- Press Enter after digitize the point > in the attribute table in column Elevation (give the desired height)> Press save Edits.

Continue with the other cross sections

807 points describe the cross sections of the main Nile, Blue Nile and White Nile.

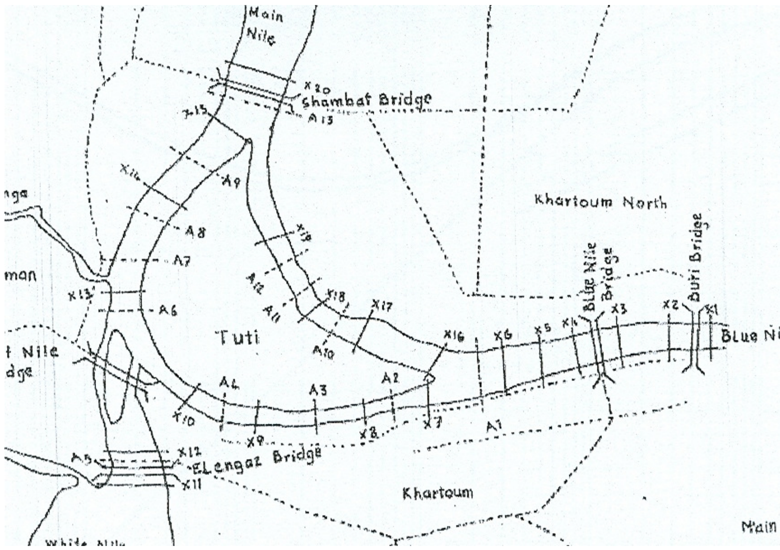


Figure 5.14: cross sections of the White Nile, Blue Nile and Main Nile(UNESCO_Chair_for_Water, 2002).

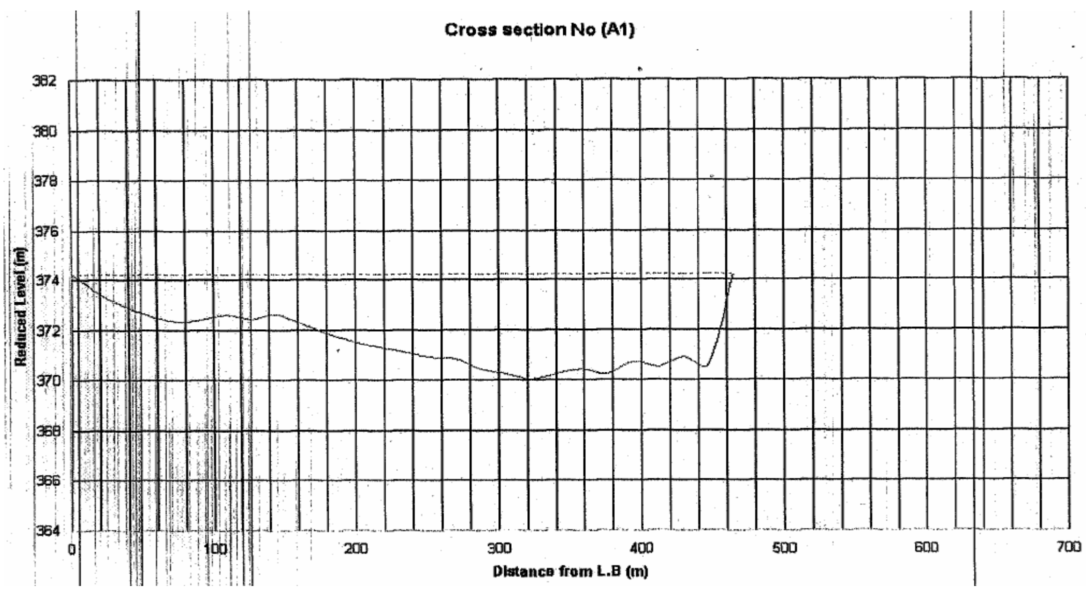


Figure 5.15: Cross section A1 at the Blue Nile(UNESCO_Chair_for_Water, 2002)

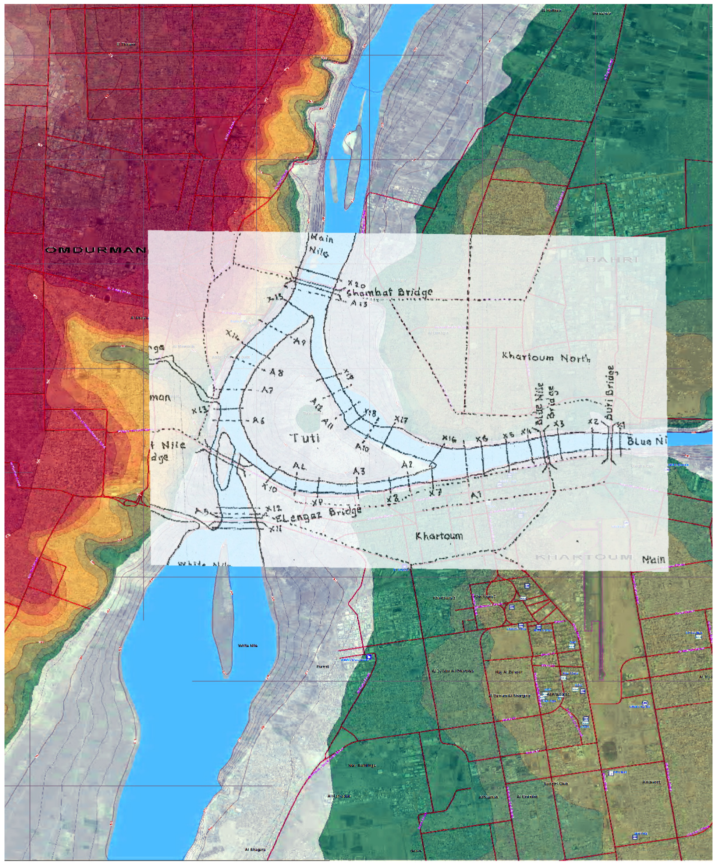


Figure 5.16 overlaid transparent cross sections on the topographical map

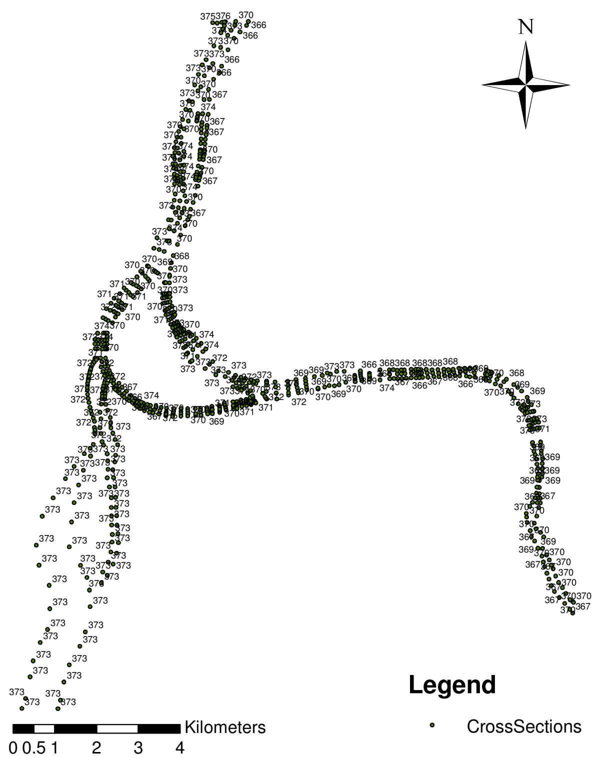


Figure 5.17: Cross sections of the Blue Nile, White Nile and Main Nile.

