

Modelling cyclone hazard in Bangladesh

By:

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Summary

This exercise deals with the use of GIS for cyclone hazard zonation, in a study area South of Chittagong, Bangladesh, using data of the April 1991 cyclone. The exercise will produce several maps of the expected number of casualties per village and population category caused by cyclone flood events with return periods of 5, 10, 20 and 50 years. Prior to this, maps have to be made of the flood depth per return period, the population density and the vulnerability of the population to flooding. For the calculation of the flood depths, use will be made of a digital terrain model and a linear flood-decay model.

Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory d:\appguide\chap03. If you have already installed the data on your hard-disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored, c:\ilwis21\data\appguide\chap03. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).



- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory c:\ilwis21\data\appguide\chap03.

3.1 Introduction

Despite the fact that the Bangladesh Government issued warnings of the impending flooding, for the April 1991 cyclone, through its Cyclone Preparedness Program, and about 3 million people could have been moved to safety, many inhabitants remained behind to protect their property. During this disaster an estimated 138,000 people were killed and large numbers of houses, agricultural lands and infra-structural works were destroyed. Hundreds of schools were damaged and seven to eight thousand vessels were lost. Almost every bridge and culvert in the area was damaged and roads were washed out.

Within two days government air drops of food and medicine started, but they were hampered by continuing bad weather associated with the storm. Nearly two weeks had passed before massive international aid could react to the disaster and it was many months before the area returned to normal.

The Banskhalī study area is situated in the East of Bangladesh, South of the city of Chittagong. Area maps and attribute tables of the geomorphology, village population, the Union-districts, roads, embankments, cyclone shelters, and the elevation of the terrain with cm accuracy are provided. Also available are a Landsat Thematic Mapper and SPOT panchromatic image. For a general introduction you can make use of a geomorphologic overview map of the whole coastal zone of Bangladesh as well as ten ground photographs of the Banskhalī area.

Some GIS files are derived from:

- Sirajur Rahman Khan (1995) - “Geomorphologic Characterization of cyclone hazards along the coast of Bangladesh”, ITC-MSc study.

Other important information on the area has been taken from:

- “GIS technology for disaster management”, prepared by the Irrigation support project for Asia and the Near East (ISPAN), as contribution to the Bangladesh Flood Action Plan (FAP19); and
- Stephen T. Ray (1994) - “An assessment of the potential of applying GIS to two aspects of disaster management: Storm surge modeling and Cyclone shelter analysis”. MSc thesis of the University of Nottingham, UK

Additional background information on the cyclones is given in the Appendix. This appendix is available in Word format in the same directory as the data files. It is recommended to read the text in the Appendix first before starting the exercise.

Structure of the exercises

- In sections 3.2 and 3.3 all the files necessary for the exercise are given.
- Information is given on the display of the different data layers, such as segment, vector, point and raster maps, attribute tables, etc.
- In section 3.4 the analysis of historical cyclone events will be explained by using graphs of surge height, wind speed, number of casualties, etc. It is also recommended to read the Appendix (Wordfile appendix.doc).

- In section 3.5 cyclone surge hazard maps will be made for different return periods of the cyclone events. Use is made of a linear decay model of the flood depth. Repeated calculation can be done with an ILWIS Script.
- Section 3.6 explains the vulnerability and risk analysis. First the vulnerabilities of the total population to certain flood depths are estimated using data of the 1991 cyclone event. The number of potential casualties per village for surge flooding with a certain return period will also be calculated. Finally the surge flood risk will be determined for each village and population category, based on the formula:
$$\text{Risk} = (\text{Probability of occurrence}) * (\text{Vulnerability of population}) * (\text{Population density})$$

3.2 Available data

During the execution of the exercise you will use several different data layers. First an overview will be given of the whole coastal zone of Bangladesh, including the points of landfall of over 20 cyclones in the period 1960 to 1991. Information on the wind speed, surge height and number of casualties is stored in a database.

Of the Banskhali area - just south of the city of Chittagong - more map files are provided on landform, elevation, Union districts, roads, rivers, embankments and population/landcover. You will also find SPOT panchromatic data and a false color Thematic Mapper image.

You will find all this information in the files:

Bdesh	A hillshading map made out of a DEM.
Bdgeom	A polygon map of the main geomorphologic units.
Landfall	A table with information on the cyclones.
Landform	The geomorphologic map, including rivers and dikes.
Shelter	A map with the locations of the cyclone shelters.
Roads	A map of the main- and secondary- roads.
Village	A map with the villages.
Union	A map of the sub-districts with a table on population.
Eleva	A point and raster map of the elevation in cm above m.s.l.
Waterlin	A coastline of the area.
Batm453	Color composite of the Landsat TM (RGB: bands 453).
Baspotx	SPOT pan image, scanned from a paper print.
Photos 1-10	Scanned ground photographs of November 1994.
Appendix.doc	Background information to be displayed /printed in Word 6.0 or higher.

