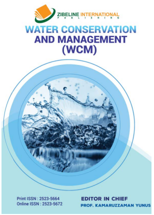

THE IMPACT OF RAINFALL VARIATIONS ON FLASH FLOODING IN HAOR AREAS IN BANGLADESH

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ABSTRACT

The north-eastern part of Bangladesh is famous for rice production and fishing. A lot of bawl shaped depressed areas are located in this region which is locally called as haor area. Among seven haor districts Sunamganj has the maximum extent of haors and net cultivable area. The flash flood which is recurrent during April and May is the number one ranked hazard that affects agriculture in Sunamganj severely. Flash flood in 2017 was the most devastated in the recent past. Different researchers predicted that the rainfall during April/May will increase here due to the impact of climate change in future. The objective of present study is to evaluate the impact of rainfalls on inundations owing to flash floods using rainfall runoff inundation model (RRI-model) proposed. Ten rainfall events are prepared for computations of inundation, using reference rainfall in April in 2017, and their sizes normalized by the reference event range from 0.6 to 2.0, respectively. The size level of a flash flood is determined by means of RRI-model by water surface elevation at Sunamganj station in the Surma river and it is translated into return period. The inundation process were computed for each of the specified rainfall events, together with inundation depths in Tahirpur upazilla (sub-district) in Sunamganj district in order to investigate the relation between the sizes of rainfall event, flash flood event and extents of inundation. The computed results suggest that the return periods of the computed flash floods are determined as 3.7,10, ---,142.86 years corresponding to the normalized rainfall sizes such as 0.6, 0.9, ---, 2.0 and suggest that inundated areas increase with the size of normalized rainfall and increase sharply in the range of rainfall size larger than about 1.1-1.2. Such results are useful to identify and quantify the associated inundated areas due to temporal variation of rainfall which is necessary for disaster preparedness and management.

KEYWORDS

Haor area, flash flood, RRI-model, return period, inundation.

1. INTRODUCTION

Flash flood is the common hazard in the north eastern part of Bangladesh due to upstream hilly topography and steep slope of the rivers flowing through the area. Many bawl shaped depressed areas are situated in this region. These bawl shaped flood plains are known as haor area. Boro rice is the only major crop in the haors. It accounts for most of the region's income and consequently providing most of its employment [1]. Flash floods suddenly inundate boro crops, damage infrastructures and often cause loss of lives and properties in haors region [2]. Almost 80% of haors area is covered by boro rice during January to May (pre-monsoon), which produces 18% of the total rice production in Bangladesh [3,4].

Farmers in haors area want to harvest the boro crop before flash flood strike the region but it is a recurrent phenomenon by which farmers experience to lose their crops. So, the flash flood during April and May is the top ranked hazard that affects agriculture in haors area severely. Marginal farmers and day labourers are the most affected people in the haor areas. The most marginalized living depends on the physical labour in agriculture field and fisheries. Nirapad Situation reported on 4 May, 2017 that farmers on seasonal crop harvesting in this region have lost approximately 263,808,000 person/day of seasonal daily labour work due to the flash flood in 2017 [5]. So, Flash flood damage (i.e. agriculture damage) in 2017 in the recent past was catastrophe for haor area.

In addition to that many researchers predicted that the flash flood intensity will increase in future in haor area. The timing of flash flooding will also be shifted. It is concluded by a group researcher that the pre-monsoon precipitation will be increased by 6.77% to 22.78% in 2050 [6]. He analyzed the impact of climate change in haor area through GCM model. On the contrary it is found by another group that the rainfall reduced all over Bangladesh in recent years [7]. The impact of climate change on the hydrological processes has been analyzed by some researchers [8]. He predicted that pre-monsoon rainfall in haor area will be increased by 11.4% in the near future (2015-2039) while this increased amount is 33.6% in the far future (2075-2099). He also found that the impact of climate change in the Meghna Basin (haor region) is larger compared to that in the other two basins in Bangladesh such as; the Ganges and the Brahmaputra.