5.1.4.5 Embedded the cross sections on the TIN

At this stage we embedded the cross sections shape file in the TIN map. The final TIN map is as shown in **Error! Reference source not found.**.
The steps to embed the cross sections are:

- 3D Analyst> Create/ Modify TIN> Add Features to TIN.
- In the Inputs (select the tin layer in Figure 5.13)> check the layer whose features are to be added to the TIN (Figure 5.17)> in the setting for selected layer in the "Tag value field" select Elevation> finally save the changes in the desired location.

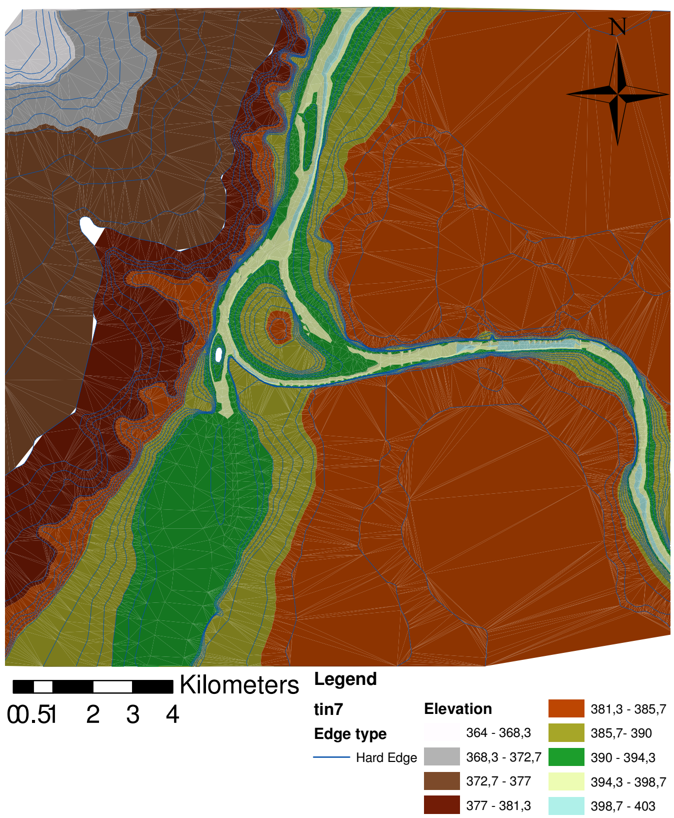


Figure 5.18: Tin map of Khartoum.

5.1.4.6 Convert the TIN to Raster

In order to import the created map to SOBEK model; we need to converted first the TIN map to Raster map as shown in **Error! Reference source not found.** . The cell size for the produced map is 67m. Finally, convert the raster map to ASCII map.
The step to convert TIN to Raster is:
3D Analyst tool> Conversion> From TIN> TIN to Raster (select the TIN input and the location of the out put Raster).

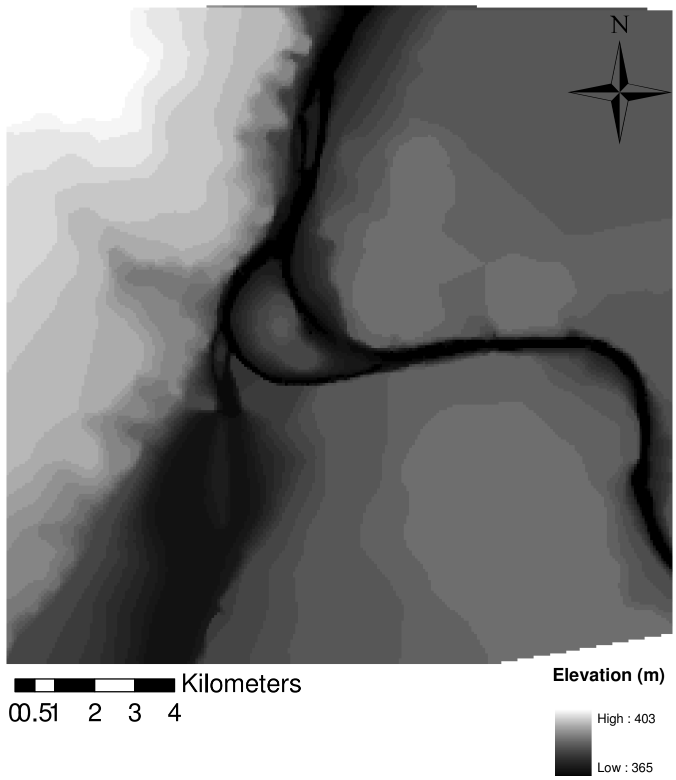


Figure 5.19: Raster file of Khartoum.

5.2 SOBEK 2D model by using elevation topographical map

A 2D hydrodynamic model SOBEK will be used to simulate the flood in Khartoum. From the literature reviews, we found that SOBEK is a robust model for simulating the flood. The Overland Flow Module which is embedded into SOBEK, is two-dimensional hydrodynamic simulation package bases on fully 2D shallow water equations. It simulates the flooding and drying process on high areas and low areas. SOBEK model requires a good elevation grid. The model produces several outputs, like, water depth, water level and velocities. In the next section the settings of the model will be described.

5.2.1 Settings of the model

Setting the model is an important phase, and it should be made carefully. The important inputs for the model for this case are:

- In the time setting for the simulation time step, the time step was 1day.Because the available data is daily data.
- The simulation period was for the flood period, the simulation taken from first of July to the end of October as shown in Figure 5.20. The selected year is 2000, because there is a satellite image during the flood period. Later the result of the model will be checked with the satellite image. The flood extent could be compared in both images.
- The simulation mode was unsteady calculation.
- The initial values are initial water level equal 2m.

- The out put options are daily time step, in order to visualize the results in a daily basis. The out put time step should be equal or more than the simulation period.