3.3 Display of the data layers

In this section we will provide you with the background for the case study. In section 3.3.1 you will study the small scale information of the whole coastal zone of Bangladesh. In section 3.3.2 the Landsat TM and SPOT panchromatic satellite images have to be analyzed. Several ground photographs can be displayed in 3.3.3 and finally all the map data layers are shown in section 3.3.4.

The exercise in section 3.3.6 is optional because making a Digital Elevation Model can take several hours.

3.3.1 Display the entire coastal zone of Bangladesh

Display the geomorphologic map with the following procedure:



- Display the raster map Bdes, the hillshading map of the whole of Bangladesh and surroundings.
- Add the geomorphologic map Bgeom as an extra data layer. To do so, select **Layers, Add Data Layer, Polygon Map**. Select from the **Add Polygon Map** dialog box Bgeom. Type 0 for the boundary width in the **Display Options** dialog box. Click **OK**.
- Zoom-in to the colored geomorphologic map. Click the left mouse button to display the names of the geomorphologic units.

Display the points of cyclone Landfall and add information from the table.



- Make sure that the maps Bdes and Bgeom are displayed. Add the point map Landfall. Display the symbols with size 10 and a red fill color.
- Double-click the points to display attribute data from the table Landfall.
- Open the table Landfall for display of the elevation data in the table. Browse through the table.
- Close all the maps and tables.

3.3.2 Display of the satellite images of Banskhal

First display the Landsat Thematic Mapper image Batm453. The image is a false color composite of the bands 4 (red), 5 (green) and 3 (blue). The spatial resolution of the image is 10 m (pixel size, because it has been resampled from the original 30 meters pixel size.).



- Double-click raster map icon Batm453. Select the check box Info and click OK.
- Browse through the image by using the mouse pointer. By clicking the left mouse button the colors of the three bands are displayed (Band 4, Band 5, Band 3). In the lower left corner of the geo-corrected image the x and y coordinates of the mouse pointer position are shown.
- Study the colors of the image, and zoom-in at selected sites.



Remark: the individual bands of the image are not available.

The map Batm453 provides information on the terrain characteristics. From west to east you first have the sea (blue color). The beach has a light image tone; the wider zone in the south is a tidal flat. Clearly visible is a north-south running river with some tributaries. In the east you find the Chittagong hills consisting of soft sedimentary rocks; the eroded parts have a light image tone. Other image tone differences are caused by various types of land use, such as homestead gardens, rice fields and roads.



- Close the map window when finished.

You are now going to look at the SPOT panchromatic image with filename Baspotx. The image is from the 22nd of January 1994 and is scanned from a paper print and resampled to a pixel resolution of 10 m.



- Display the raster map `Baspotx`.
- Browse through the image. Study the image characteristics such as gray tone and pattern. Try to recognize the homestead gardens of the villages, the hills, the roads, and the lower parts in the terrain. Zoom-in, if necessary. Do you also see the embankment near the coastline?
- Look also at the map properties by selecting **Edit, Properties**. You now find information on the size of the map, the pixel size, and the domain `Image`. Close the **Properties** dialog box.

3.3.3 Display of ground photographs

Ten ground photographs taken during the November 1994 fieldwork can be displayed. The pictures are intended to give an impression of the terrain only; the point locations are not always at their exact locations.



- Add as new data layer to the map `Baspotx` the point map `Photos`. Choose an appropriate symbol size and color.
- Select **Layers, Double Click Action, Execute Action, OK**.
- Double-click a point to display a ground photograph. Some information is given at the top of the photo.
- Close the map window.

3.3.4 Displaying segment and point data layers

In this exercise you combine the SPOT panchromatic image with some existing data layers, such as the landuse (map `Village`), the geomorphology (map `Landform`), the roads (map `Roads`) and the point elevation data (map `Eleva`).



- Display the map `Baspotx`.
- Add as data layer the Polygon map `Village`. Select **Boundaries only** and boundary color **green**. Click **OK** and you see the boundaries of the land use in green. These are digitized segments.
- Compare the map `Village` with your own visual interpretation.

- Look also at the map properties by selecting **Edit, Properties**. Information is displayed on the map size, the Identifier domain **Village** and the number of polygons. Close the **Properties** dialog box.

All landuse data is stored in the table **Village**. You can display this data using the pixel information window.



- Open the pixel information window. Make sure that this window is displayed next to the **SPOT** image and that also the **Catalog** in the **Main** window is still visible.
- Drag-and-drop the polygon map **Village** into the information window.
- Read the table information while browsing through the village areas.
- Add also the data layer **Landform** to the map window (polygon map with red boundary color).
- Drag-and-drop polygon map **Landform** into the pixel information window and “browse” again through the **SPOT** image.



