Application of Remote Sensing and GIS Techniques for Flood Vulnerability and Mitigation Planning in Munshiganj District of Bangladesh

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ABSTRACT Munshiganj district is situated on the mixed floodplains of rivers the Ganges (Padma), the Brahmaputra (Jamuna), and the Meghna. Every year even during normal rainy season floodwater drains through bordering rivers of the area to the Bay of Bengal. Most of the severe floods affect the area and cause maximum damages to the lives and properties in comparison to other areas. On the other hand, the area is densely populated and the number is rapidly increasing rising the number of people at risk.

This study was carried out to create flood vulnerability map of Munshiganj district using satellite and GIS techniques. Landsat TM data was used to generate a land cover, and JERS-SAR and RADASAT data were combined to map flooded area in a normal flood event. Combining them with population data a population distribution map was produced according to land use types. Subsequently, this outcome was compared with flooded area mapped using satellite data in creating population that is at risk during a normal flood event. Attempt was made to identify shelters in a flood event based on information such as existing schools/hospitals location, topography and accessibility. Prioritization of shelters was carried out based on population at risk during a normal flood event. Finally, a flood mitigation plan for Munshiganj district based on evacuation was proposed considering selected center capacities and the accessibility

Keywords: Flood, Mitigation, GIS, Remote Sensing

1. INTRODUCTION

Flood is the most devastating natural phenomenon that affects and disrupts the well being of a society, especially poor people who are vulnerable to disaster due to limitation of their resources. Most of the natural disasters in Asia are related to flood and causing maximum damage to lives and properties in comparison to other disasters. Bangladesh probably is the most affected country by natural catastrophes, especially the flood.

Bangladesh is known as the 'land of rivers' and the major rivers are the Ganges, the Brahmaputra and the Meghna with a complex network of 230 rivers including 57 internationally trans-boundary (cross boundary) rivers. The Ganges (Padma), the Brahmaputra (Jamuna) and the Meghna are the large rivers systems in the world covering a combined total catchments area of about 1.6 million sq km and extending over Bhutan, China, India and Nepal of which only 7% falls in Bangladesh (FFWC, 2001). These rivers systems and their tributaries drain huge rainfall and snow-melting water of the subcontinent to the Bay Bengal. Topography of the country is mostly flat except some part in the northeast and southeast, which are hilly. The land elevation varies from 3 to 90 m MSL. More than 50% of the floodplain is within 5m MSL. The very location and the topography make the country vulnerable to floods.

Flood is a regular phenomenon in Bangladesh. Almost every year floods affect the country seriously during the southwest monsoon (June-September). According to historical records (FFWC 2001) five devastating floods occurred in the 19th century (1842, 1858, 1871, 1885 and 1892) and sixteen such floods occurred in the 20th century (1900, 1902, 1907, 1918, 1922, 1954, 1955, 1956, 1962, 1968, 1970, 1974, 1984, 1987, 1988, 1998). These floods affected large areas and caused damage of many resources of the country. The highest number of death was recorded in 1988 flood (2,379 people). And the largest amount of damage caused by 1998 flood was estimated to be 270 million US$ at the current price in 2002. The estimated annual average flood damage is about 21 million US$.

Bangladesh experienced an unprecedented flood during July-August 2004. About one third of the country was flooded and about 30 million of rural and urban people were directly affected. Millions were displaced from their

homes and lost their earning opportunities. Official number of death was about 500 but this rose to very high level due to post flood calamities. Road, railway and other infrastructures were destroyed. .

Every year, during normal precipitation, some part of the country is inundated and people accept it as *normal flood*. It is flood only when heavy rainfalls or snow melting occur in the west, north and the east causing simultaneously flooding in the Ganges, the Brahmaputra, the Meghna and their tributaries with rise of water above danger levels. This phenomenon gets momentum when it associated with rise of water level in the Bay of Bengal due to lunar cycle or other reasons like global warming.

It has been observed that incidence of flood has increased in the last two decades (1980 and 1990) with the increase in flood damages compared to earlier. (Figure1) Since early sixties Bangladesh has implemented a good number of flood control and drainage (FCD) projects covering about 30 percent of the land area of the country (FPCO 1995). Unfortunately, all these structural measures could not restrict the occurrence of flood. Decades of study, investigations and research at home and abroad over the years have all led to one conclusion that complete flood control in the country like Bangladesh is neither possible nor feasible.