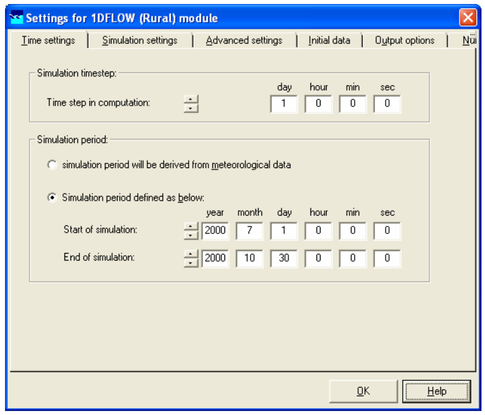


Figure 5.20: Setting of the model

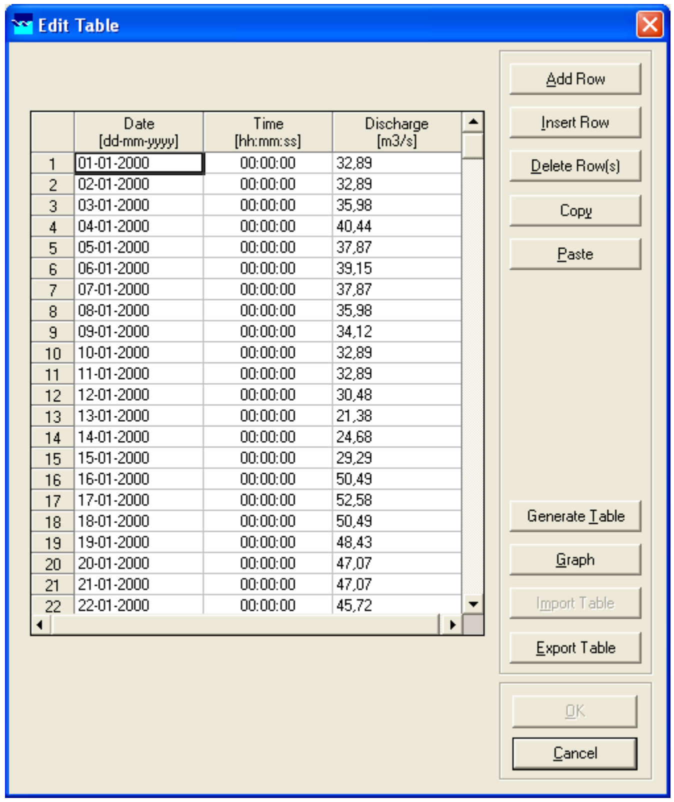
- The elevation topographical map which is made in section 5.1.4.6, will be converted from Raster to ASCII in the GIS environment, and then imported the 2D grid to SOBEK environment. Feature files for the Blue Nile, White Nile and Main Nile could be imported also

- In this model Chezy equal to 40 was used for the 2D grid,
  (Lindeburg, 1992)

$$C = \frac{v}{\sqrt{r_h} * S}$$

C: Chezy roughness coefficient
S: Water surface slope (=bed slope for steady uniform flow) [m/m]
r_h: Hydraulic radius (r_h=A/P = flow depth for infinitely wide channel) [m]
A: Cross-sectional area [m^2]
P: Wetted perimeter [m]
v= flow velocity
For sensitivity analysis Chezy equal to 35 and 45 were also used. However, SOBEK show no sensitivity to different Chezy numbers.

- **Upstream boundary condition**
  There are two upstream boundary conditions for the model, one in the Blue Nile and the other on the White Nile.
  The Blue Nile boundary condition is the daily discharge measurement at Khartoum Station for the year 2000 as shown in Figure 5.21. The plotted daily discharge is as shown in Figure 5.22 It is the boundary condition for the right river. Attention should be made to the format of SOBEK tables when pasting or filling the boundary condition tables. The Blue Nile boundary condition in reality is four kilometres upstream from the model boundary. The Blue Nile part at this place has the same feature. This location of boundary condition considered as first analysis.



	Date [dd-mm-yyyy]	Time [hh:mm:ss]	Discharge [m3/s]
1	01-01-2000	00:00:00	32,89
2	02-01-2000	00:00:00	32,89
3	03-01-2000	00:00:00	35,98
4	04-01-2000	00:00:00	40,44
5	05-01-2000	00:00:00	37,87
6	06-01-2000	00:00:00	39,15
7	07-01-2000	00:00:00	37,87
8	08-01-2000	00:00:00	35,98
9	09-01-2000	00:00:00	34,12
10	10-01-2000	00:00:00	32,89
11	11-01-2000	00:00:00	32,89
12	12-01-2000	00:00:00	30,48
13	13-01-2000	00:00:00	21,38
14	14-01-2000	00:00:00	24,68
15	15-01-2000	00:00:00	29,29
16	16-01-2000	00:00:00	50,49
17	17-01-2000	00:00:00	52,58
18	18-01-2000	00:00:00	50,49
19	19-01-2000	00:00:00	48,43
20	20-01-2000	00:00:00	47,07
21	21-01-2000	00:00:00	47,07
22	22-01-2000	00:00:00	45,72

Figure 5.21: Tabulated daily discharge measurements in Khartoum station for the year 2000.

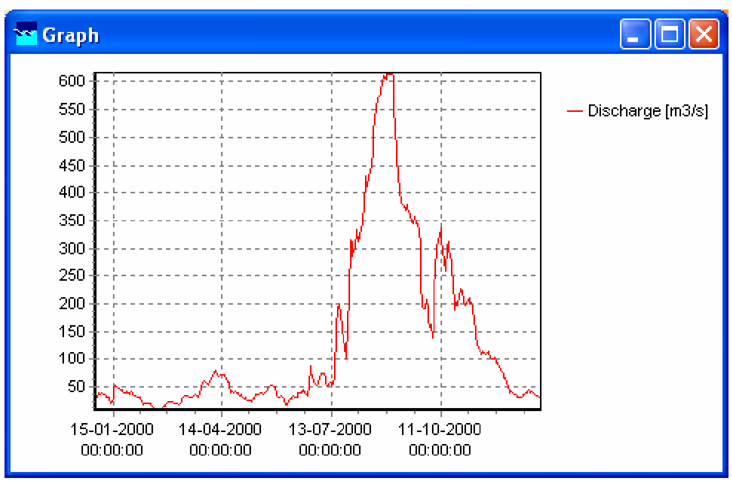


Figure 5.22: plotted discharge measurement in Khartoum station for the year 2000.

The White Nile boundary condition is the daily discharge measurement at Jabal Awlia Dam. The plotted daily discharge is as shown in Figure 5.23. It is the boundary condition for the left river. The selected year was 2000. In July we see that for some days the discharge is zero, because at that time the gates of Jabal Awlia Dam were completely closed. So, there was no any measured discharge. The White Nile boundary condition in reality is 30 kilometres upstream the model boundary. This distance considered to be long. But, the slope of White Nile is very mild. Improvement in future could be made for the model by combining 1D/ 2D model.

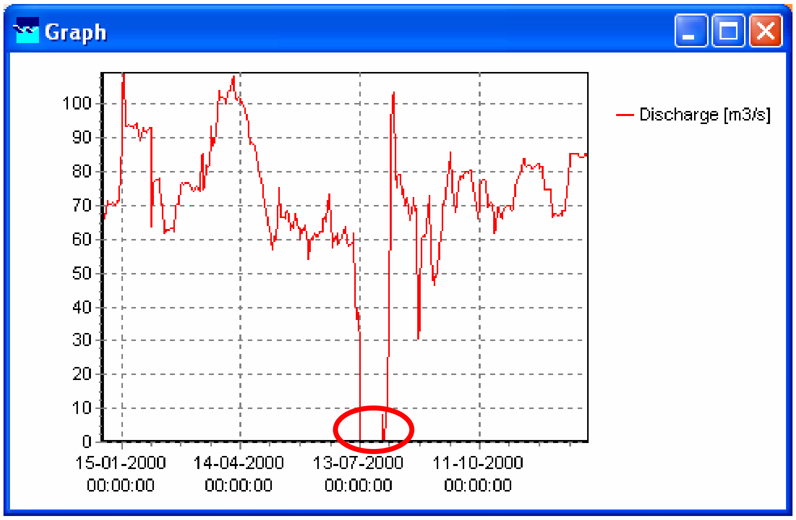


Figure 5.23: plotted discharge measurement in Jabal Awlia station for the year 2000.