Where are “low” and where are “high” areas and hills?
Does this correspond with your own interpretation of the image?



- Also drag-and-drop polygon map **Union** into the pixel information window. **Union** means local district; here the total population is given.
- Finally add the polygon map **Union** (display only the boundaries in orange) and the segment map **Roads**.
- Change the layers **Union**, **Village**, **Landform** and **Roads** in the list in the **Layer Management** dialog box by clearing the check box **Show** for each of them. Click the **redisplay** button. The vector maps are not shown anymore.

Finally, point information can be displayed as follows:



- Add as new data layer to the map window the point map Eleva. In the Display Options window select Attribute Eleva.
- Choose an appropriate symbol color and size. Click a red circle to display the elevation.

Remark: if you click in between the elevation points, not the elevation but the pixel value is being displayed!

- Drag-and-drop the Digital Elevation Model of the area (map Eleva). It will substitute the image Baspotx in the map window. This raster map is made from the interpolation of the individual points.
- Select Edit, Properties of the map Eleva and read the information in the window. The domain is Value. Close the Properties dialog box.
- Select the check box Show of the map Landform in the Layer Management dialog box, redisplay the map window.
- Add the map Eleva to the pixel information window and browse through the image to know the information from the maps Landform and Eleva.
- Close the map window and the pixel information window.

3.3.5 Rasterizing the maps

For the surge modelling (Section 3.5) and risk analysis (Section 3.6) you need to perform several calculations in MapCalc. For this you have to rasterize the maps.



- Rasterize the map Landform using the option PolRas in the Operations-list. Give the output raster map the same name. Use the Georeference: Baspotx.
- Repeat the same procedure for the polygon maps Union and Village using the same georeference.
- Rasterize the segment maps Waterlin and Roads. Save the raster map with the same name and use for all the maps the georeference Baspotx. Check the results.

3.3.6 Creating a Digital Elevation Model by point interpolation (optional)

Because the interpolation may take several hours, this can only be done if there is sufficient time available.



- Select from the main menu **Operations, Interpolation, Point, Interpolation, Moving Average**. Select the point map `Eleva` and the attribute `Eleva_cm`. Use the georeference `Baspotx`; the domain: `Value`; and a value range: 0–1500 with a precision 1.
- Select **Weight function, Inverse Distance; Limiting Distance: 700**. The output map name is `Dem`. Click **OK**.
- Double-click raster map `Dem`. Now the map will be made according to the expression displayed in the command line. This may take a long time (about 2.5 hours).

3.4 Analysis of historical cyclone events

During the years 1797 to 1991, Bangladesh was hit by 59 severe cyclones, of which 32 were accompanied by storm surges. Full information on all historical events is given in the Appendix (Word file: `appendix.doc`). Concerning 20 of these cyclones, information for the whole of Bangladesh is stored in the ILWIS table `Landfall` on wind speed, surge height, loss of lives and properties, tidal height during the event, etc.

First you will display graphically the relationships between the data in the different attribute columns for the whole of Bangladesh. This will be repeated for the Chittagong coast after a selection has been made using **Table Calculation**. Finally the return period is given for the cyclone events, as calculated by Khan (1995).

3.4.1 Analysis of the table `Landfall`

First you are going to display the table `Landfall` and make a graph of different column combinations. Next you are going to select the values from only the Chittagong /Banskhali area.



- Double-click the table `Landfall` from the Main window. Display the table in a full screen for a good overview. The table has the columns

Domain of the table;
Zone number;
the name of the Zone (our study area is Chittagong);
the year of the landfall;
the month of the landfall;
the wind speed;
the surge height in m;
the tidal height during the landfall in m.;
the number of death (casualties).

- Select: Options, Show Graph. Select Wind for the X-axis and Surgeh_m for the Y-axis. Click OK. Select the Point, circle and the color red in the Edit Graph dialog box.
- Select OK to display the graph on the screen. As you see, the “cloud” of points is rather large. The reason for this is that the relation between Wind speed and Surge height differs in the various coastal zones. The relation will be better if we select the data from only the Chittagong zone (Zone 3).
- Close the graph window.

Now do the same for the Chittagong area. First you have to make extra columns of data from zone 3 using Table Calculation :



- Type in the command line the following TabCalc formula:
`Wind3:=iff(Zone=3,Wind,0)`↵
Meaning: if the value in the column zone =3 (Chittagong zone), then select the values from the column wind, otherwise give value 0.
- Repeat the above described procedure and make the columns Surge3 (from the old column Surgeh_m), and Tidal3 (from the old column Tidalh_m).
- For the real height of the floodwave we have to add the surge height to the tidal height. Use the MapCalc formula:
`Waveh3:=Surge3+Tidal3`↵
- Create a graph (points) of the following table column combination:
Wind3 in the x-axis and Surge3 in the y-Axis.
- Do the same (in the same graph window) for :
x-axis: Wind3 y-axis: Waveh3
x-axis: Wind3 y-axis: Death
x-axis: Surge3 y-axis: Death

- Evaluate the results. Draw conclusions.
- Close the graph window and the table window.