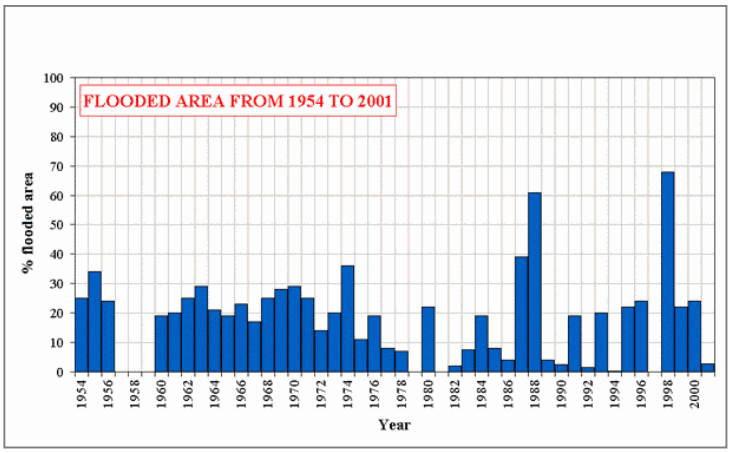

Figure1. Flooded area in Bangladesh from 1954 to 2001(Source: FFWC 2001)

People in Bangladesh accept flood as a part of their life that bring both good and evils. A *normal flood* that occurs every year is not a problem for them as they are habituated to accept it. However, Bangladesh experiences severe floods affecting large number of people in the extreme case. Therefore, it is vital to develop a plan to live with flood and prepare an appropriate land use planning and mitigation measure.

2. OBJECTIVES

Objectives of the study were to evaluate the use of GIS and remote sensing for the following;

- Preparation of flood map and identify vulnerability of flood area
- Develop a criteria and identify suitable locations for shelters
- Identify best route for evacuation
- Propose suitable flood mitigation/evacuation plan

3. STUDY AREA AND THE DATA

Munshiganj district lies approximately between 23°22′ to 23°40′ N latitudes and 90°05′ to 90°42′ E longitudes (Fig. 1) selected for this study. The area of the district is about 919 sq km and is bounded by the Jamuna in the west, the Padma and the Meghna in the south, the upper Meghna in the east and Lakhya in the north. The Dhaka city is located in the north of the study area. The population of the study area is 1,293,972 according to the population census of 2001 (BBS 2004). The main physiographic units of the area include the floodplains of the Padma, the Jamuna, the Meghna and the Old Brahmaputra rivers. The agro-ecological regions include mix Brahmaputra floodplain, Meghna floodplain, active Ganges floodplain, aerial beel, old and new Brahmaputra floodplain, active Brahmaputra floodplain, and Jamuna floodplain. Ground elevation ranges from 18m above the sea level in the north to 4m in the south. There are six upazilas (Sub-district) in this district.

The study area has a tropical and humid monsoon climate characterized by the twice-yearly reversal of air movement in the area. From December to March (winter) airflows from northeast, while from June to September (summer) it flows from the southwest; these two periods of air movement are called the northeast and southwest monsoon. The southwest monsoon originates over the Indian Ocean and carries warm moist air that produces some of the highest rainfalls in the area. So, southwest monsoon is often simply referred to as the "monsoon" meaning rainy season. A reversal of the monsoon takes about two months. The first reversal occurs in April-May when the change of regional wind direction is from northeast to southwest via northeast and the second reversal occurs in October-November when the change is from southwest to northeast via southwest. These periods of changing wind direction are called the pre-monsoon and post-monsoon seasons. Climate is mainly influence by the Indian Ocean monsoon climate. Average annual rainfall ranges from 1400 mm in the southwest to 2200 mm in the northeast. About 85% of the rainfall occurs during monsoon i.e. from June to September. Monthly average rainfalls from 1993 to 2003 of the study area and for the whole country are provided in the Figures 4 and 5. Flood comes from three sources: direct rainfall, over bank spills from the major boundary rivers and over bank spills from the international or regional rivers. Each phenomenon occurs alone or combines with others. Average temperature varies from 25° to 35° C during the year. Sometimes it falls below 10° C during the winter.

Following are the data used for the study.

- Landsat TM 2002 February
- JERS SAR (L Band) 1996 June
- ADEOS AVNIR 1996 November
- RADARSAT (Scan SAR Wide mode) 2004 July
- SRTM 2000
- Population (Sub-district) 2001
- Landuse and Land elevation scanned images
- Water bodies, Agricultural land, Metal roads, School/College and Hospital interpreted from Aerial Photographs of 1999-2000.
- Administrative boundaries, roads