A projected that the pre-monsoon rainfall in haor area will increase about 0.42-75% by 2080 due to the global warming condition [9]. In this context, it is important to evaluate the impact of rainfall variations in haor area. In addition to that it is also important to identify the vulnerable area which will be affected by flash floods due to the impact of rainfall variations in future. The objectives of this study are 1) to find out a relationship between rainfall amount and water level return period, 2) to evaluate the impact of rainfalls on inundations owing to flash flood, and 3) to identify the vulnerable area which will be inundated in future due to the increased rainfall amount.

2. STUDY AREA

Tahirpur upazilla (sub-district) in the Surma river basin in Sunamganj district is studied here. The basin area is covered by the Indian hilly region at upstream and irregular low elevated area inside Bangladesh at downstream (Figure 1). Bangladesh is located at the interface of two quite different settings. The north of the country lies on the Himalayas foot plain and the Khasi-Jainta hills, and the south lies on the Bay of Bengal and the Indian Ocean [10]. Due to this setting, many rivers pass through these low-lying areas and fall ultimately into the Bay of Bengal. The topography of the north-eastern part of Bangladesh is irregular; both small hills and depressed lands are located [11]. Indian part in my study basin is mainly hilly area and all of the rivers originated from India (Figure 1). Bangladesh part in the studied basin is mainly used for agriculture while Sylhet metropolitan area mainly represents the urban area. Sunamganj station in the surma river is the main station in the studied basin. So, the model is calibrated and validated at Sunamganj station.

Tahirpur upazilla is a border upazilla with an area about 315.33 km². The land area is about 295.4 km², reserve forest is about 7.93 km² and rest of 12.00 km² is riverine area. Many haors are located in Tahirpur such as; Angaruli, Shanir, Matian, Mohalia, Halir, Gurmar etc [12]. Five active sluice gates are located in Tahirpur to drain out the water from haors with gravity [12]. Baulai river is the main river passing through Tahirpur upazilla and meet at downstream with the Surma river (Figure 1).

The average annual rainfall in Sunamganj is 4055 mm [12]. From May to September, the rainfall in this region is high while it is low in the winter (December to March). The world highest precipitate area Cherrapunji is located a few kilometers far from the Bangladesh border inside the studied basin (Figure 1). Heavy rainfall occurred during flash flood period in 2017 caused sudden inundation and massive agriculture damages in haor area. About 167.4 M$ agriculture damage was caused by the flash flood in 2017.

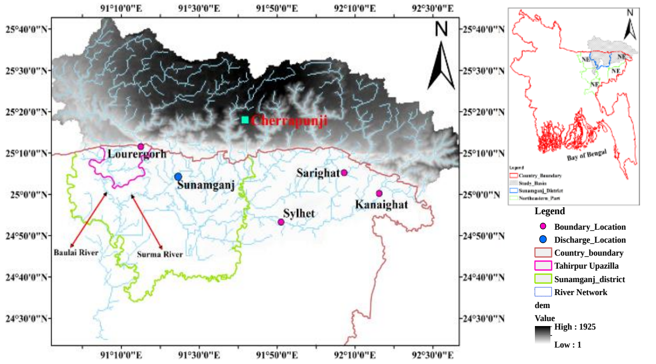

Figure 1: An Overview of the Studied Basin

3. METHODOLOGY

A methodology of this study is presented in Figure 2. A hydrodynamic model namely Rainfall-Runoff-Inundation (RRI-model) developed by International Centre for Water Hazard and Risk Management (ICHARM) is used for this study [13]. RRI-model is capable of simulating rainfall-runoff with associated inundation simultaneously. It deals with slopes and river channels separately. The flow directions inside model change based on water levels.

The RRI-model is calibrated with the flash flood in 2017. As a model input information, downloaded flow direction data is modified to match the river path with the original river shape. Variable rainfall amounts were applied in RRI-model considering the rainfall patterns in 2017 to simulate the respective water level at Sunamganj station. Rainfall pattern in 2017 is chosen because it is the historical highest rainfall pattern in the recent past. The simulated water levels by RRI-model are used to calculate the respective return periods using the probability curve by Gumbel analysis. The required parameters for Gumbel analysis have been calculated by 42 years (1975-2016) pre-monsoon highest flood level (HFL) data at Sunamganj station in the Surma river.