3.4.2 Return period of the cyclones

From the literature (Khan, 1995) there is information on the following return periods of the cyclone events along the whole Bangladeshi coast (Figure 3.1 and table 3.1).

Table 3.1: Surge heights for different areas and different return periods

Return period	Probability in 100 yr.	Entire coast (m)	Zone1 Sundarban (m)	Zone2 Noakhali (m)	Zone3 Chittagong (m)
5 years	0.2	4.0	4.1	4.5	3.7
10 years	0.1	4.7	5.0	5.6	4.1
20 years	0.05	5.4	5.7	6.2	4.7
50 years	0.02	6.1	6.6	7.1	5.1

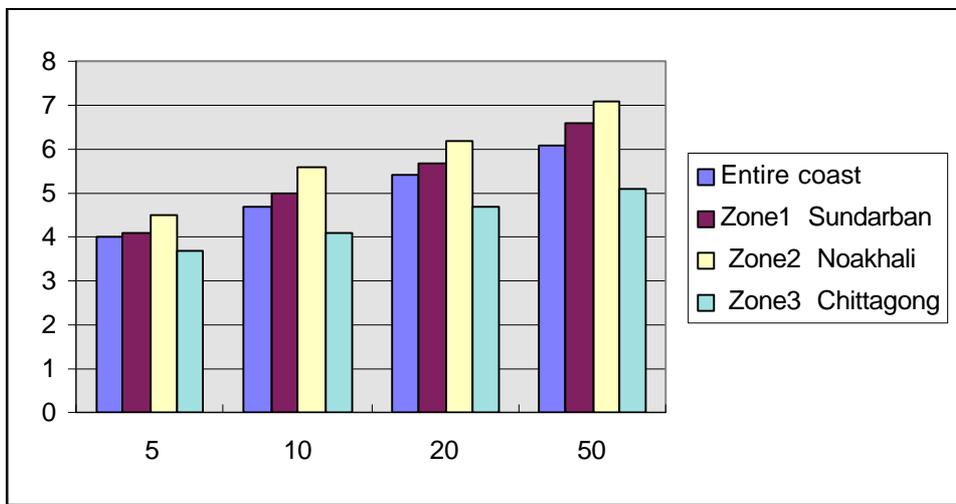


Figure 3.1: Surge heights for different areas and different return periods

3.5 Cyclone flood modelling

During this exercise you will make a map of the flood water depth during the April 1991 cyclone in the Chittagong/Banskhali area. For this two models will be used:

1. a surge model based on historical records of cyclone flooding in Bangladesh; and
2. the Digital Elevation Model (DEM) of the area.

3.5.1 The Surge Decay Coefficient (SDC)

Before starting the calculations for the surge model, you have to find out how the surge depth decreases inland. This is the so-called *Surge Decay Coefficient (SDC)*, which will be different for each surge height. The SDC is a function of the friction caused by surface forms (morphology, embankments and elevated roads) and land cover (houses, rice fields, homestead gardens with trees, etc.). The contribution to the friction of all the terrain elements to the SDC is not fully understood and is still being investigated. However, from historical records we know that in areas with low or no dikes along the coast the surge depth will be more or less constant; after this it will decrease until a certain distance inland.

The data from the total limit to inundation from the coastline for different storm surge heights have been taken from the Multi-purpose Cyclone Shelter project (MCSP, 1993) in Bangladesh. Some of these data for the whole coast of Bangladesh are presented in the table 3.2.

Table 3.2: Relation between flood height and inundated area

Flood height (meters)	Area under constant surge depth (distance from coast in meters)	Total inundated area (distance from coast in meters)
3.7	415	2000
4.1	520	2900
4.7	580	3900
5.1	670	4200
5.6	760	4400
6.0	880	4700
6.5	1000	5000

From field data of the flood wave of the April 1991 cyclone in the Chittagong/Banskhali area we know that it was 6.5m. high near the coast and extended approximately 5000 m. inland. This wave height includes a tidal height during the time of landfall of 1.7m. This means that the actual surge height in the Banskhali area was “only” 6.5m - 1.7m = 4.8m. According to table 3.1 the surge height of 4.8m has a return interval of a little bit more than 20 years. For the modelling we take a constant surge depth of 1000m starting at the coastline (see table 3.2). Further inland the surge depth decreased with the SDC (see also figure 3.2).

