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Assessment of Flooding Scenarios and Flood Risk Due to Storm Surges Using DEM: A Case Study of Dacope Upzila

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Abstract-Dacope Upzila in Khulna district of Bangladesh is a badly affected area due to storm surge during cyclone Aila and Sidr. In this study, the Digital Elevation Model of the site is developed using GIS interface. The assessment of flooding scenarios and flood risk are performed for the Upzila due to storm surge. The study reveals that approximately 371.6 km^2 of the site is flooded due to the height of storm surge of 7m above the mean sea level. It is also found that about 47 km^2 and 269 km^2 are at high risk according to age group population data and household construction materials data, respectively while 222 km^2 and 58.5 km^2, and 102.6 km^2 and 44.1 km^2 are at moderate and low risk, respectively. Moreover, the household survey reveals that about 25.3% of population is highly vulnerable while 22.4% and 52.3% of them face moderate and low vulnerability, respectively.

Keywords- DEM, Census Data, Household Survey, Cyclone Sidr and Aila.

I. INTRODUCTION

The overflow of water that submerges usually dry land is called a flood. Flooding is usually occurred due to tropical cyclone generated storm surges (Wijetunge and Marasinghe, 2015)[2]. The abnormal rise in seawater level during a storm is called storm surge or storm tide which is measured as the height of the water above the normal predicted astronomical tide.

A storm's winds pushing water onshore causes the surge primarily. Bangladesh is situated on the Ganges Delta and the many distributaries flowing into the Bay of Bengal. Due to the geographical location, Bangladesh is a disaster-prone country.

Due to its unprotected shore, the coastal area is highly vulnerable to storm surge induced flooding occurred due to tropical cyclone. The combination of coastal flooding and bursting of river banks is a common phenomenon which severely affects the landscape and society of Bangladesh.

Bangladesh has an extensive sea coastline, rendering the nation very much at risk of periodic widespread damage. In Bangladesh, about 26,000 km^2 (around 18% of the country) is flooded on each year, killing over 5,000 people and destroying more than seven million homes.Especially, in 1966, 1987, 1988 and 1998, the floods have caused devastation in Bangladesh throughout history. In 2007, the South Asian floods also affected a large portion of Bangladesh. During cyclone Sidr (on 15 November 2007), the height of storm surge was about 5m to 6m in the South-Western coastal zone of Bangladesh.

During cyclone Aila (on 25 May 2009), the height of storm surge was about 3m to 4m in the South-Western coastal zone of Bangladesh. When the flood is occurred on Dacope Upzila, the saline water enters into the ponds. As a results, the concentration of salinity of the pond water increases. The people of that area cannot use the water collected from the ponds as drinking water. So, they face the scarcity of pure drinking water.

II. LITERATURE REVIEW

Bangladesh is located in South Asia with a coastline of 580 km (360 mi) on the northern littoral of the Bay of Bengal. Besides, it is a densely-populated, low-lying and riverine country. Due to the geographical location, Bangladesh has a broad deltaic plain subject to frequent flooding, and a small hilly region crossed by swiftly flowing river. The driving forces like urbanization, development along the flood plains, mass migration, industrialization and fragmentation / consolidation of agriculture land alter the land use pattern and significantly affect the hydrologic processes.

Due to the effect of this land transformation, the flood flow increases. Land use pattern, frequency of flooding, characteristics of flood including depth and duration are the factors that influence the damage. The flood management is the development of hazard maps. Because hazard mapping is essential to understand the nature and characteristics of the community's risk.

III. DATA USED

1. Age Group Population Data:

The age group population data are collected for the study area from Khulna Zila Report (BBS, 2011) downloaded from the website of Bangladesh Bureau of Statistics (BBS) [5]. These data are shown in Table 1.

Table 1. Population data based on age group.