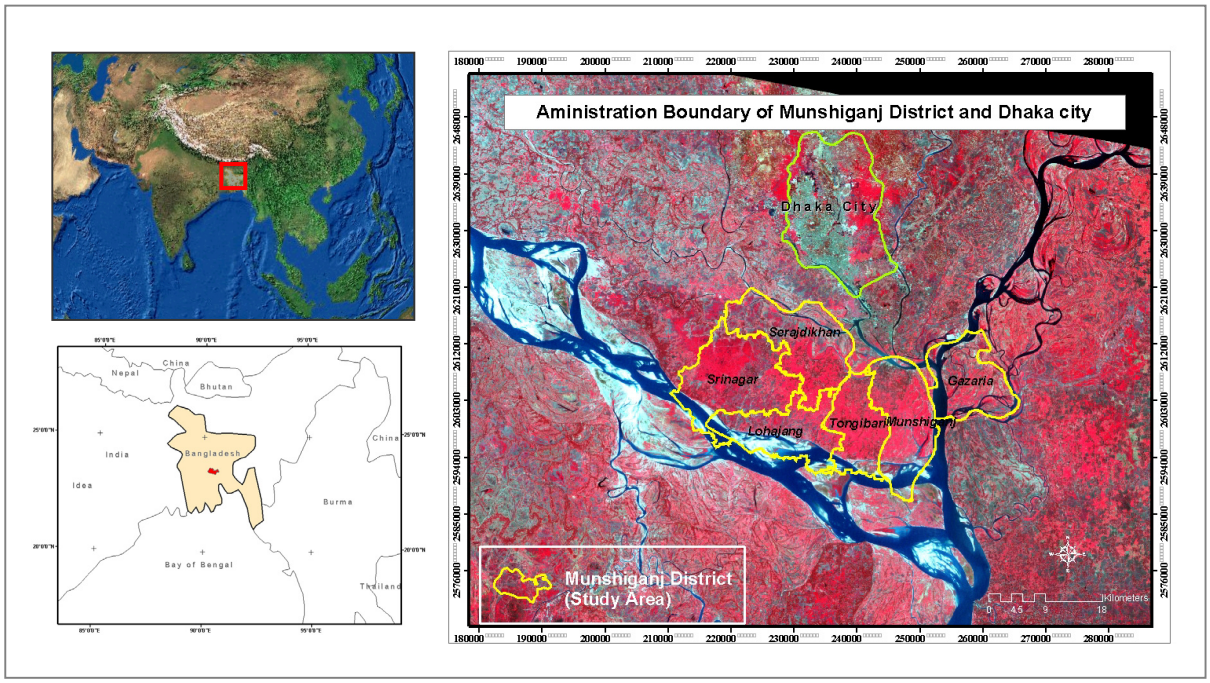

Figure 2. Location map of the study area

4. METHODOLOGY

Conceptual flowchart of the analysis is shown in Figure3. This figure shows the main input information analysis method and output. Some of the derived maps using satellite of other data was carried out under Japan Aerospace Exploration Agency (JAXA) Mini-Project with Bangladesh Space Research and Remote Sensing Organization (SPARRSO) in 2004. They are landuse map, normal flood map and population affected based on land cover as population density. Further it was attempted to develop the methodology to identify the suitable of shelter location, shelter's serviceable area as well as path to evacuate people while flood occurring.

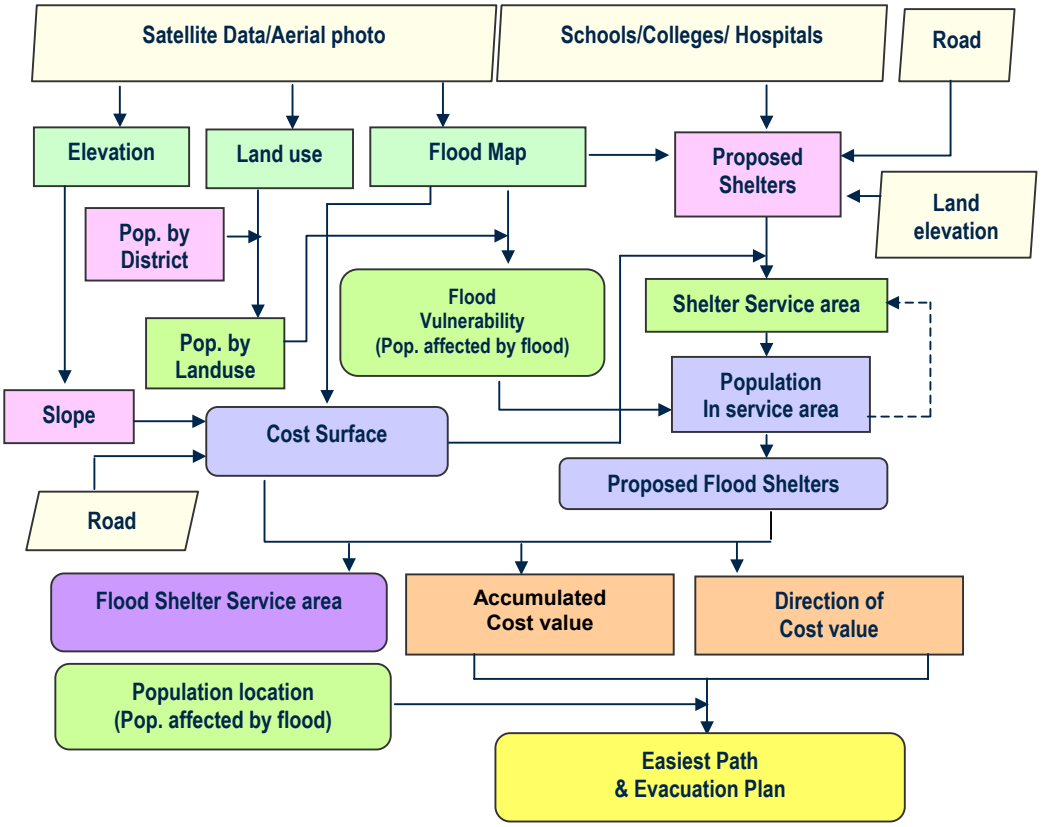

Figure3. Flowchart depicting major steps of analysis

4.1 Land use map

The vector data layers on land cover of the study area were generated for preparation of land use map. The data layers have been generated from aerial photographs taken during 1999-2000. The land cover and the land use of the study area were found to be very heterogeneous. Therefore, visual interpretation, the most primitive method in land feature interpretation has been applied using aggregated datasets with on screen digitization technique. ADEOS AVNIR data and Landsat TM data were used for interpretation of the confused land features of the study area.