The *Surge Decay Coefficient (SDC)* is calculated as follows:

$$SDC_{RP} = \frac{\text{Surge height} - \text{Avg. elevation of the land at the end of the surge}}{\text{Width total inundated area} - \text{Width area with constant surge}} \quad [3.1]$$

From the values in the above figure we find:

$$SDC_{RP=20yr(Chittagong)} = \frac{(650 - 263)cm}{(5000 - 1000)m} = 0.097[cm/m] \quad [3.2]$$

This value will be used in the next exercise on surge modelling

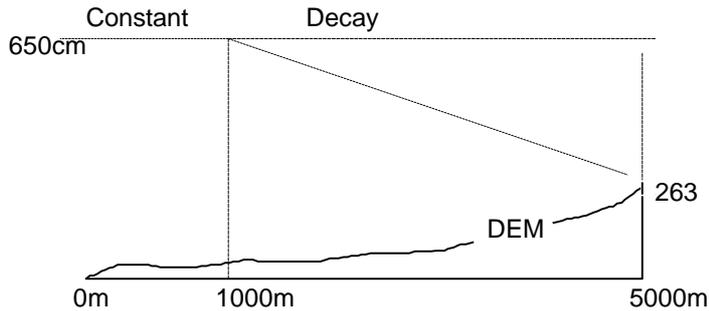


Figure 3.2: Illustration of the decay inland of a surge height of 650 cm at the coastline

3.5.2 Surge modelling - basic methods

The steps for a surge modelling of a 650 cm high flood wave are the following:

1. First create a distance map starting at the coastline to at least 5000m inland. The coastline is given in the raster map `Waterlin`. First we remove the sea part. After this we save the result as the map `Codist`.
2. Next create several maps of the surge inundation depth for a flood height near the coast of 650 cm:
 - One map from the coastline until 1000m inland, as if there is no decay and relief. To be saved as `In650a`.
 - An other map from the decay starting at 1000m inland and giving linear decreasing values until 5000 m inland, to be saved as `Sdc650`.
 - A map in which the values from the map `Sdc650` are subtracted from the map `In650a`. This map has to be saved as `In650b`.
 - Finally you subtract the values of the elevation map `Eleva` from the map `In650b`. This is the map `In650c`.
 - To exclude the area at more than 5000m from the sea we remove all negative values. The final map is the hazard map and should be saved as `Ha650f`.

1. Distance calculation starting from the coast



- Calculate a distance map using `Waterlin` as the starting map. Give precision 1.0. The output map is `Distance`.

- Display the result and check the image values.
The distance calculations are also performed in the direction of the sea. Exclude the sea with the formula:

```
Codist:=iff(Landform="Sea",0,Distance)↵
```

2. Calculation of surge inundation depth (flood height near the coast 650 cm)



- Type the following MapCalc formula in the command line to make the inundation map until 5000 m from the coast for a coastal flood height of 650 cm as if there were no decay and no relief:

```
In650a:=iff(Codist<=5000,650,0)↵
```

Save the map with domain Value and precision 1.0. Check the values.

- Make a map of the decay from 1000 until 5000 from the coast. Type the formula:

```
Sdc650:=0.097*(Codist-1000)↵
```

The formula describes that for each meter distance from the coast (starting after 1000m) the map will be reduced by the Surge Decay Coefficient (SDC). Save the map with domain Value and precision: 1.0. Check all the values.

- Subtract the pixel values of the Sdc650 map from the pixel values of the In650a map. Make the resulting map In650b with domain Value and check the pixel values.
- Subtract the elevation map from In650b. Save the map as In650c with domain Value and check the pixel values. As you will see, some pixels in the east have a negative value.
- Finally exclude the negative values in In650c, which make no sense for further calculations. The final hazard map is:

```
Ha650f:=iff(In650c<=0,0,In650c)↵
```

- Display the map and check the pixel values. Close the map.

3.5.3 Surge hazard modelling with an ILWIS script

In this exercise you will make several hazard maps per return period. In the maps you include per return period both the extend of the flooded area and the flood height per pixel (magnitude of the hazard) .

The procedure is as follows:

- a. For each recurrence interval the corresponding Surge Decay Coefficient has to be calculated using the data from the tables 3.1 and 3.2. Do not include the tidal influence in the calculations.
- b. Flood Hazard maps per return period have to be made. This can be done relatively fast by using the ILWIS script option. With a script you make a sequenced list of ILWIS operations, equivalent to a batch file. In the script dialogue box, type your lines of calculations and operations. The parameters in a script must be written as %1, %2, %3, etc. The script can be run from the command line in the main window.
- c. Name the final hazard map Harety (ret = return period).

a. Calculation of the Surge Decay Coefficient interval (Chittagong zone)

Example: Return period 5 years. Corresponding surge height: 370 cm.