Category	Age Group	No. of Male	No. of Female	Both (Male & Female)	Percent	Ranking $R_{(i)}$
1	Age < 5 Years	5765	5692	11457	7.5	3
2	5 < Age < 25 Years	28280	28981	57261	37.6	2
3	25 < Age < 60 Years	34556	34273	68829	45.2	1
4	Age > 60 Years	7690	7079	14769	9.7	3

2. Household Data Based on Construction Materials.

The household construction materials data are also collected for the study area from Khulna Zila Report (BBS, 2011) downloaded from the website of Bangladesh Bureau of Statistics (BBS) [5]. These data are shown in Table 2.

Table 2. Household data based on construction materials.

Category	Construction Material	No. of House	Percent of house	Ranking $R_{(i)}$
1	Pucca (Brick)	1072	2.9	1
2	Semi-Pucca (Cement Block)	2064	5.7	2
3	Kutcha (Mud)	31866	87.6	3
4	Jhupri	1367	3.8	4

3. Household Survey Data:

The household survey data are collected from (Hossen, 2016) [3]. Table 3 shows the weighting factor for each major component of contributing factors.

Table 3. Weighting factor for each major component of contributing factors.

Major contributing factor	Major components	Weighting factor w_i
Sensitivity	1.Demographic standing	4
	2.Land characteristics	1
	3.Rural standing	2
	4.Water resources	3
Adaptive capacity	1.Educational background	3
	2.Economic strength	1
	3.Assets	2
Exposure	1.Climatic condition related to river	1
	2.Previous flood events	2

Then the major contributing factors are calculated for the study area using the equation (5). These values are shown in Table 4.

Table 4. Major contributing factors for the study area.

Major contributing factor	Dacope Upzila
Sensitivity	0.494
Adaptive capacity	0.343
Exposure	0.380

IV. METHODOLOGY

1. Study Area:

Dacope is an Upazila of Khulna District in the Division of Khulna, Bangladesh. Figure 1 shows the location of study area. It is located at 22.57°N and 89.51°E. It has a total area of 991.6 km².

2. Development of Digital Elevation Model (DEM) of the Study Area:

At first, a path is created in Google Earth open source software, which covers most of the study area and surroundings. Then TCX Converter open source software is used to extract the elevation data from the path. From this extracted elevation data, a preliminary DEM is developed using Geostatistical Analyst (Geostatistical Wizard) Tool in ArcGIS 10.4.1 version software.

Then the required DEM of the study area is clipped from preliminary DEM with shape file of the study area using Data Management (Raster Processing) Tools in ArcGIS 10.4.1 version software. Fig2 shows the elevation map of the study area.

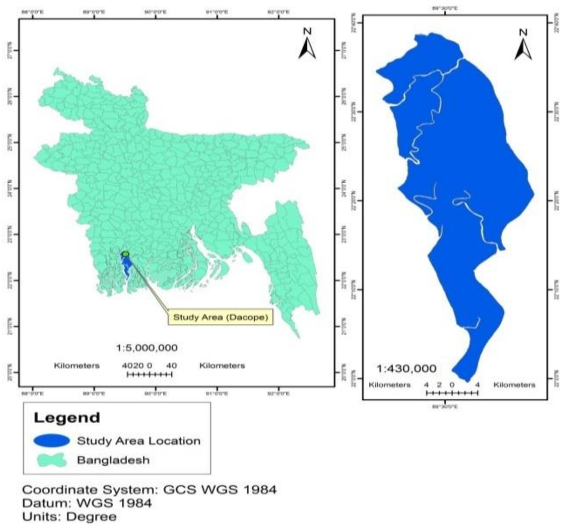

Fig1.Location map of the study area.

In Figure 2, it is observed that the altitude of the study area varies from 0 to 28m. It is also observed that the northern part of that area is low but the southern part of that area is very high.