- **Downstream boundary condition**

The Main Nile boundary condition is the daily water level measurement at Tamaniat. The plotted daily water level is as shown in Figure 5.24. It is the boundary condition for the Main Nile. The boundary condition is taken for the year 2000. The boundary condition in reality is two kilometres downstream the location in the model. Improvement in future could be made for the model by combining 1D/ 2D model.

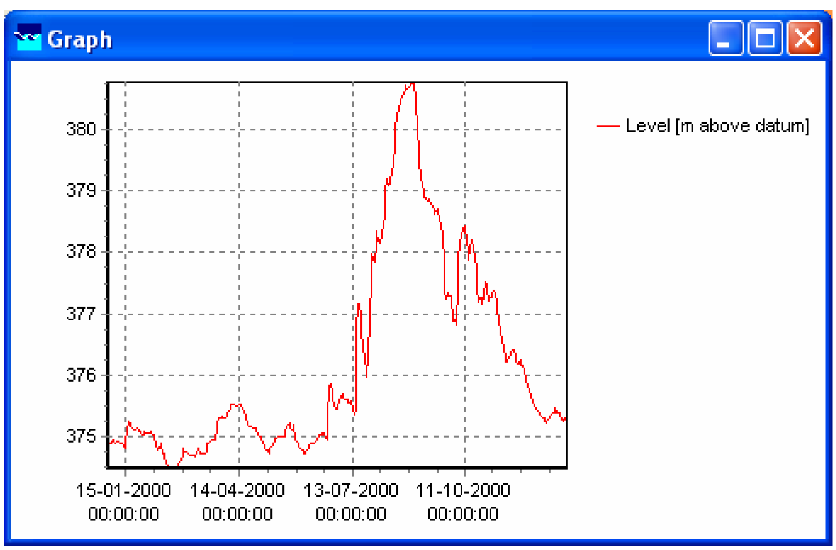


Figure 5.24: Tamaniat water level at the Main Nile for the year 2000.

- History points have included in the model for detailed information about the water depth, water level and velocity. Figure 5.25 shows the model set up and features.

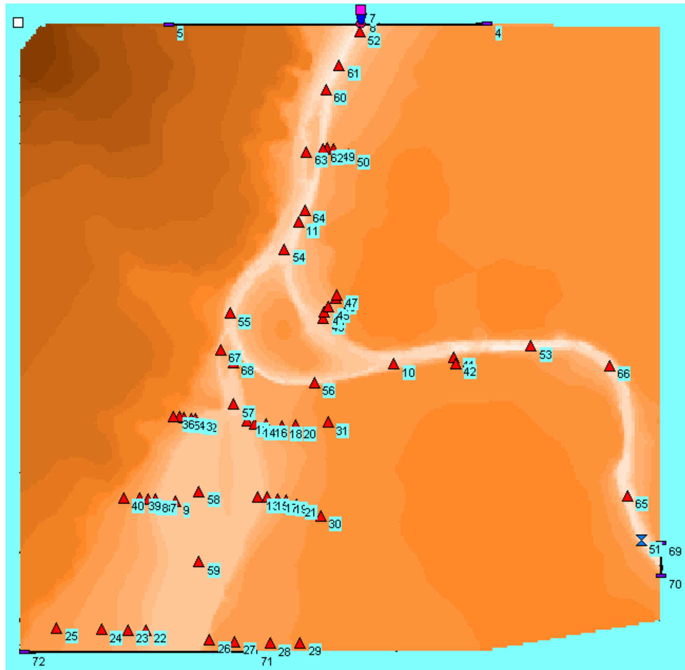


Figure 5.25: The model setup and features for the 2D model of Khartoum

6 Result of 2D model in Khartoum

6.1 Comparison between the topographical elevation map and SRTM elevation map

SRTM provides digital elevation map for the entire globe, it's easy and free to acquire and download elevation map for the desired areas from this free web site. In this section a comparison between the topographical elevation map and SRTM elevation map will be made, in order to evaluate the reliability of the SRTM map. If the difference is small and acceptable, then we can use the SRTM elevation map to simulate and forecast the flood for large areas in Khartoum and in other affected cities. In order to achieve this evaluation the SRTM elevation map and the elevation topographical map were imported to the GIS environment. Then we subtracted the two elevation map as follow.

Spatial Analyst Tools > Math > Minus> Determine the location of the two maps and determine the location of the out put map.

The map in Figure 6.1 was the difference between the two elevation maps. By looking at the legend of the map I found that the differences range from 17m to -18 m, which is very big difference. If we look at location (1) the difference is up to 18m, the reason for this is there are many towers along the bank of the Blue Nile. SRTM elevation map interpolates those high buildings. Moreover in location (2) the differences are also high, because there are some mosques, Friendship Palace (high tower) and high trees. In addition, in location (3) the cells look like a wall which is blocking the river. The reason for this wall, there is a big bridge which connects Khartoum province (right side) and Omdurman province (left side) as shown in (Figure 6.2). In location (4) the difference is up to 8m, because there are some trees along the right bank of the White Nile. (Figure 6.2) in the left part the flooded trees on the bank of the river.

From the above results we can conclude that the difference between the elevation topographical map and SRTM map is big. The range between the minimum difference and maximum difference is 35m. For flood analysis and flood simulation we need a high accuracy on the elevation map. So, the free SRTM elevation map is not suitable for simulating and forecasting the flood in Khartoum.