After that, the relationship between the rainfall amount (normalized rainfall using 2017 rainfall pattern) and water level return period size is developed. RRI can simulate the water level in the river and associated inundation simultaneously. By this way, the inundated area was then computed for each of the specified normalized rainfall events using ArcGIS tool, in Tahirpur upazilla in Sunamganj district in order to investigate the relationship between the sizes of rainfall event, flash flood event and extents of inundation.

3.1 Sources and Preparation of RRI Data

HydroSHEDS data was downloaded from the NASA Shuttle Radar Topography Mission (SRTM) website [14]. It is a website maintained by United States Geological Survey (USGS). Hydrological information was collected from Bangladesh Water Development Board (BWDB). The point-based rainfall information was distributed over the simulation domain by Thiessen polygon method. Land use information was downloaded from DIVA GIS [15] and it is then further processed by ArcGIS tool to categorize into three different land classes. Boundary conditions at four locations are applied such as; Kanaighat and Sylhet in the Surma river, Sarighat in the Sari Goyain river and Lourergorh in the Jadukata_Baulai river (Figure 1).

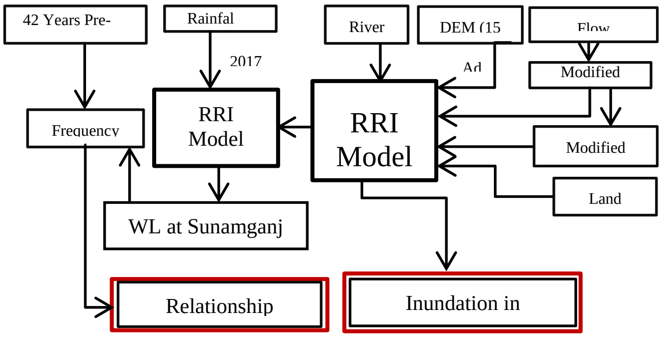

Figure 2: A Schematic Diagram of this Study

3.2 Water Level Frequency Analysis

Flood frequency represents the probability of occurrence of a specific flood event. Frequency analysis is one of the main techniques for defining the relationship between the magnitude of an event and the frequency of occurrence. Reliable flood frequency analysis has vital role for floodplain management. The flood characteristic mainly depends on the rainfall and flood plain characteristics. There are three types of extreme value distribution such as; Gumbel-type, Frechet-type, and Weibull-type. But, Gumbel distribution analysis has only been considered in this study to calculate the water level return period. The required parameters for Gumbel analysis have been calculated by 42 years (1975-2016) pre-monsoon highest flood level (HFL) data at Sunamganj station in the Surma river.

Plotting position is important for plotting in a probability paper thus Gringorten plotting position has been considered in this study. Water Level frequency analysis has done by Gumbel distribution using the formula presented below:

$$F(x) = e^{-e^{\{-\lambda(\mathrm{x}-x_0)\}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \square\square\square$$

$$q_i = \frac{i-0.44}{n+0.12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$\mathrm{x}_0 = \overline{x} - 0.45 * \mathrm{s(x)}$
$\overline{x}$ = Mean Value of the Data Set
$\mathrm{s(x)}$ = Standard Deviation of the Data Set
$\lambda = \frac{1.28}{\mathrm{s(x)}}$ *and*
$\mathrm{F(x)} = \mathrm{Non-exceedence\ probability}$
$\mathrm{a} = 0.44, \mathrm{n} = \mathrm{the\ sample\ size\ and}$
$q_i = \mathrm{Exceedence\ probability}$

4. RESULTS AND DISCUSSIONS

4.1 Model Simulation

The model is calibrated for the flash flood in 2017 and the selected parameters are shown in Table 1. The studied basin has been categorized into three different types namely hilly area, crop area and urban area. It is set K_v (vertical saturated hydraulic conductivity) =0 to represent the hilly area as the lateral subsurface flow and saturated excess overland flow dominate here. In the cropped or agriculture area, the vertical infiltration is very important thus Green-Ampt (G–A) infiltration model was considered [16]. It has been set by K_a (lateral saturated hydraulic