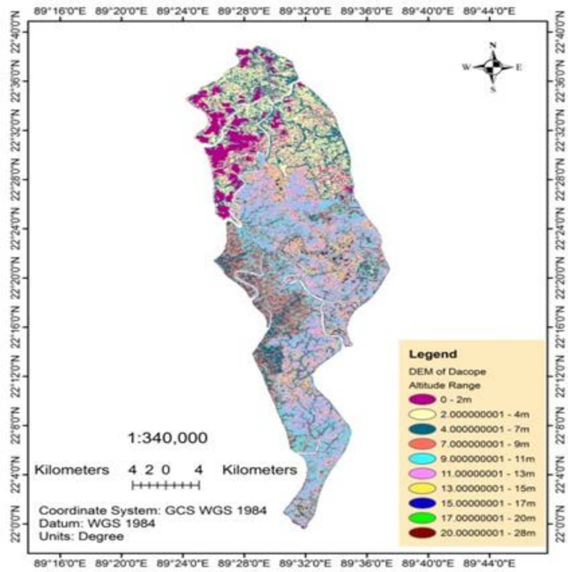

Fig2.Elevation map of the study area.

3. Assessment of Flooding Scenarios of the study area:

At first, The Spatial Analyst (Raster Calculator) Tool is opened in ArcGIS 10.4.1 version software. Then the condition (altitude is less than or equal to 1m) is set up in Raster Calculator (say for 1m height of storm surge). Then ok. The DEM of flooding scenario is automatically developed for 1m height of storm surge. Then the flooded and non-flooded part of that area is calculated using Spatial Analyst (Zonal Geometry as Table) Tool. Finally, the map of flooding scenario is developed for 1m height of storm surge using GIS interface. In the same way, the maps of flooding scenario are developed for other height of storm surges (2, 3, 4, 5, 6 and 7m).

4. Vulnerability Analysis of the Study Area:

The vulnerability analysis of the study area is performed based on the age group population data, household construction materials data and household survey data. The details of methodology are described below.

4.1 Population vulnerability analysis based on age group:

In this analysis, the population vulnerability rankings are assigned to each age group according to Table 1 as used by Samarasinghe and Nandalal (2010) [1]. The Population Vulnerability Index is calculated using the following equation.

$$PVI = \Sigma_{(i=1-4)} FP_{(i)} \times R_{(i)} / \sum_{(i=1-4)} R_{(i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where,
PVI = Population Vulnerability Index
$FP_{(i)}$ = Fraction of population of each age group
$R_{(i)}$ = Vulnerability ranking of each age group.

4.2 Building vulnerability analysis based on construction materials:

In this analysis, the building vulnerability rankings are assigned to each category building according to Table 2 as used by Samarasinghe and Nandalal (2010) [1]. The Building Vulnerability Index is calculated using the following equation.

$$BVI = \Sigma_{(i=1-4)} FB_{(i)} \times R_{(i)} / \sum_{(i=1-4)} R_{(i)} \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where,
BVI = Building Vulnerability Index
$FB_{(i)}$ = Fraction of the Buildings of each category
$R_{(i)}$ = Vulnerability ranking of buildings of each category

4.3 Household vulnerability analysis based on field survey data:

Vulnerability is a function of contributing factors such as exposure, sensitivity and adaptive capacity. Each contributing factor is subdivided into major component factors. Again these component factors are divided to sub component factors. The questionnaire was designed in such a way that each question is tied to a sub component.

According to the answer given to a question a numerical value is assigned to each sub component (Samarasinghe and Nandalal, 2010) [1]. The weighting factors were assigned to each major component of contributing factors according to Table 3 as used by Samarasinghe and Nandalal (2010) [1].The standardized index value of each sub component is calculated using the following equation.

$$Index\ (sHH) = (Shh - S_{min}) / (S_{max} - S_{min}) \ldots\ldots\ldots\ldots 3$$

Where,
Shh = Original sub component value for the household,
S_{min} = Minimum sub component value for the household,
S_{max} = Maximum sub component value for the household.

The major component values for the household are calculated using the following equation.

$$M(HH) = \Sigma_{(i=1-n)} Index\ (sHH)_i / n \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where,
M(HH) = Major component value for the household,
n = Number of sub-components belonging to a major component.