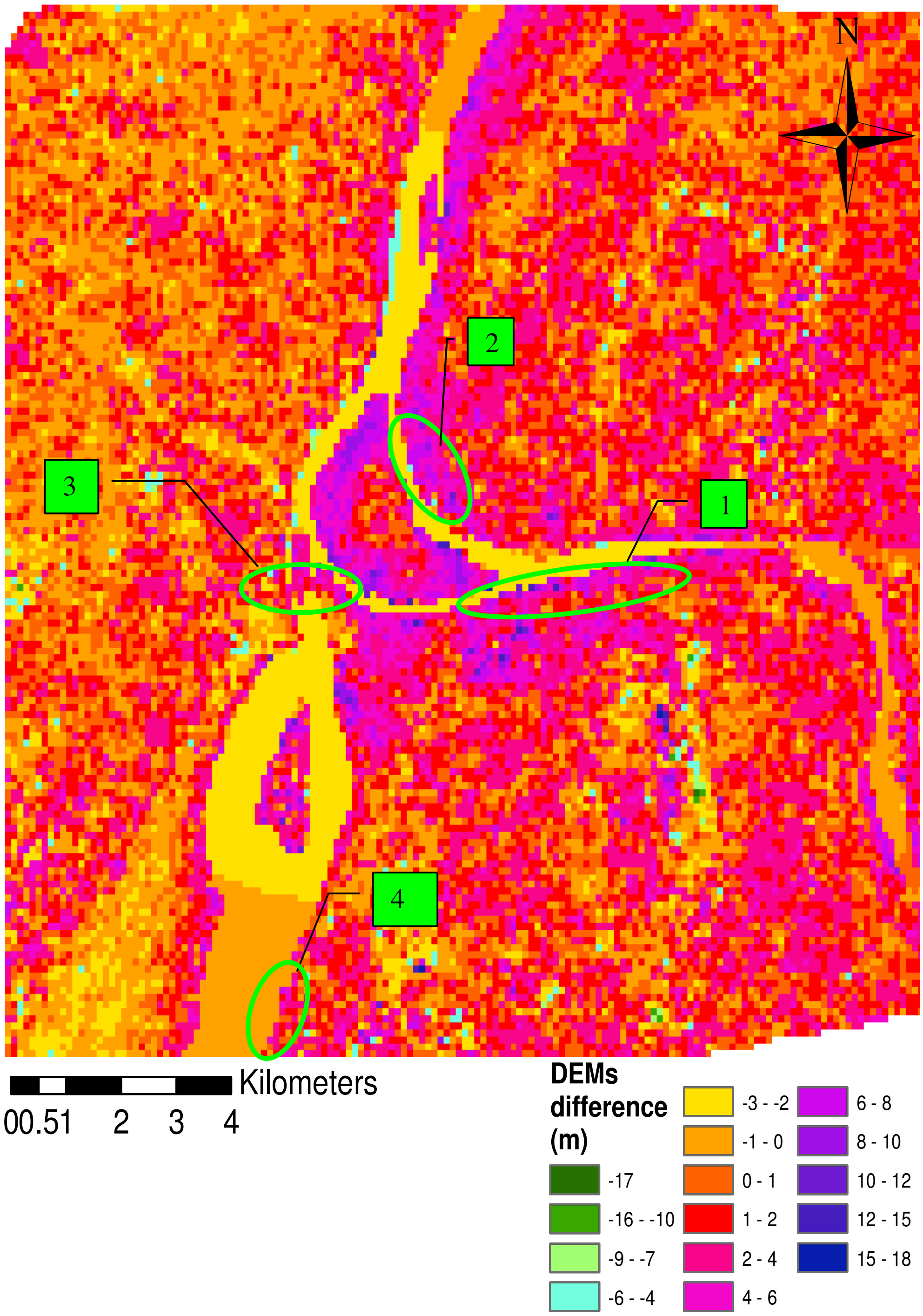


Figure 6.1: Differences between topographical map and SRTM map

Figure 6.2: Trees at location 4 and the bridge at location 3.

6.2 Remote sensing

6.2.1 Introduction

Remote sensing is the science and art of obtaining information about a phenomenon without being in contact with it. Remote sensing deals with the detection and measurement of phenomena with devices sensitive to electromagnetic energy. This process involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, by which they may be identified and categorized by class/type, substance, and spatial distribution. It is based on the principle that objects reflect or emit radiations in different wavelengths and intensities depending on specific conditions. An aircraft, spacecraft, satellite or ship may be used for this purpose equipped with recording devises such as camera, laser, radar, sonar, seismograph, gravimeter, etc. These devices are sensitive to electromagnetic energy such as light, heat and radio waves (from the target object) and help to analysis the electromagnetic spectrum by studying energy interactions and providing information in the form of digital mapping. With advancements in information technology remote sensing is prominently being carried out using digital processes.
Remote sensing makes it possible to collect data on dangerous or inaccessible areas. Moreover, replaces costly and slow data collection on the ground, ensuring in the process that areas or objects are not disturbed. (http://en.wikipedia.org/wiki/Remote_sensing).

6.2.2 Remote sensing images before and after the flood

Remote sensing images before and after the flood are valuable source for estimating the affected area by flood. Moreover, we can visualize the affected area without being on the flooded area. In addition, we can compare the result of model extent map with the satellite images.

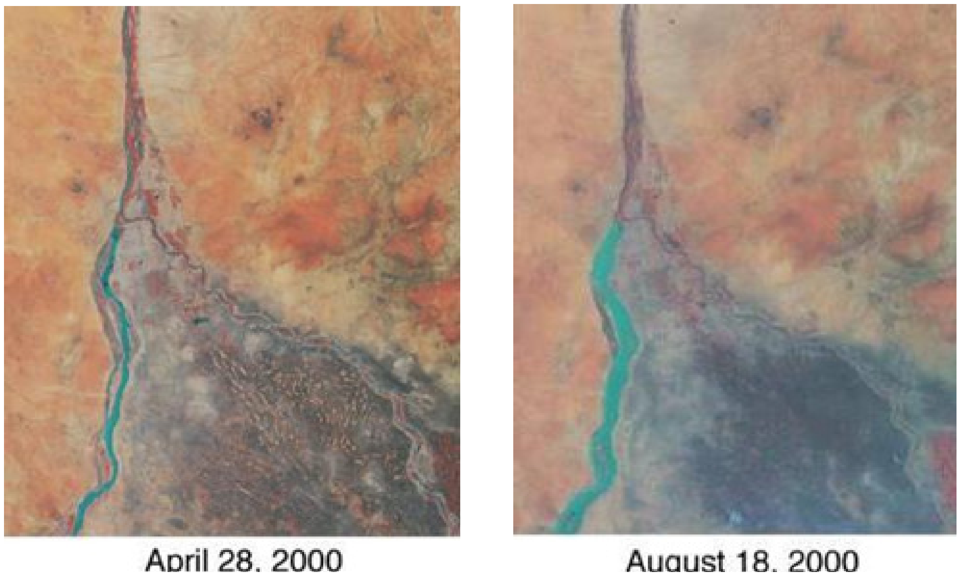


Figure 6.3: Remote sensing images before and after the flood for the year 2000.

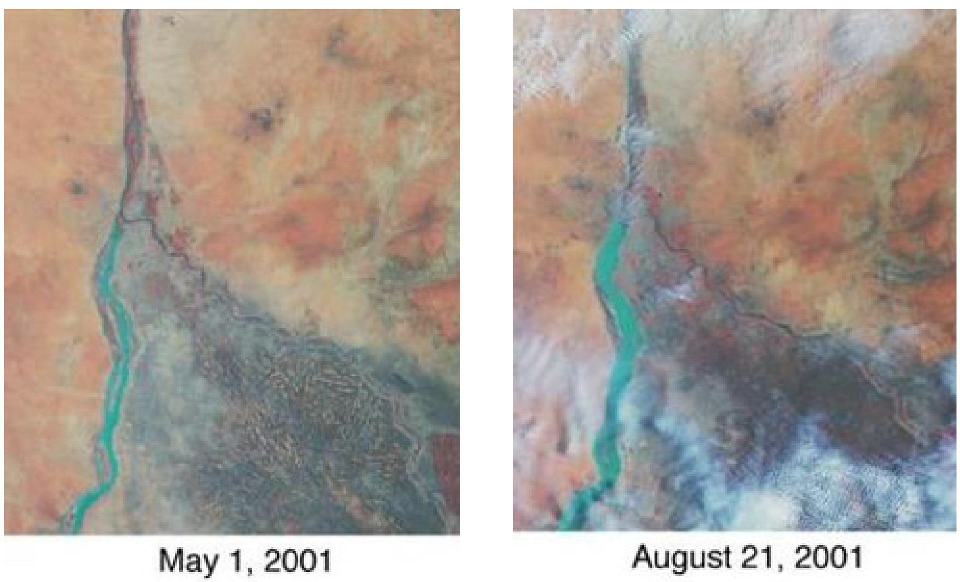


Figure 6.4: Remote sensing images before and after the flood for the year 2001.