4.2 Flood area map

This was generated combining optical and SAR data. Attempt was made to combine two sensor data as a way of practical usage of satellite data during rainy season where it is impossible to acquire optical sensor data. ADEOS AVNIR, JERS SAR along with and RADASAT were used for interpretation of the flooded and non-flooded area. Simple threshold classification technique and visual interpretation were used in interpreting both optical and SAR images. It was not difficult to interpret flooded areas on SAR images. Except for few locations, scattering from flooded areas were comparatively low when compared to other areas. The intermediate mean value created confusion, these areas were found summer rice with floodwater and the brighter area was hyacinth on the floodwater. In this cases, optical images and field verification had been used to further clarify flooded and non-flooded areas where there was ambiguity in interpreting satellite data. Also, the optical images helped in identifying water features that are not affected due to rainfall.

4.3 Flood vulnerability map

Flood vulnerability map was generated from population affected by flooded area. Population information received from statistical department was in Union (sub-district) basis. This data merely states the number of people registered in a given Union, but does not reveal real spatial distribution of population. It is unrealistic to say that population density is uniform through out a given sub-district as the inhabited area could be a fraction of the total land area of a district. Sub-district was not an appropriate spatial size to use for population distribution, but village base data which could be the suitable spatial unit to represent population distribution was not available. The question of estimating a realistic population distribution was attempted incorporating land use categories with population of sub-districts. In order for establishing different population densities with respect to land use classes, population density ratio of 3 major landuse classes in each sub-district was assumed as shown in Table1.

Upazila Name	Agricultural & Water Bodies	Rural	Urban
Sirajdikhan	0	1	2.31
Sreenagar	0	1	1.85
Gazaria	0	1	1.98
Munshiganj	0	1	5.64
Tangibari	0	1	3.07
Lohajang	0	1	2.39

Table1. Population ratio of rural and urban areas for different Upazilas of Munshiganj district. (Source: SPARRSO 2001)

4.4 Proposed flood shelters

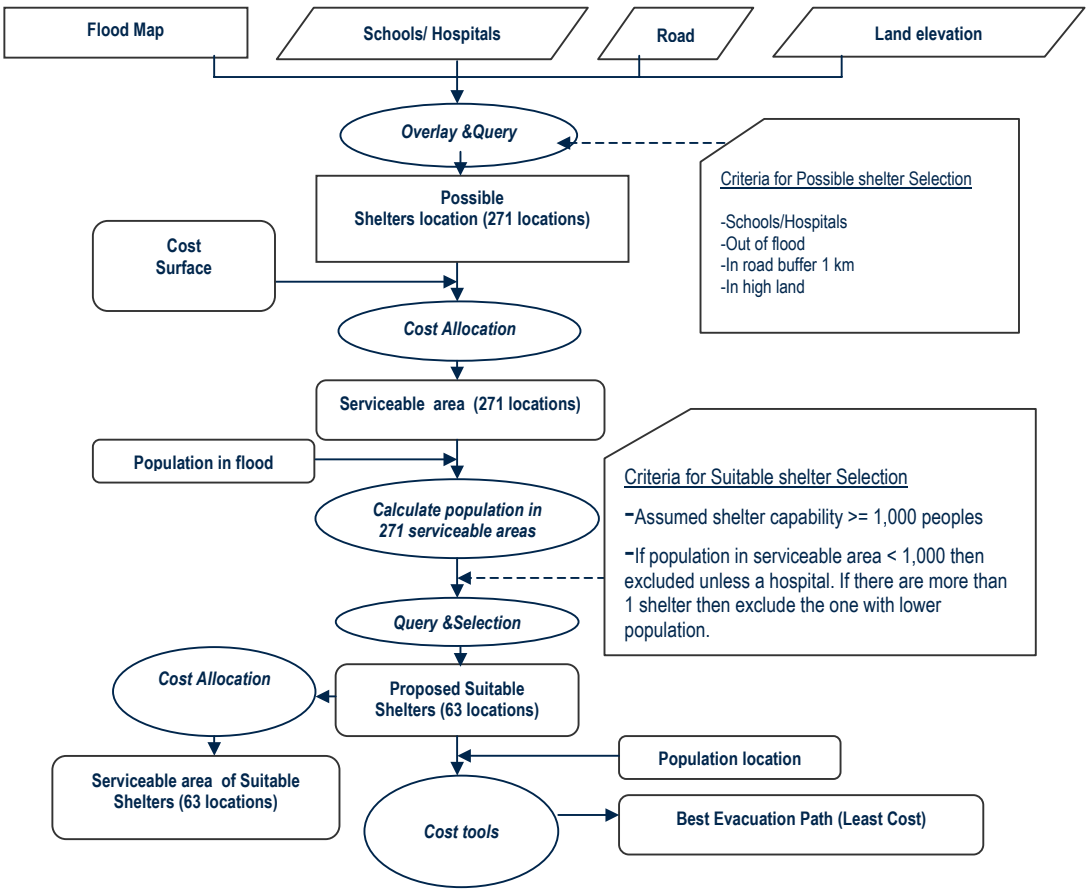

Figure4. Flowchart on steps of proposed flood shelter analysis

The criteria for selecting a shelter at initial stage was based on four factors as given below;