The major contributing factors (exposure, sensitivity, or adaptive capacity) for the households are calculated using the following equation.

$$CF(HH) = [\Sigma_{(i=1-n)} W_i \times M(HH)_i] / [\Sigma_{(i=1-n)} W_i] \ldots\ldots 5$$

Where,
CF(HH) =Major contributing factor (exposure, sensitivity, or adaptive capacity) for the household,
$M(HH)_i$ = Major component values for the Households,
W_i = Weight factor of each major component,
n =Number of major components in each contributing factor.

Then the Flood Vulnerability Index for the household is calculated using the following equation.

$$FVI = [E(HH) - A(HH)] \times S(HH) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where,
FVI = Flood Vulnerability Index,
E(HH) = Calculated exposure score,
A(HH) = Calculated adaptive capacity score,
S(HH) = Calculated sensitivity score for the household.

5. Flood Risk Analysis of the Study Area:

The risk is considered as a function of Hazard & Vulnerability (Samarasinghe and Nandalal, 2010) [1].

"Risk" = "Hazard x Vulnerability"

At first, the risk analysis of the study area is performed based on the age group population data, household construction materials data and household survey data using Spatial Analyst (Raster Calculator) Tool in ArcGIS 10.4.1 version software. Then the risk area is reclassified into four categories (Risk free, Low, Moderate, And High) using 3D Analyst (Raster Reclass) Tools in ArcGIS 10.4.1 version software. The risk area is calculated using Spatial

Analyst (Zonal Geometry as Table) Tool. Finally, the risk maps of the study area are developed based on the age group population data, household construction materials data and household survey data using GIS interface.

The risk area is classified into four categories. Table 5 shows the classification of the risk area.

Table 5. Classification of the risk area.

Category	Risk Value Range	Risk Classification	Index
1	0 - 0	Risk Free	1
2	0 - 0.33	Low Risk	2
3	0.33 - 0.84	Moderate Risk	3
4	> 0.84	High Risk	4

V. RESULTS AND DISCUSSIONS

1. Assessment of Flooding Scenarios of the Study Area:

Dacope Upzila is variably affected for different height of storm surges above the mean sea level.

1.1 Flood affected area for 1m height of storm surge:

If the height of storm surge raises 1m above the mean sea level, approximately 8.6 km^2 areas of Dacope Upzila will be flooded. So, the flooded part of the study area will be about 0.9%. Figure 3 shows the flooding scenario of the study area for 1m height of storm surge.

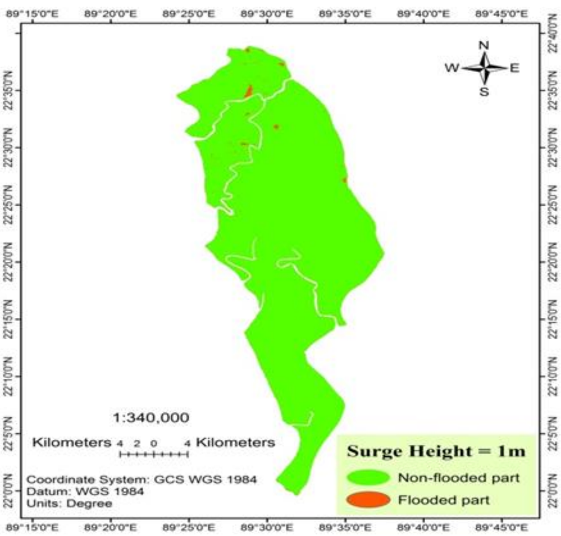

Fig 3. Flood map for 1m height of storm surge.

1.2. Flood affected area for 2m height of storm surge

If the height of storm surge raises 2m above the mean sea level, about 47.1 km^2 areas of Dacope Upzila will be flooded.About 4.7% of the study area will be flooded. Figure 4 shows the flooding scenario of that area for 2m height of storm surge.