Throughout history, the rising and falling waters of the mighty Nile River have directly impacted the lives of the people who live along its banks. These images of the area around Sudan's capital city of Khartoum capture the river's dynamic nature. Acquired by the Multi-angle Imaging Spectro Radiometer's nadir (vertical-viewing) camera, they display the extent of the Nile waters before and after the onset of the rainy seasons of 2000 Figure 6.3 and 2001 Figure 6.4. The images are displayed in "false colour", using the camera's near-infrared, green, and blue bands. With this particular spectral combination, water appears in shades of blue and turquoise, and highly vegetated areas show up as bright red. Each of these images represents an area of about 130 kilometres x 150 kilometres.

The left branch shows the water of the White Nile which originates from Victoria Lake and the right branch shows the water of the Blue Nile which, originates from

Tana Lake in Ethiopia. Converge at Khartoum, and continue to flow northward as the Main Nile. Although the most obvious feature in these images is the increased width of the White Nile between May and August, careful inspection shows that the Great Nile is at its widest in August 2001 (note in particular the area between the clouds near the top of this panel). Heavy rains in the Blue Nile catchment area of the Ethiopian highlands led to a rapid overflow of the river's floodwaters into the main stream of the Great Nile, leading to extensive flooding, the worst effects of which occurred north of Khartoum. According to the Food and Agriculture Organization (FAO)of the United Nations, tens of thousands of people have fled their homes, and the number of people in need of urgent food assistance in Sudan.

Overall prospects for Sudan's 2001 grain crop were already poor prior to the flooding due to a late start of the rainy season in parts of the country. Following two consecutive years of serious drought, precipitation arrived too late to save the grain harvest that normally begins in late August.

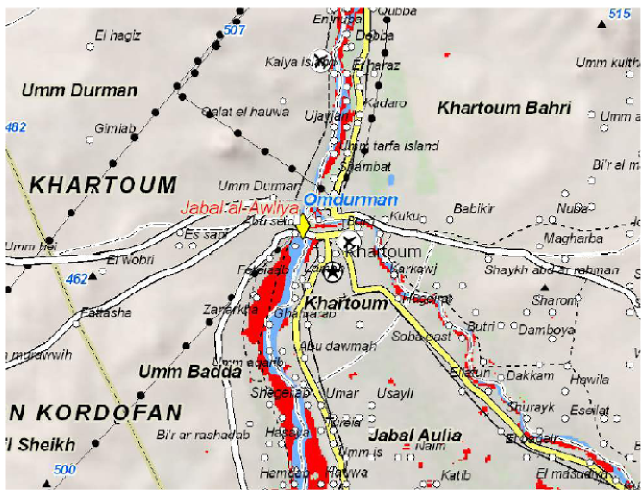


Figure 6.5: Remote sensing image for the flood for the year 2007

This map illustrates satellite detected flood water over the affected places in Khartoum. Those areas likely covered with flood water at 2-4 September 2007 are shown in red and are distinguished from Nile River (in blue) as measured on 29 May 2007. This is a preliminary analysis and has not been validated in the field.
This map was produced by United Nations Institute for Training and Research (UNITR) Operational Satellite Applications Programme (UNOSAT).

6.3 Overlay the model result with the remote sensing image

The result from the 2D model SOBEK have been extracted from SOBEK and imported to GIS environment. The satellite images in Figure 6.3 have been imported also to GIS environment. The satellite images then georefreced . The two images overlaid above each other. The model result was put on the top, the map set on 30% transparency. The satellite image was taken on 18 of August in 2000. The extracted image from SOBEK was taken also in the same day. The circle in Figure 6.7 shows a little over estimation because there are streets at this location, the streets are not included in the model. The result from the model is almost the same like the remote sensing image.