- Calculate SDC for all return periods using the formula 3.1. First you have to fill in all data in the table below using the information from the tables 3.1 and 3.2.
- After this, you estimate the average elevation at the end of the area under surge by:
 First making a map of the elevations at the total surge distance from the coast using the maps Codist and Eleva (or DEM).
 Example MapCalc for the elevations at approx. 2000m from the coast (strip of 5m wide):

```
Elev370:=iff((Codist>=2000)and(Codist<=2005), Eleva,0)↓
```
- Next display the histogram of this map in a tabular form and make with TabCalc an extra column with average values using the average function Average.

We exclude all the terrain above the surge height near the coast:

```
Elev:=iff(Value<=370,Value,?)↓
```

```
Avgelev:=avg(Elev)↓
```

- Calculate the value of SDC using the pocket line calculator and the existing function SDC. Write the result manually in table 3.3
- Repeat this for the other maps; fill in the table below.

Table 3.3: Table to be completed manually

Return period	Surge height Chittagong (cm)	Area under const. Surge (m)	Inundated area (m)	Avg. elev. at end of surge (cm)	SDC (cm/m)
5 yr.	370	415	2000	278	0.058
10 yr.					
20 yr.					
50 yr.					

b. Flood hazard mapping per recurrence interval using ILWIS script



- Open the script, *Surge*. Study the Script file (which is printed below). Do not change it! The Script file gives all the steps for the calculation of the surge inundation depth (as explained in section 3.5).
- Exit the script file.

Script file

```
%1:=iff(Codist<=%2,%3,0)
%6:=%4*(Codist-%5)
%7:=%1-%6
%8:=%7-Eleva
%9:=iff(%8<=0,0,%8)
```

Explanation

- %1 : flood map as if there were no decay and relief (in \underline{x} a.mpr) \underline{x} :flood height
- %2 : the width of the inundated area
- %3 : the flood height along the coastline (surge plus tidal height)
- %4 : the value of the Surge Decay Coefficient (SDC)
- %5 : the width of the area under constant surge
- %6 : the map Sdc \underline{x} .mpr (reduction by the SDC)
- %7 : the map In \underline{x} b.mpr (\underline{x} : surge height along the coast)
- %8 : the map In \underline{x} c.mpr (\underline{x} : surge height along the coast)
- %9 : the final hazard map Haz \underline{r} ety.mpr (\underline{r} : return period of the surge height \underline{x})

Landform, Eleva, Codist: existing maps used for the calculations

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- Type in the command line of the main window the following for the 5 year return interval with a surge height along the coast of 370 cm (values from first row in the above table):


```
Run Surge In370a 2000 370 0.058 415 Sdc370
In370b In370c Ha05y
```
- Meaning: run surge %1 %2 %3 %4 %5 %6 %7 %8 %9
- Hit the enter key and wait until all the calculations have been performed automatically. The maps In370a-c, Sdc370 and Ha05y are being made.

For the flood hazard modelling for the different recurrence intervals we first have to make a table with all the data necessary to run the script files.

Table 3.4: Table to be completed, containing input parameters for the script

	%	5 yr.	10 yr.	20 yr.	50 yr.
Flood height at coast (cm)	<u>x</u> (cm)	370			
Map: In <u>x</u> a	% 1	In370a			
Width inundation (m)	% 2	2000			
Flood height at coast (cm)	% 3	370			
SDC	% 4	0.058			
Width constant surge (m)	% 5	415			
Map: Sdc <u>x</u>	% 6	Sdc370			
Map: In <u>x</u> b	% 7	In370b			
Map: In <u>x</u> c	% 8	In370c			
Map: Harety	% 9	Ha05y	Ha10y	Ha20y	Ha50y

☞

- Create the formulae to be typed in the command line of the main window for return intervals of 10, 20 and 50 years:

Flood hazard map with 10 year return interval - Ha10y:


```
Run Surge _____
                %1 %2 %3 %4 %5 %6 %7 %8 %9
```

Flood hazard map with 20 year return interval - Ha20y:

Run Surge _____
 %1 %2 %3 %4 %5 %6 %7 %8 %9

Flood hazard map with 50 year return interval - Ha50y:

Run Surge _____
 %1 %2 %3 %4 %5 %6 %7 %8 %9

- Check the above formulae and the script file carefully.
- Type the first in the command line and press **Enter**. Make sure that there is always one space in between the parameters.
- Repeat this for the other formulae.
- Check all the hazard maps: Ha05y, Ha10y, Ha20y and Ha50y.

3.6. Vulnerability and risk analysis

After making hazard maps per flood return interval we can also make a vulnerability map of the inhabitants of the villages in the area. By calculating the population density we can then estimate the number of people at risk for a certain surge height. Finally we calculate the risk for certain categories of people, such as children, elderly, women and men.