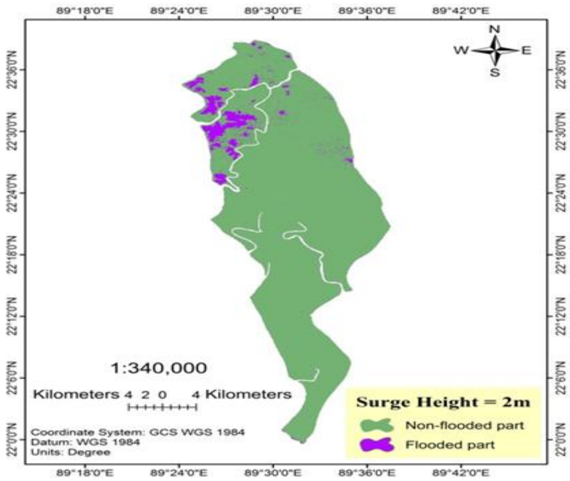

Fig 4. Flood map for 2m height of storm surge.

1.3 Flood affected area for 3m height of storm surge:

About 94.1 km^2 area of Dacope Upzila will be flooded if the height of storm surge raises 3m above the mean sea level. About 9.5% of the region will be flooded. Figure 5 shows the flooding scenario of the study area for 3m height of storm surge.

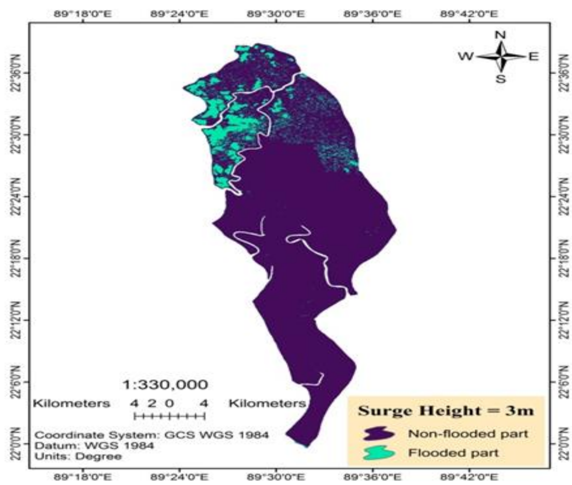

Fig 5. Flood map for 3m height of storm surge.

1.4 Flood affected area for 4m height of storm surge:

If the height of storm surge raises 4m above the mean sea level, approximately 177.2 km^2 areas of the study area will be flooded. About 17.9% of that area will be flooded. Figure 6 shows the flooding scenario of that area for 4m height of storm surge.

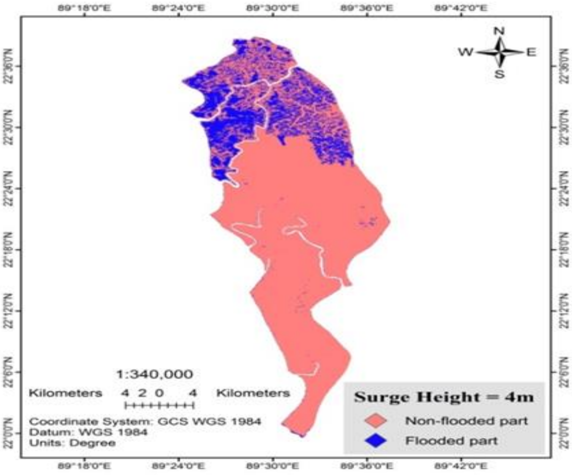

Fig 6. Flood map for 4m height of storm surge.

1.5 Flood affected area for 5m height of storm surge:

When the height of storm surge raises 5m above the mean sea level, about 269 km^2 area of Dacope Upzila is flooded. The flooded part is about 27.1%. The flooding scenario of the study area for 5m height of storm surge is shown in Figure 7.