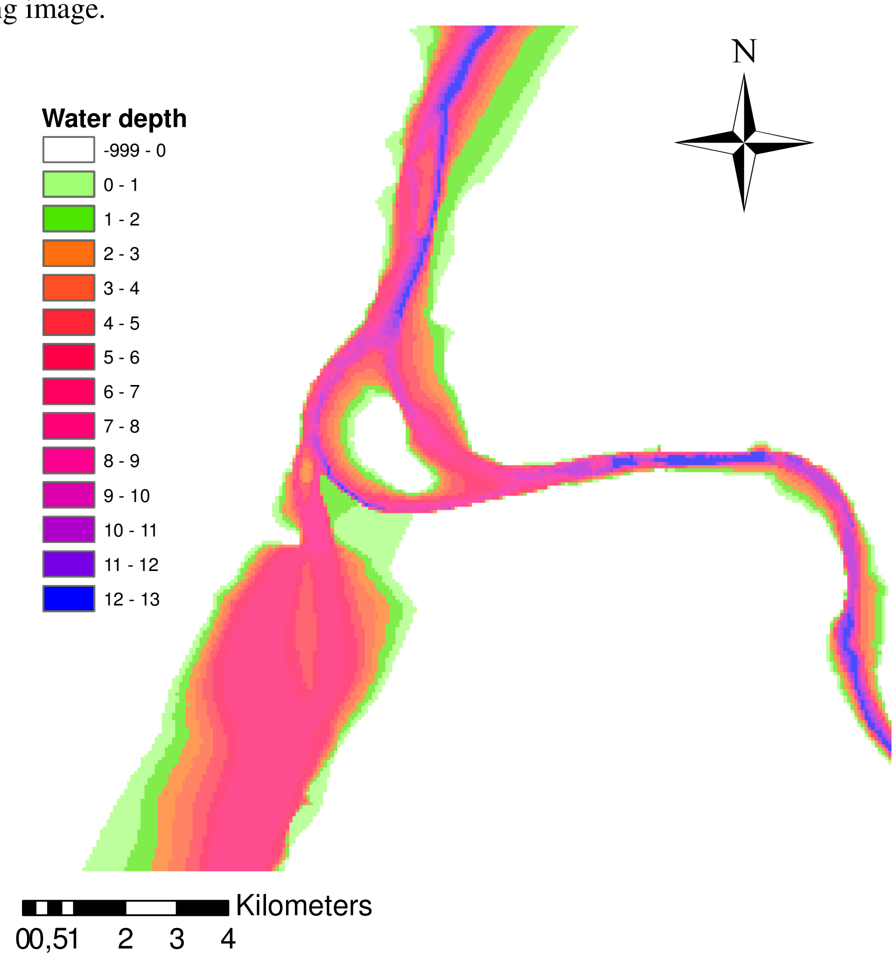


Figure 6.6: Flood on 18 of August 2000 in Khartoum

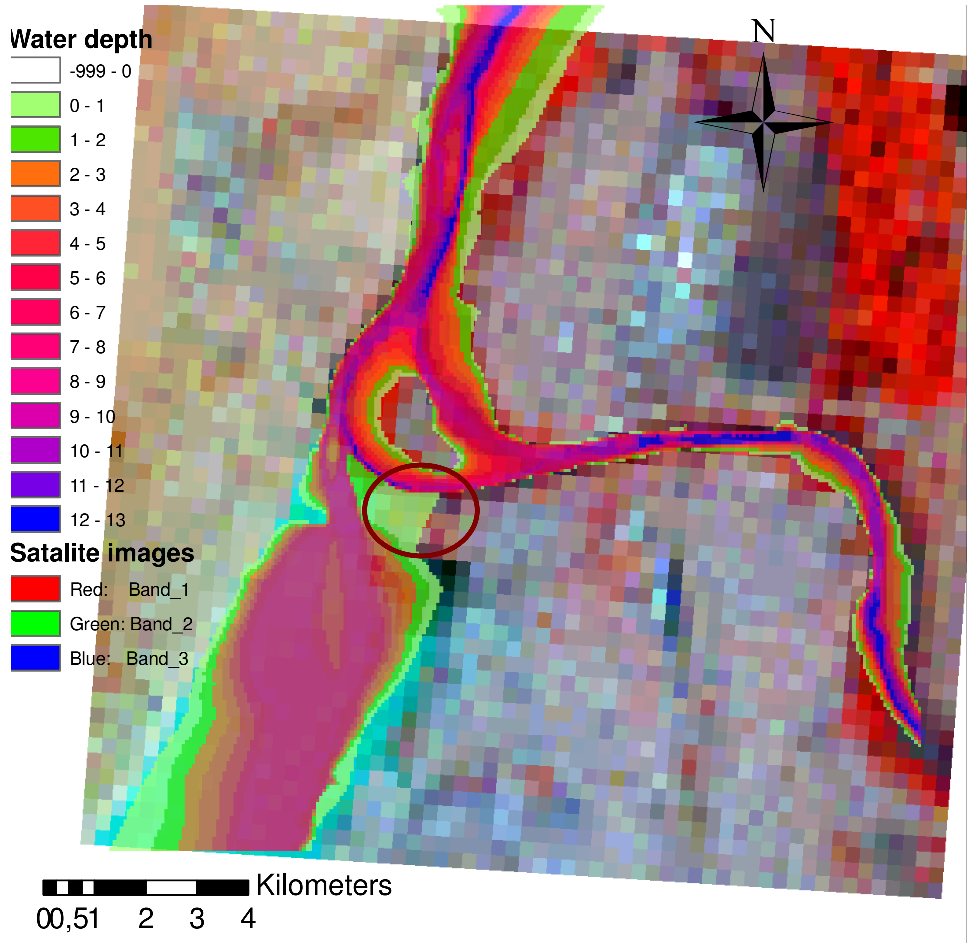


Figure 6.7: Overlay of the model result with the remote sensing image.

6.4 Expected climate change scenarios

Africa is the most vulnerable region to climate change, as a result of low adaptive capacity of the African population IPCC, (2001). The majority of the researches show that there will be an increase of the flow in the Blue Nile as shown in the literature review in section 1.4.6. Based on these results, different scenarios for the year 2006 (highest records in the last 9 years) could be generated. After the satellite image compared with the model result for the year 2000, it gave satisfactory result. Then we increased the upstream boundary condition discharge by 10%, 20% and 30%. The downstream boundary condition water level increased also by the same amount.
The flood depth and flood extent will be analysed in the coming sections.

6.4.1 Flood depth and extent map for different scenarios

The highest discharge in the Blue Nile recorded in the last 9 years was on 29th of August 2006. The model gave for the base case the following results as shown in Figure 6.8, the result has been extracted to GIS environment as shown in **Error!**

Reference source not found.. The circled part in Khartoum is affected by the flood but the depth of water is 0.16 meter.

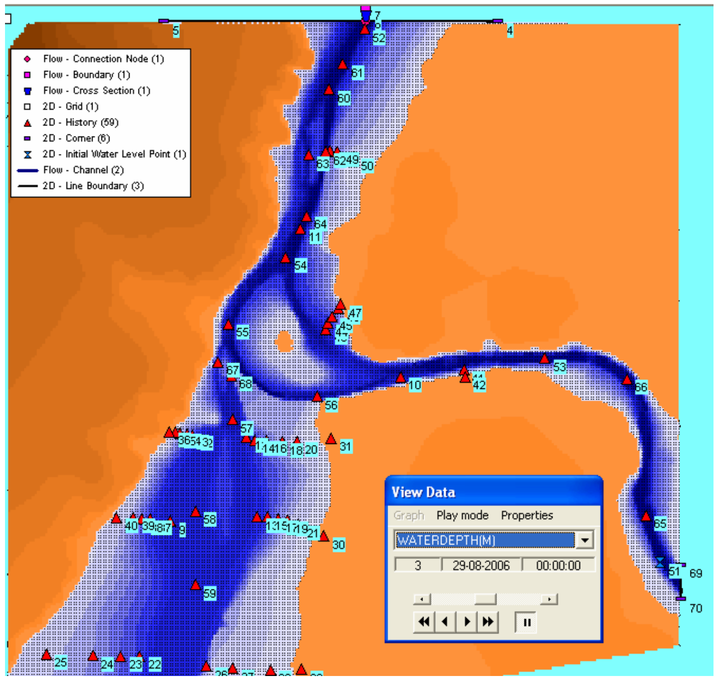


Figure 6.8: SOBEK result for flood extent and depth for 29 of August 2006

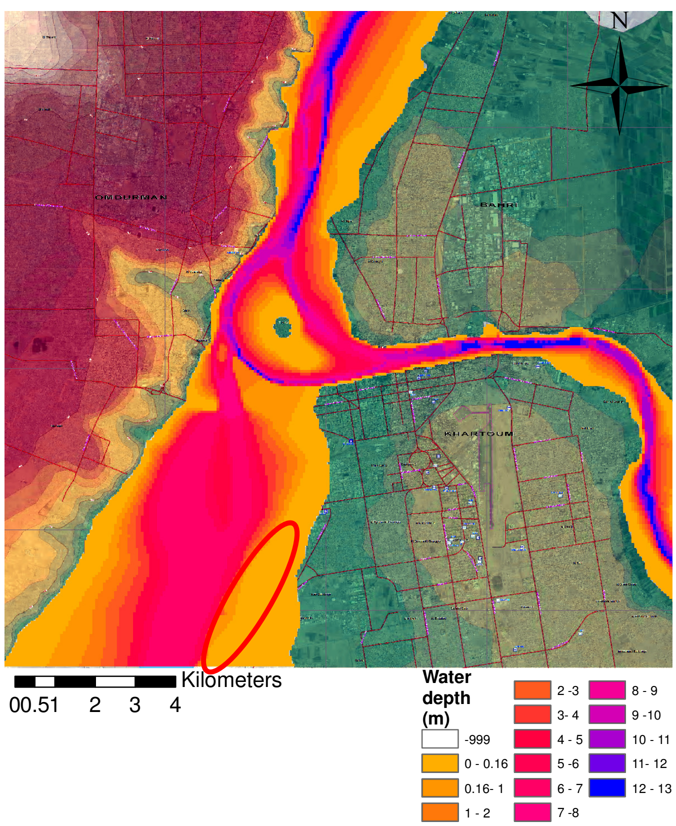


Figure 6.9: Flood extent and depth for 29 of August 2006.