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conductivity) =0. The urban area has been set by both K_a=0 and K_v=0 as the overland flow dominates (no infiltration loss or no subsurface flow) here. S_f denotes the suction at the vertical wetting front while F_{limit} is the upper limit for the cumulative infiltration depth in the G–A model. The parameters n_{river} and n_{land} represent the Manning's roughness coefficients for river and land surfaces respectively (Table 1).

Table 1: Parameters Considered in RRI-Modeling

Parameters	Hilly Area	Crop Area	Urban Area
n_{river} ($m^{-1/3}$ s)	0.03		
n_{land} ($m^{-1/3}$ s)	0.15	0.15	0.15
K_{sv}/K_v (m/s)	0	1.89d-6	0
$_\varphi$ (gammaa)	-	0.471d0	0
(Sf=faif) (m)	-	0.273d0	0
K_a (m/s)	0.1d0	0.d0	0.d0
F_{limit} (m)	-	0.471	0
β	8.0d0	8.0d0	8.0d0

Figure 3 shows the daily simulated and observed discharge and water level at Sunamganj station during flash flood period (16 March to 19 April) in 2017. The rainfall in 2017 was mainly concentrated into a few days (Figure 3). The rainfall event in 2017 was the historical extreme flash flood event. Model performance is evaluated through the Nash-Sutcliffe efficiency (NSE) and RMSE-observations standard deviation ratio (RSR) calculation. The calculated NSE (RSR) are 0.95 (0.22). According to the criteria of Moriasi, it can be inferred that the model efficiency and performance is very good [17].

In this study, the water level at Sunamgnaj is very important. So, the peak water level is calibrated to match with the observed peak water level. Therefore, when the peak water level better matches with the observed peak, it is stopped the model calibration. Discharge is also considered to check the river capacity. The natural river cross sections are not rectangular rather the active width of the river changes over time with respect to WL. In the model, rectangular cross sections for the rivers were assumed (Figure 4). Although the cross-sectional shape is different but the capacities at peak are similar for both of the cross sections. This assumption leads the gaps in WL at the initial and falling stages.