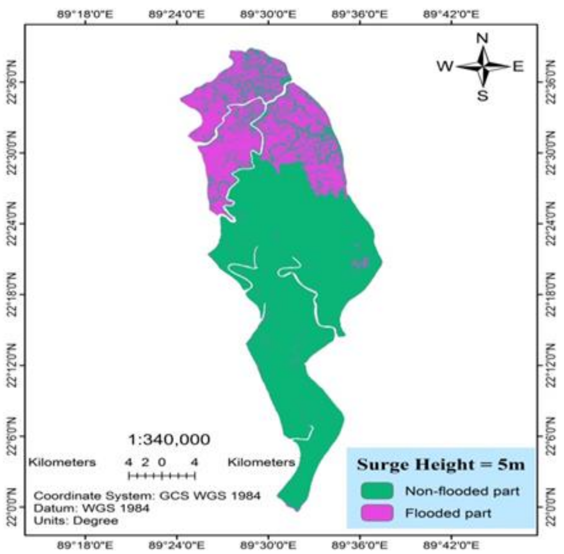

Fig 7. Flood map for 5m height of storm surge.

1.6 Flood affected area for 6m height of storm surge

Besides, About 327.4 km^2 area of Dacope Upzila is flooded when the height of storm surge raises 6m above the mean sea level. Overall, the flooded part of the study area is 33%. Figure 8 shows the flooding scenario of that area for 6m height of storm surge.

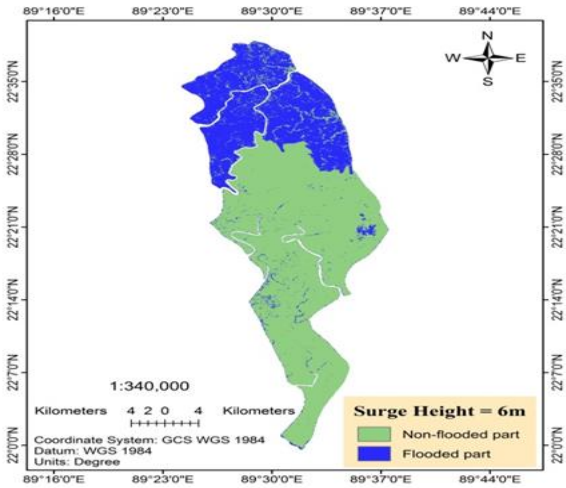

Fig 8. Flood map for 6m height of storm surge.

1.7 Flood affected area for 7m height of storm surge:

In the same way, about 37.5% of the study area will be flooded if the height of storm surge raises 7m above the mean sea level. The flooded area will be about 371.6 km^2. The flooding scenario of that area for 7m height of storm surge is shown in Figure 9.

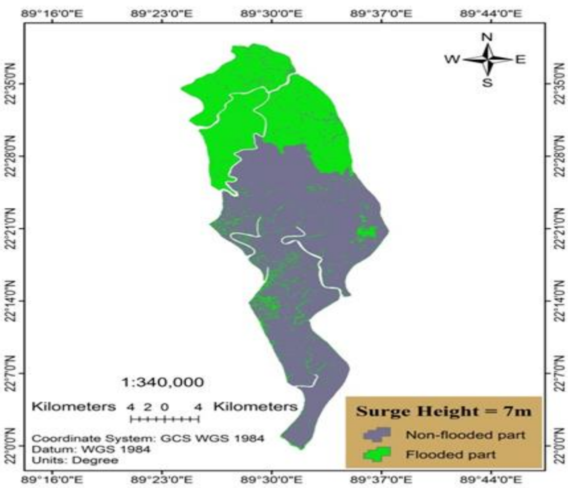

Fig 9. Flood map for 7m height of storm surge.

2. Assessment of Flood Risk of the Study Area:

When the flood occurs on the study area, the people of different age are under the different category of risk. Besides, the different types of household are under the different category of risk.