1. Existing of schools/colleges/hospitals
2. It should be not in normal flood area
3. Should be within 1 Kilometers of asphalt/metal road
4. Need to be located in high level

271 schools/colleges/hospitals satisfied that above criteria. Spatial distribution of these 271 identified facilities showed that it is necessary to minimize this numbers as 271 is too large to consider as shelters. Also it was found some were located close to each other suggesting fewer numbers could satisfy the shelter need. This was done based on the fact that there should be at lease 1,000 persons in the serviceable area of each facility. Also, convenience to reach a shelter from a village was introduced using cost surface concept.

4.5 Cost Surface

Cost is the "trouble" or "difficulty" to reach a shelter from place of living. It a person is required to select a shelter among 2 or 3, it could be first done on the distance. But in some cases the linear distance may not the critical factor as these could be un passable areas between shelter and place of living. This un passable area could be a river, flood area, mountain etc. in which case we can assume higher difficulty. In the Cost Surface this is evaluated for each cell on defined factors. In the present study four factors that could influence the selection of a shelter was used to create the cost. Those are Flood Depth, Road Surface Density, Road Accessibility and Slope. The percentage of influence by each factors was assumed as 40:30:20:10, for Flood Depth, Road Surface Density, Road Accessibility and Slope respectively.

Flood Depth: This factor was defined as most influence factor (40%) for cost surface. During flood it is not possible to travel and difficulty increases with flood depth. This assumption excludes boats etc.

Road Surface Density: This was considered as second most influencing factor (30%). Road density of each cell was calculated based on road type assigning 20 meters to metal road and 8 meter to rest. More road provides better access. That is less cost.

Road Accessibility: This factor say the distance to road. Away from road less accessibility then high cost. This influence was considered to be 20% influence compare to others.

Slope: The slope is a factor that affects to travel time and indicate topography that cannot cross. As the study area is in the flood plane slope degree is not quite different.

Finally, combining all four factors using weighted overlay technique in GIS software tools in raster environment cost was created. The detail of weighting and reclassify score are shown in Table2.

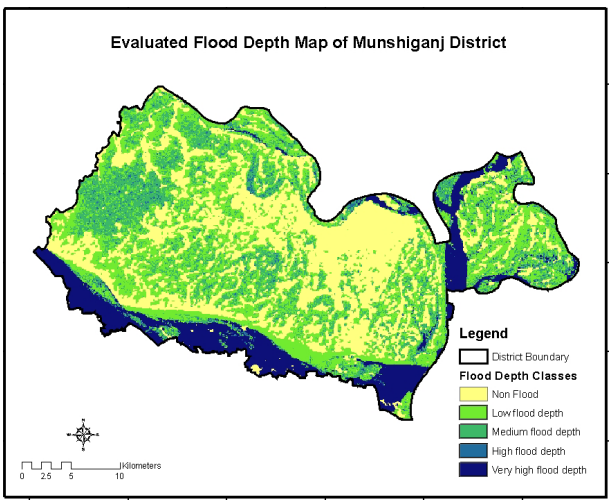

Figure5. Flood Depth Map

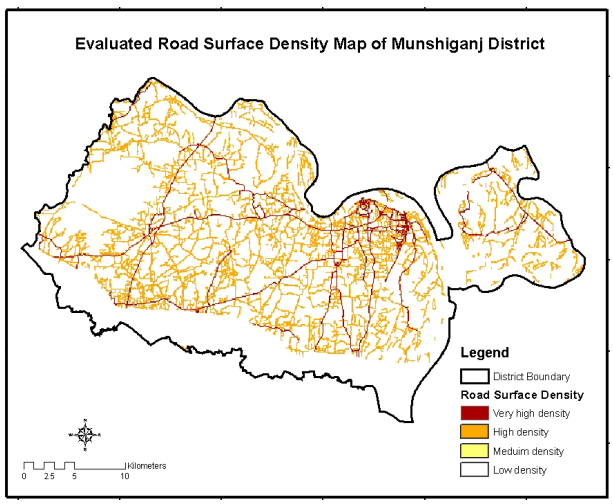

Figure6. Road Surface Density Map

Factors	% Influence For cost	Classes	Interpretation	Cost score
▪ Flood depth	40	- Non Flood - Flood + Elevation > 5 M. - Flood + Elevation >3 - 5 M. - Flood + Elevation > 1 - 3 M. - Flood + Elevation <= 1M.	-No flood -Low flood depth -Moderate flood depth -High flood depth -Very High flood depth	1 2 3 4 5
▪ Road surface density	30	- Metal road area > 10% - Metal road area <=10% or Soft road area > 10% - Soft road area <=10% - All road area = 0%	-High density -Moderate density -Low density -No road density	1 2 3 4
▪ Road accessibility	20	- Inside Metal &Soft road buffer - Inside Metal buffer 500 m. - Inside Soft road buffer 100 m. - Outside Metal &Soft road buffer	-Very high accessibility -High accessibility -Moderate accessibility -Low accessibility	1 2 3 4
▪ Slope	10	- Slope 0 - 5 % - Slope 5- 10 % - Slope > 10 %	-Low steep slope -Moderate steep slope -High steep slope	1 2 3