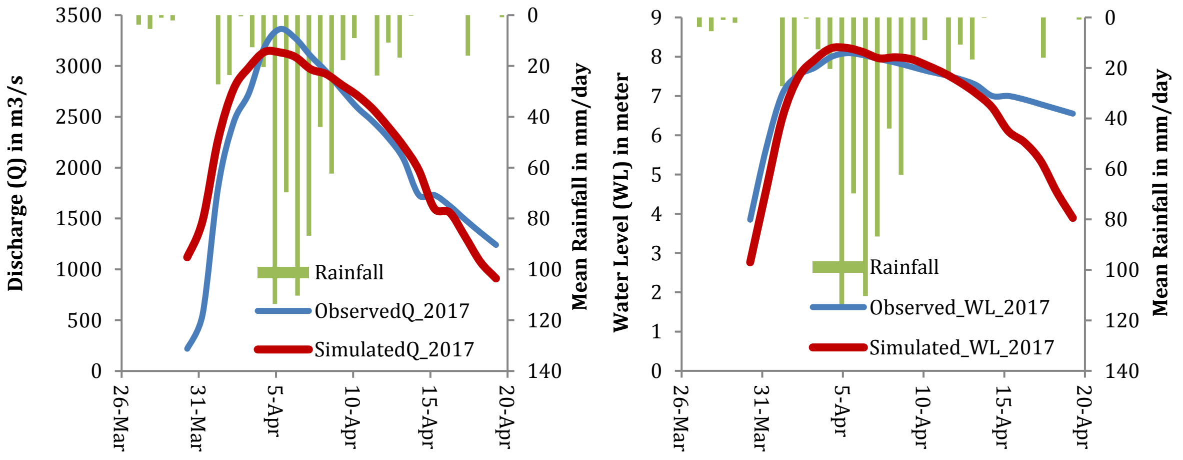

Figure 3: Observed and Simulated Discharge and Water Level at Sunamganj in 2017

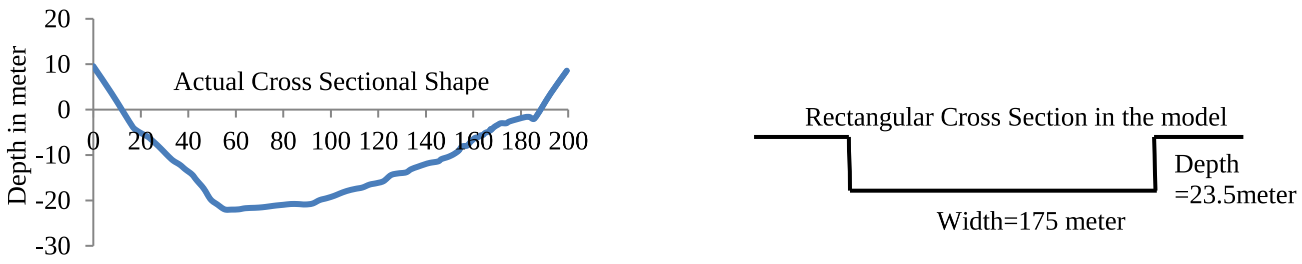

Figure 4: Cross Section of the Surma River at Sunamganj Station

4.2 Water Level Return Period

The water level return period by Gumbel distribution and by normalized rainfall (rainfall ratio) is presented in Figure 5. Ten rainfall events are prepared using reference rainfall in 2017, and rainfall sizes normalized by the reference events range from 0.6 to 2.0, to calculate the return period of water level simulated by RRI-model. A few researchers analyzed that the rainfall in the recent years over Bangladesh is decreased while many researchers predicted up to 75% rainfall increasing trend in future [9]. In this context the normalized ratio was chosen from 0.6 to 2.0. The water level return period increases sharply in the range of rainfall size larger than about 1.1-1.2. Masood predicted that pre-monsoon rainfall in this region will be increased by 11.4% in the near future while it is 33.6% in the far future [8]. It will cause about 20-year water level return period size (WLS) in the near future and 40 year WLS in the far future while the actual return period of flash flood in 2017 was 12.7 year. A few observed water level data shows as outlier while Gumbel distribution follows a line (Figure 5(a)).