3.6.1 Vulnerability analysis of the population

The *vulnerability* of the people to flooding is the *degree of loss* to the total population, or particular categories, resulting from flooding with a certain depth. It has to be expressed on a scale from 0 to 1.

Unfortunately we do not have sufficient good data on the vulnerability for the people to certain surge flood depth values. From the April 1991 cyclone in the Chittagong area we know that the casualty figures in several of the villages near the coast were as high as 70 percent of the population. In a belt at some distance from the coast, but still in the hazard zone, the casualty rate was in the range of 30-35 percent. In the whole coastal belt, including the areas at the foot of the hills outside the hazard zone, deaths were probably up to 20-30 percent of the existing population. The causality rates for the different population categories were as follows: Children: 50%, Women: 25%. Elderly: 15% and Men: 10%

(Source: Cyclone 91 - An environmental and perceptual study. 1991, Bangladesh Center for Advanced Studies).

Although several warnings were given before the impact of the April 1991 cyclone, only about 16 percent of the population moved to safer places, such as a cyclone shelter or the foothills. The primary reason for staying home was fear of burglary.

The small farmers risked their lives, because they were poor and did not want to take risk of becoming even poorer.

Based on the above figures we assume the following for our calculations of the vulnerability to surge flooding of the people living in the area:

- a. "Near the coast" (= 1500m) the vulnerability is 0.7. By using the inundation map *In650f* and the distance map *Codist* we can calculate the average flood depth at 1500 from the coast: 323 cm;
- b. "At some distance from the coast" (we assume in our case = 3000m) the vulnerability is 0.3 and the average flood depth 171 cm;
- c. The vulnerability function increases linear with flood depth;
- d. The vulnerability of 1.0 is reached at a arbitrary depth of 450 cm
- e. About 16% of the total population moved to safer places prior to the disaster.

Based on the above described assumptions the relationship between the flood depth and vulnerability is described in the table below. We have also included a column with the Vulnerability Coefficients (*V_c*). The *V_c* gives the increase in vulnerability per cm growth of the flood depth and is also an indication of the steepness of the line in the graph. The *V_c* of a flood depth of 0.0 cm is of course 0.000. The *V_c* of the flood depth between 0.0 and 171 cm is 0.00175, between 171 cm and 323 cm 0.00217 and between 323 cm and 450 cm the highest at 0.00222. Above a flood depth of 450 cm the Vulnerability is always 1.0. Check all this values by yourself.

By multiplying the *V_c* with the flood depth values of the four hazard maps *Ha05_y*, *Ha10_y*, *Ha20_y* and *Ha50_y* we will get the final vulnerability maps *Vu05*, *Vu10*, *Vu20* and *Vu50*.

Table 3.5: Relation vulnerability and flood depth

Flood depth (cm)	Vulnerability	<i>V_c</i>
0.0	0.0	0.000
171	0.3	0.00175
323	0.7	0.00217
450	1.0	0.00222

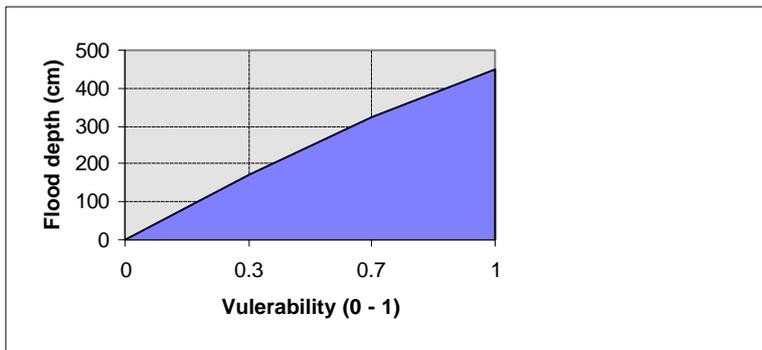


Figure 3.3: Relation vulnerability and flood depth (see also Table 3.5)

In the next step the Vulnerability Coefficient has to be multiplied by the pixel values of the four hazard maps per flood depth class. At a greater depth of 450 cm the vulnerability is always 1.



- Use the ILWIS Script option in MapCalc to make the vulnerability maps Vu05y, Vu10y, Vu20y and Vu50y.
- Select from the main window: File, Create, Create Script.
- Type the formula below in the Create script dialog box and give it the name: Vulner:

```
%1=iff(%2=0,0,iff(%2<=171,%2*%3,iff(%2<=323,%2*%4,iff(%2<=450,%2*%5,1))))
```

Try to understand the syntax of this formula

- Run the script file Vulner from the command line in the main window

%1: Vu05y or Vu10y, Vu20y, Vu50y

%2: Ha05y or Ha10y, Ha20y, Ha50y

For all the maps: %3: 0.00175, %4: 0.00217, %5: 0.00222

- Check the values of all the vulnerability maps.