Table2. Weighting influence's factors and scoring's factors for cost surface analysis

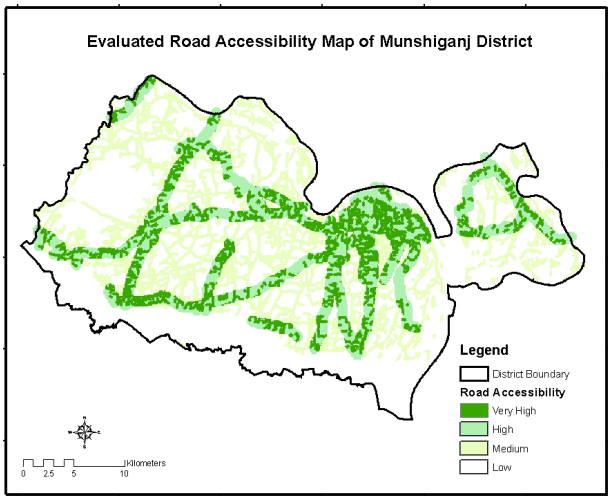

Figure7. Road Accessibility Map

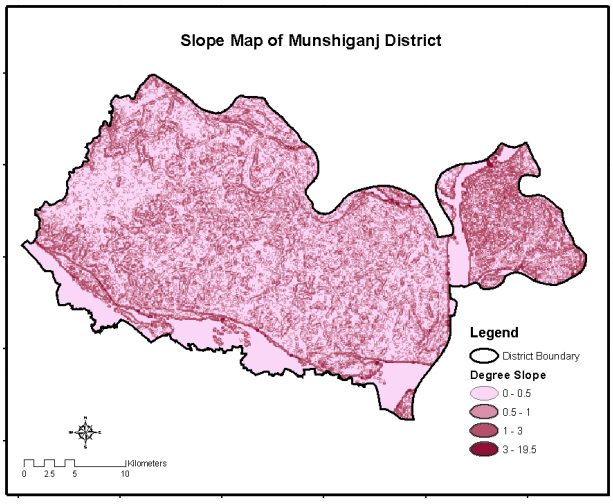

Figure8. Degree Slope Map

4.6 Shelter's serviceable area and best evacuation path

Shelter's serviceable area: As discussed in section 4.4, these are 271 facilitated to be used as shelters. Simple visual observation shows that smaller number of facilities can serve as shelters because some are too close to each other with less population area in the vicinity. In section 4.5, it was should that serviceable area of a shelter will not simply depend on geographical distance, rather it should be based on the "difficulty" to arrive at a place which was discussed as cost. The shelter location points (271) and cost surface which generated in section 4.5 were input in Cost allocation tool in ArcGIS to identify the zone of each source cell that could be reached with the least accumulative cost. This analysis is very useful for evacuation planning, suppose people is living in between two shelters with equal distance, if the topography are same then we can say that people can go to either shelter. If the topography (travel surface) are not the same such as way to go to the first shelter have more road, not high steep slope and no flood then it have least cost.

Best evacuation path: Calculation of the best way to go (least-cost path) was done by using Cost distance tool in ArcGIS. The analysis consider destination and origin together with cost surface. Origin in where people live and in this case it was assumed this location to be the centroid of polygon that are identified as flood affected areas. Destinations were the shelters that were identified in previous section. The tool calculates accumulated cost of traveling from any particular location to each shelter points and generate least cost path.

5. RESULT

Figure 9 and 10 shows Landuse map and the flooded / non-flooded areas of the study. There are four categorize of land use: agriculture, built-up, settlement and water bodies. During normal flood 61% of the study area is affected by flood and the affect is very prominent in west of the study area.