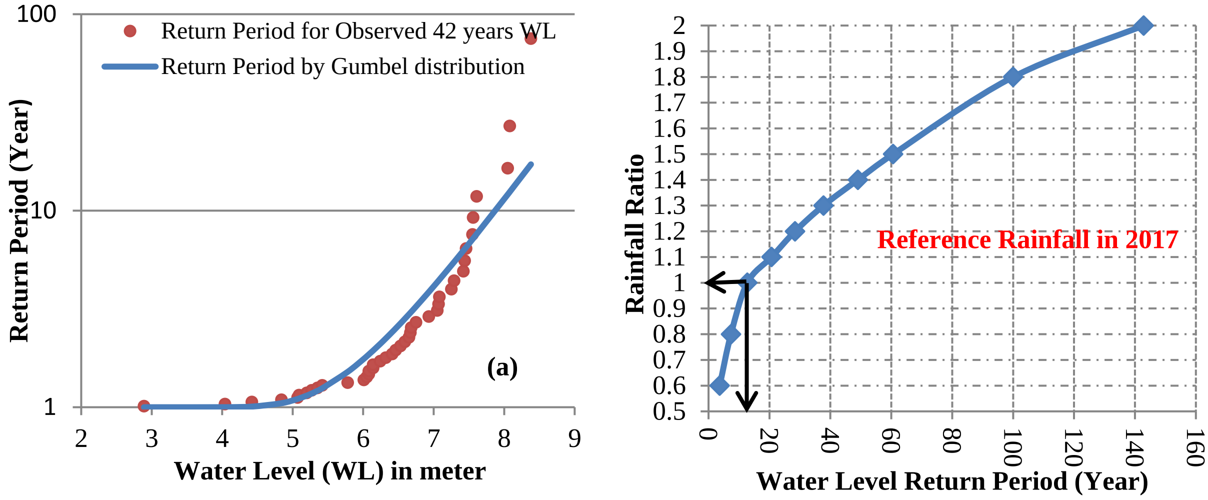

Figure 5: (a) Gumbel Distribution of the Observed 42 years WL (b) Water Level Sizes due to Different Normalized Rainfall using Reference Rainfall in 2017