2.1. Assessment of flood risk based on age group population data:

At first, the Population Vulnerability Index (PVI) is calculated using the equation (1). The calculated value of PVI is 0.191. Besides, it is also found that the different parts of the flooded area due to the height of storm surge of 7m above the mean sea level are under the different categories of risk after analyzing the flood risk using GIS interface. These are shown in Table 6.

Table 6. Classification of the flooded area based on age group population data.

Risk Category	Risk Area (km^2)	Percent of Risk
Low risk	102.6	10.3
Moderate risk	221.8	22.4
High risk	47.1	4.7

From Table 6, about 47.1 km^2 area of the flooded region is under the high risk. Because, the children of age less than 5 years and the people of age greater than 60 years live more at that area. About 545 nos of children and 702 nos of old people are under the high risk. They are highly affected by the occurred flood. Besides, about 221.8 km^2 area is under the moderate risk. Because, the people of age within the range between 5 < age < 25 years live more at that area. About 12810 nos of people of the above age range are under the moderate risk while 7124 nos of people of age within the range between 25 < age < 60 years are under the low risk. Figure 10 shows the flood risk map based on age group population data.

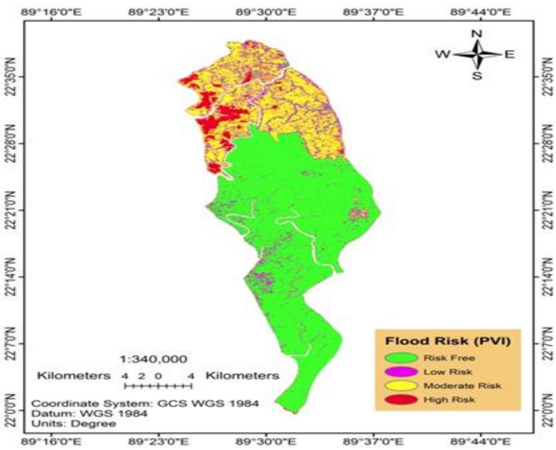

Fig 10. Flood risk map based on age group population data.

2.2. Assessment of flood risk based household construction materials data

At first, the Building Vulnerability Index (BVI) is calculated using the equation (2). The calculated value of BVI is 0.292. Besides, it is also found that the different parts of the flooded area due to the height of storm surge of 7m above the mean sea level are under the different categories of risk after analyzing the flood risk using GIS interface. These are shown in Table 7.

Table 7. Classification of the flooded area based on household construction materials data.

Risk Category	Risk Area (km^2)	Percent of Risk
Low risk	44.1	4.4
Moderate risk	58.5	5.9
High risk	269.0	27.1

From Table 7, about 269 km^2 areas of the flooded part are under the high risk because the number of Jhupri and Kutcha household is more in this area. So, these households are highly affected by the occurred flood. About 371 nos of Jhupri and 1880 nos of kutcha households are present in the high risk area. Moreover, about 58.5 km^2 area is under the moderate risk because the large numbers of semi-pucca households are present in this area. It is also found that about 122 nos of semi-pucca households are present in the moderate risk area. About 44.1 km^2 area is under the low risk because the large numbers of pucca households are present in this area. Approximately 48 nos of pucca households are present in the low risk area. Figure 11 shows the flood risk map based on household construction materials data.

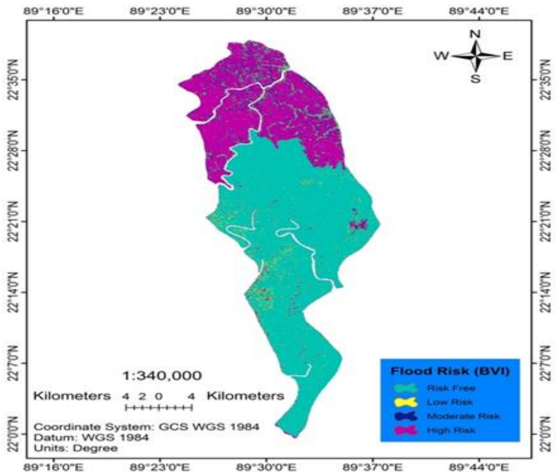

Fig 11. Flood risk map based on household construction materials data.