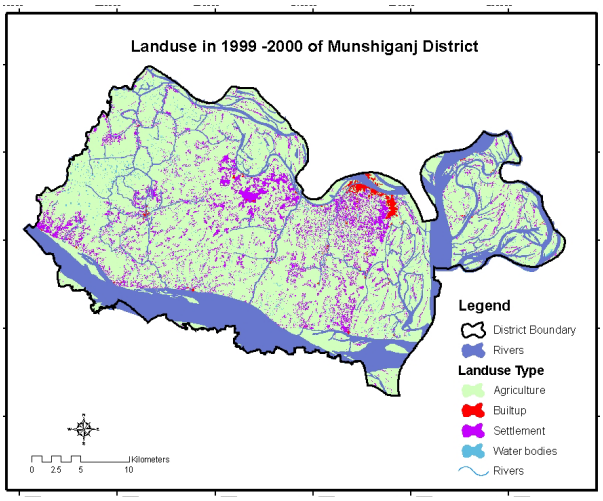

Figure9. Landuse map in 1999-2000

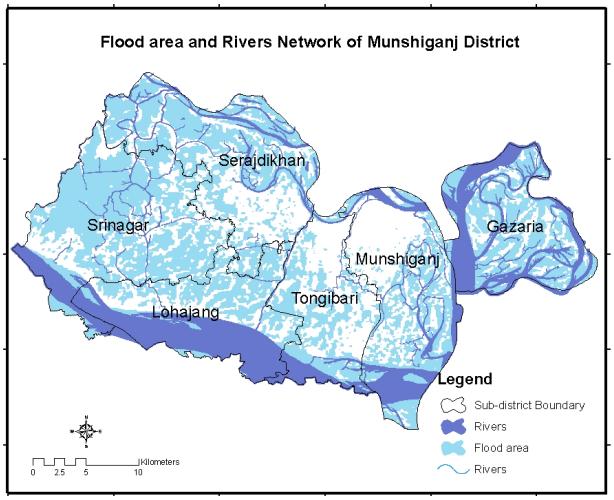

Figure10. Food and non-flood area

Flood vulnerability map shows in Figure11. It was found that almost all union of this district are inundated during flood season. In terms of area and population affected by flood, the Serajdikhan is the most affected Upazila due to it is comparatively in lower elevation. Lowest affected area is Tangibari.

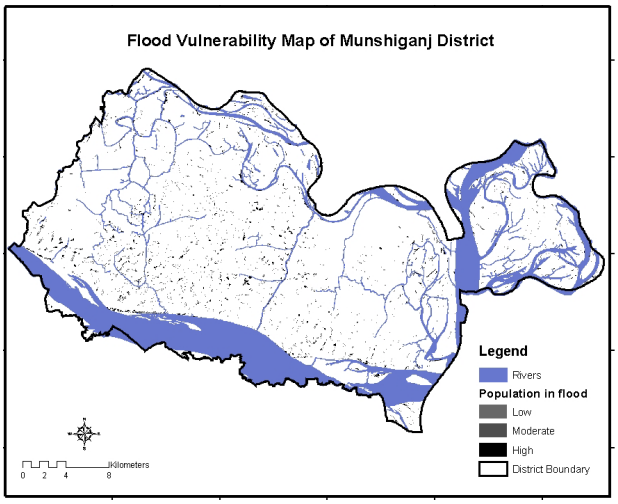

Figure11. Flood vulnerability map

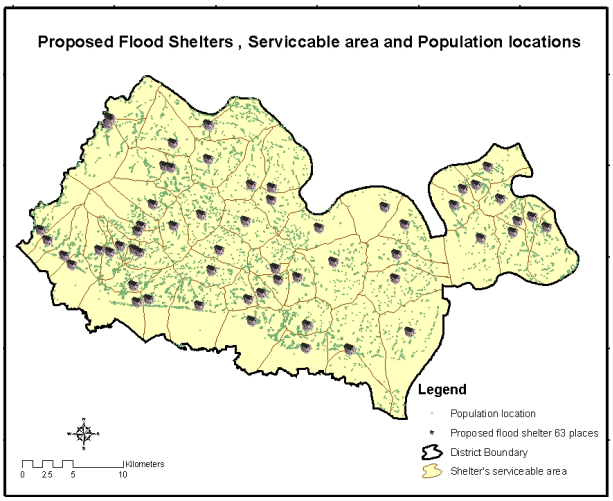

Figure12. Propose flood shelters and Serviceable area

Figure12 is the generate map with 63 shelters based on population limit and cost surface. The boundaries represent serviceable areas of each identified shelter.

In Figure13 shows Cost Surface classified into three classes; High, Moderate and Low. The low cost is areas mostly in high density of road and outside flood area. Propose 63 flood shelters and Cost Distance are shown in Figure14. The Cost Distance Surface illustrates smooth continues surface of accumulated cost value. The least cost is found at near shelter and increasing with the distance.