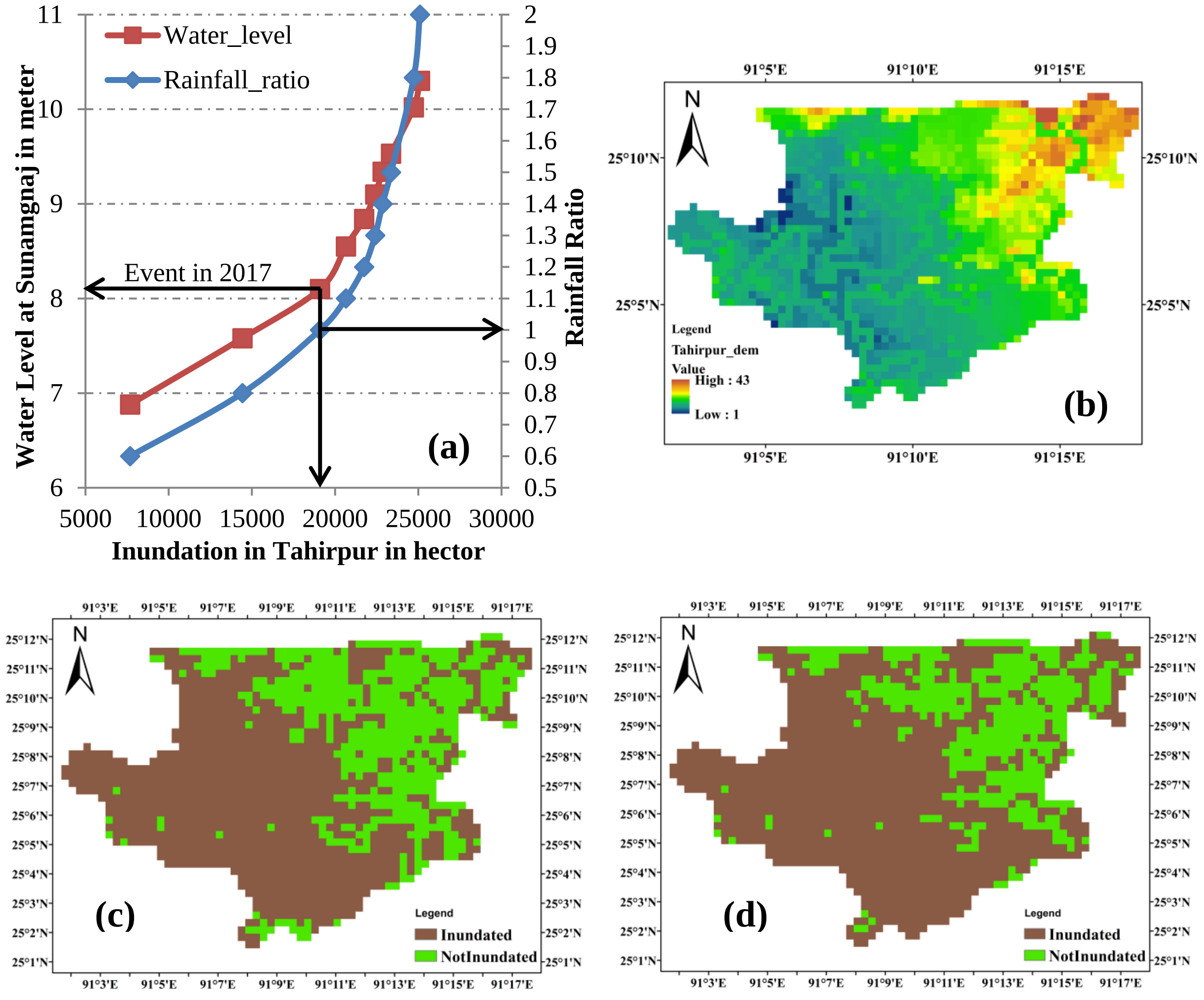

Figure 6: Tahirpur Upazilla (a) Relationship between Inundated Area due to Normalized Rainfall and Simulated Water Level at Sunamganj (b) Land Elevation (c) Inundation due to 10% increase in Rainfall (d) Inundation due to 30% increase in Rainfall

4.3 Inundation in Tahipur Upazilla

The inundated area in Tahirpur upazilla with respect to different rainfall ratio and associated simulated water levels have been presented in Figure 6. The land elevation of Tahirpur is also depicted in Figure 6(b). Most of the housing are located in the north-eastern part of Tahirpur and rest of the parts is mainly agriculture or permanent water body. Inundated area in Tahirpur due to 10% and 30% increase in rainfall has also been shown in Figure 6(c) and 6(d). Inundation depth respect to different rainfall events can be calculated through RRI-model while the extent of inundation with respect to different normalized rainfall is calculated using ArcGIS tool. If the inundation depth is more than 10 cm, it is considered as inundated area. The inundated area in Tahirpur increases with the increasing rainfall size. This inundation increased sharply in the range of rainfall size larger than about 1.1-1.2. This is due to the land area characteristics. Initially, the rate of increasing in inundation is high while it decreases with the increasing water level and rainfall ratio (Figure 6(a)). It means, initially more area is inundated but inundation depth is lower while for the further increasing in water level or rainfall amount, water spreads less rather the inundation depth is increased. This characteristic cause of initially higher extends of inundation. The topographic information of Tahirpur shows that the middle and lower part is low elevated while the elevation in the north eastern part is higher. So, more water can easily be accumulated in the middle part of Tahirpur. A lot of haors are located in the middle part of Tahirpur. So, initially this low elevated area is inundated while for the further increasing in rainfall amount causes of increasing in inundation depth. The flash flood return period and water level at Sunamganj in 2017 was 12.7 and 8.09 meter respectively. It caused for inundation in Tahirpur about 19000 hector. If the rainfall increases 11.4% in the near future and 33.6% in the far future as predicted by some group researchers, it will cause for inundation about 20500 hector and about 23000 hector in Tahirpur respectively [8]. The lower part in Tahirpur is mainly be affected due to heavy rainfall while this inundated area gradually shifted to upward (Figure 6(c) & 6(d)).

5. CONCLUSION

This study considers the flash flood in 2017 as reference rainfall pattern to evaluate the impact of rainfall variations in Tahirpur upazila. Ten normalized rainfall events were prepared and simulated to calculate the associated water level at Sunamganj station in the Surma river. Gumbel distribution was considered for developing a relationship between rainfall amount and water level return period. Finally, ArcGIS tool was used for inundation analysis.

The calculated return period of flash flood in 2017 was 12.7 year. The same event will cause approximately 20-year return period size in the near future and approximately 40-year return period size in the far future due to the impact of climate change. The inundated area in Tahirpur increases sharply in the range of rainfall size larger than about 1.1-1.2. Initially, the rate of increasing in inundation is high while it decreases with the increasing water levels and rainfall amounts. The flash flood in 2017 caused inundation about 19000 hector in Tahirpur. If the rainfall increases 11.4% in the near future and 33.6% in the far future, it will cause inundation approximately 20500 hector and approximately 23000 hector in Tahirpur respectively. The increased inundation gradually moves towards north-eastern part of Tahirpur.

This study is only uses the rainfall pattern in 2017. Future study should consider other rainfall patterns to generalize the results. Such results are useful to identify and quantify the associated inundated areas due to temporal variation of rainfall which is necessary for disaster management.

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