2.3. Assessment of flood risk based on household survey data

At first, the Flood Vulnerability Index (FVI) is calculated for the study area using the equation (6). The calculated value of FVI is 0.018. Besides, it is also found that the different parts of the flooded area due to the height of storm surge of 7m above the mean sea level are under the different categories of risk after analyzing the flood risk using GIS interface. These are shown in Table 8.

Table 8. Classification of the flooded area based on household survey data.

Risk Category	Risk Area (km^2)	Percent of Risk
Low risk	194.4	19.5
Moderate risk	83.1	8.4
High risk	94.1	9.5

From Table 8, Approximately 94.1 km^2 area of the flooded region is under the high risk because the educational background, economic strength, climatic conditions related to rivers and the drinking water supply facilities are not quite good in this area. It is also found that approximately 3482 nos of houses are present in the high risk area.

Approximately 83.1 km^2 areas is under the moderate risk because the economic strength, educational background, water supply facilities and the climatic conditions related to rivers are lightly good compared to the high risk area. As a result, the number of household under the moderate risk is less than the high risk area.

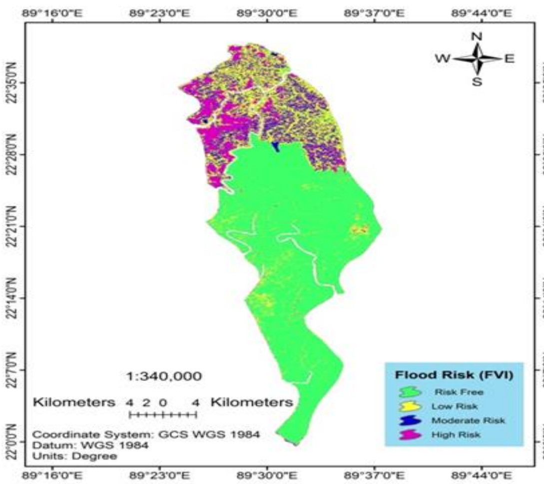

Fig 12. Flood risk map based on household survey data.

Approximately 3075 nos of houses are present in the moderate risk area. On the contrary, about 194.4 km2 area is under the low risk. Because the climatic conditions related to the rivers, educational background, economic strength and the water supply facilities are quietly good in the low risk area. As a result, the number of household is greater than the high and moderate risk area. Approximately 7191 nos of houses are present in the low risk area. Figure 12 shows the flood risk map based on household survey data.

VI. CONCLUSIONS

For the Dacope Upzila, in Khulna district, it is found that most of the people and the households are highly vulnerable due to natural disaster including storm surge. It is also found that about 371.6 km^2 area of the above mentioned Upzila is flooded due to the height of storm surge of 7m above the mean sea level. Approximately 37.5% of the Upzila is flooded. The deposition of a thin veneer of salt on the agricultural fields reduces the subsequent crop production. The Saline water intruded into the ponds and shrimp ghers is flooded.

As a result, the people of the area cannot use the pond water as the drinking water. After analyzing the flood risk of the study area using ArcGIS interface, it is found that about 47 km^2 and 269 km^2 are at high risk according to age group population data and household construction materials data, respectively while 222 km^2 and 58.5 km^2, and 102.6 km^2 and 44.1 km^2 are at moderate and low risk, respectively.

Moreover, the household survey reveals that about 25.3% of population is highly vulnerable while 22.4% and 52.3% of them face moderate and low vulnerability, respectively. Moreover, approximately 3482 nos of houses are present in the high risk area while 3075 and 7191 nos of houses are present in the moderate and low risk areas, respectively. So, the population and households are the major vulnerable dimensions. The results obtained from this study will be helpful for the local and national level authorities for the future planning / improvement / taking some steps to minimize the vulnerability and risk of the study area due to severe flooding.

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