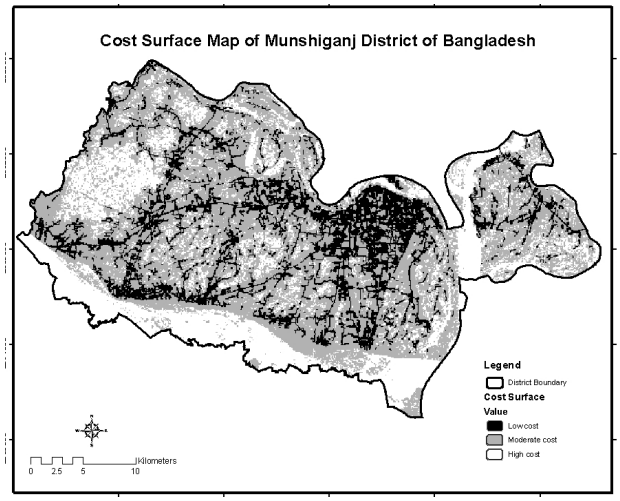

Figure13. Cost Surface map

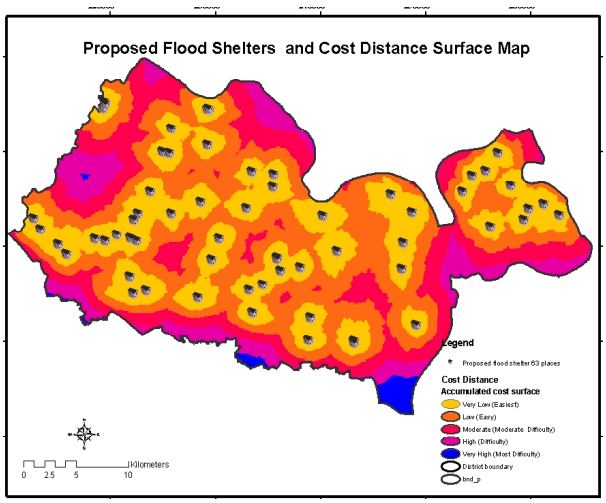

Figure14. Propose flood shelters and Cost Distance Surface map

Figure15 shows the best path for evacuate people in each serviceable area of 63 shelters as they were assumed that the capability of a shelter is at least 1,000 people. When comparing the evacuation path with road networks and flood prone area, it was found that this analysis is rather precise. The best path provides less difficulty to travel to a shelter. It was found most of them are at the road networks and away from flooded areas. Some paths were observed as travel path even they are flooded due to low flood levels and un availability of roads. Figure16 is an enlargement showing a shelter, population location in flood and best path for evacuation.

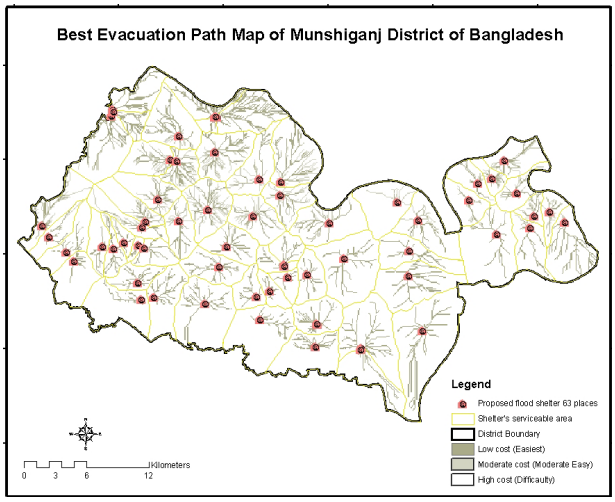

Figure15. Least cost path for evacuation for 63 shelters

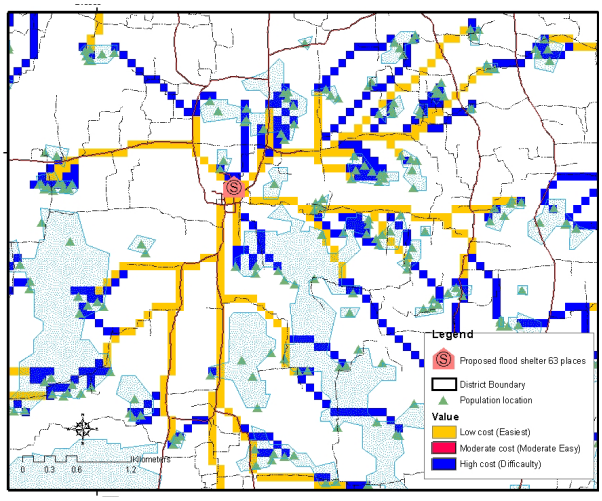

Figure16. Least cost path with road networks and flood area

6. CONCLUSION

It was possible to use satellite data for flood area mapping with reasonable accuracy using SAR and combining it with optical images. It could be said that this usage has high potential in practical usage of satellite data in flood area mapping, specifically in tropics. Visual interpretation is rather straightforward and easy to carryout with limited resources.

It may be required to combine with digital elevation model to rectify in areas where there is a high canopy cover. Also, the method used to estimate the population density gives reasonable approximation as the population data was re-distributed according to land use classes. The final product, flood risk map is the combination of land-use, flood area and population distribution. This combined information analysis was easily carried out within GIS environment demonstrating the potential of GIS system.

It was found that GIS is a promising tool for examining cost surface, identifying suitable flood shelters as well as generating best evacuation path for mitigation plan. It could be said that for mitigation plan can acquire more information from this analysis such as evacuation zone that face difficulty to evacuate people.

In the present study it was possible to convert cost surface to travel time so that it could be more useful for decision making for evacuation in emergency case. Further, the above analysis could further improve with incorporation of other relevant factors such as speed and travel time. More important and accurate results can be developed if it is possible to collect information on village location, village population and school capacities.

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