3.6.2 Calculation of the population density

In the next exercise you are going to calculate the number of people at risk per village. Information on the population is given in the maps and tables `village` and `union`. In the table `Village` extra columns will be made with the population density and population category per village. After this, a raster map will be made using the information from the newly made columns. For the risk analysis we assume that 16% of the population has moved to safer places prior to the cyclone disaster (after the warning).



- Display the polygon map and the table `Village`. Rasterize the map, if that has not yet been done.
- Use TabCalc to make extra columns of the density in hectares of the total population and those of children, men, women and elderly people.
Subtract first 16% of the population.

```
Detot:=(Popul-0.16*Popul)/(Area_m/10000)↵
```

Choose precision 0.01.

- Create the columns Dechild, Dewomen, Deelder, Demen.
- Now create raster maps of the population densities of the different population categories using the data in the newly made columns. The syntax of the formula to be typed in the command line of the main window is:
`OutputMap:=InputMap.Table.Column`

Give the output maps the same name and same precision as the columns in the table. The input map and table is Village. First create the output map Detot.

3.6.3 Calculation of the number of casualties per village

Example: Surge once in 50 year

To calculate the total number of casualties per village and per population category caused by a cyclone disaster with a certain return interval, you need the following maps:

- a. The vulnerability maps: Vu05y, or Vu10y, Vu20y and Vu50y
- b. The population density maps: Detot, Dechild, Dewomen, Deelder, Demen.

If you work in a group, do not create the maps for all the return intervals yourself. To save time, split up the work between your colleagues and let every person make the maps for only one return interval. Compare the results. Also create sure that there is enough space on the hard-disk available; delete the photos or other maps, if necessary.

In the exercise we give an example of the calculations for a return interval of 50 years. For the calculation of the number of casualties we have to multiply the vulnerability map with the population density map. However, we have to correct the vulnerability value for the individual population categories. Children for instance have the highest vulnerability (50% of the total vulnerability of the whole population) and men “only” 10%. The data are given in the table below:

Table 3.6: The vulnerability for different population categories

Population category	Vulnerability %
Total	100
Children	50
Women	25
Elderly	15
Men	10



- Calculate the number of total casualties per hectare and per village for a once in 50 year flooding:

$$Ca_{tot50y} = Vu_{50y} * De_{tot}$$

Select precision: 0.01.

- Check the values of the map.
- Do the same for children, women, elderly and men. Correct the vulnerability with the percentages in the above table. Save the maps as *Cachi50y*, *Cawom50y*, *Caeld50y* and *Camen50y*.
- Ask your colleagues to create the same maps for return periods of 5, 10, and 20 years. Compare and discuss the results.

During a return period of 50 years the flood will occur statistically twice. To calculate the total number of casualties after for instance 50 or 100 years, we also have to take into account the population growth in the area, which is about 2.5% per year. For this you can use the formula:

$$A_n = A_0 * (1 + \text{perc} / 100)^n \quad [3.3]$$

A_n = the amount after n years

A_0 = the amount in year 0

perc = the growth rate as perc. per year

n = the number of years



- Add to the table *Village* two columns with the total population per village after 50 and 100 years. The column names are *Poaf50y* and *Poaf100y*.

In *TabCalc* type:

$$A_n := A_0 * \text{pow}((1 + 2.5 / 100), n)$$

- Add to the table *Village* two columns with the population densities, taking into account an increase of the village area of 25% in 50 years and 50% in 100 years. The column names are *Deaf50y* and *Deaf100y*.
- Create raster maps out of the columns with the same name and calculate the number of casualties per hectare after 50 and 100 years. Select precision: 0.01.
- Save the maps as *Caaf50y* and *Caaf100y*.

3.6.4 Calculation of surge flood risk in a 100 year period

The flood risk for a certain return interval is the statistical chance that people drown due to the surge event. It is the product of the probability of occurrence of the event in 100 years, the vulnerability and the number of people living in the area. This means that the risk may change due to the frequency of the cyclones in the future, the population growth and, for instance, the building of dikes, cyclone shelters, etc.



- Create a map with the risk for surge flooding of the total population in the villages per hectare for a probability of 50 years:

Riskmap:=probab.of occurrence * vulnerability map * pop.density map

Save the map as Ritot50y.

- Do the same for the population categories.
- Save the maps as Richi50y, Riwo50y, Rield50y and Rimen50y.
- Compare your results with the risk maps of the colleague students with different return intervals.

References

Only the references of the exercise are listed. At the end of the word file appendix.doc a much longer list is given.

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