From the result of the flood depth map for the year 2006 with extra 10% in flow, the flood is evaluated at history point number 27, 28 and 29 as shown in Figure 6.10. The water depth was represented by a bar chart as shown in Figure 6.13. Khartoum state at history point number 29, no flood, and at history point number 28, the flood depth is 0.6 meter, and in history 27 the depth is 1.6m.

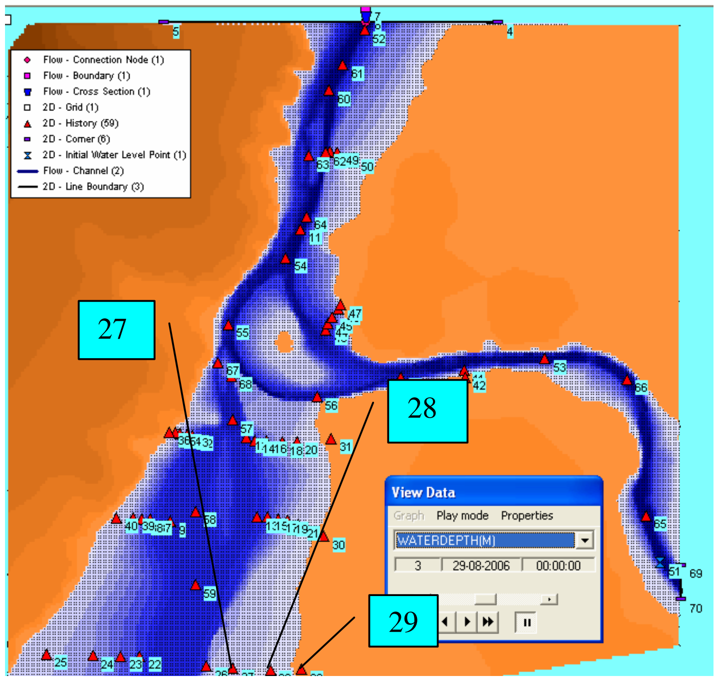


Figure 6.10: SOBEK result for flood extent and depth for 10% extra than29 of August 2006

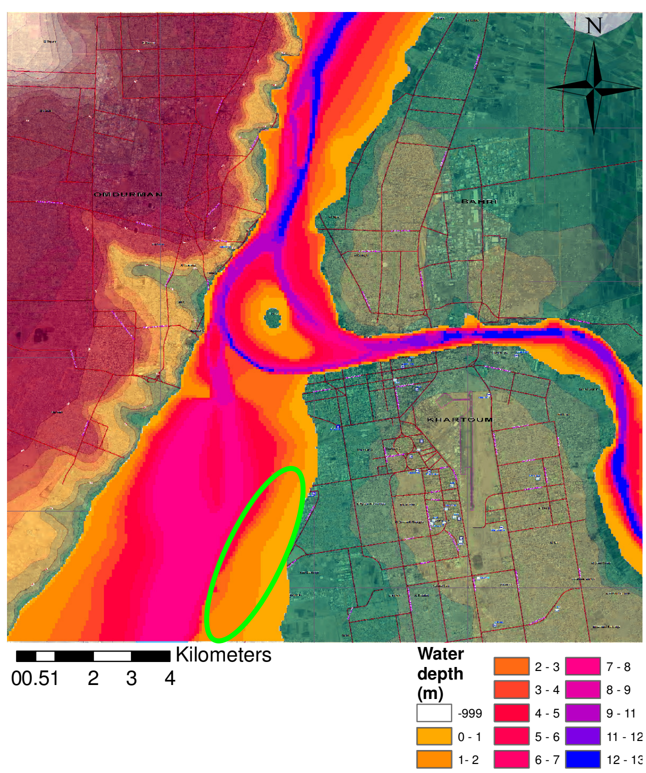


Figure 6.11: Flood extent and depth for 10% extra than 29 of August 2006.

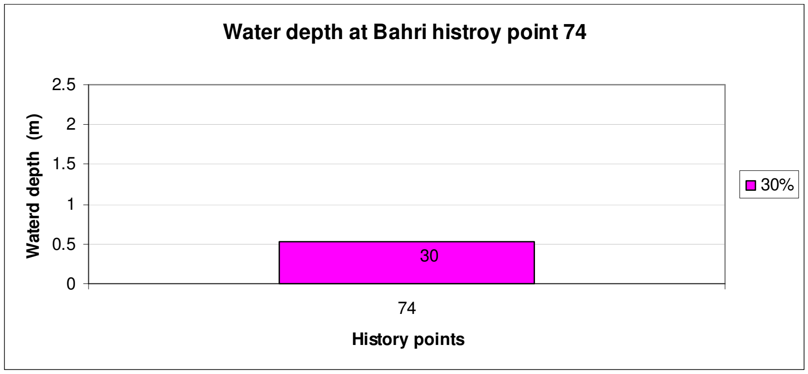


Figure 6.12: water depth at observation point number 74

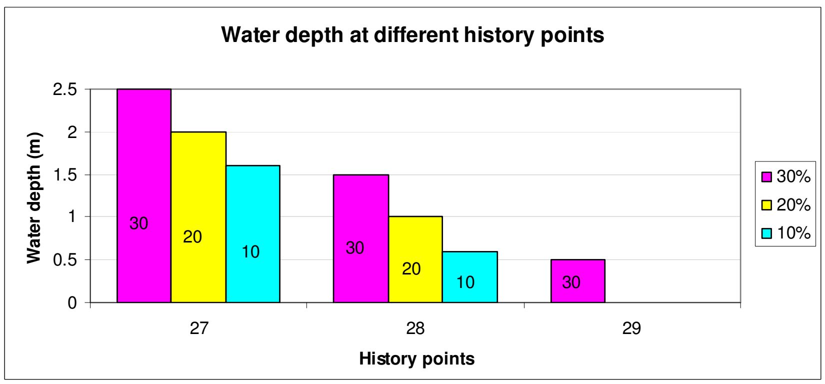


Figure 6.13: water depth at observation point number 27, 28 and 29

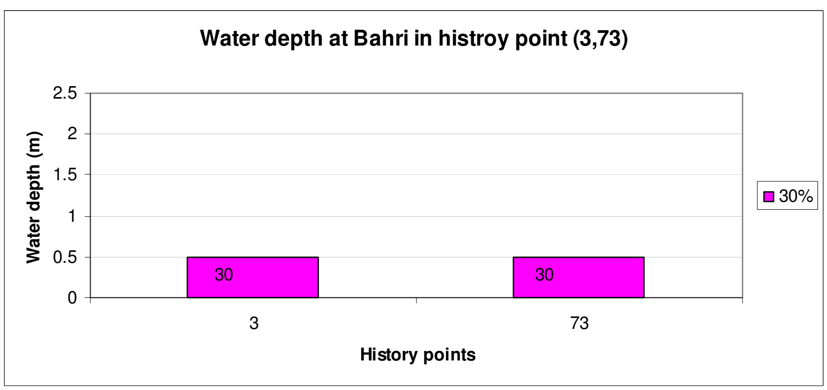


Figure 6.14: water depth at observation point number 30 and 73

From the result of the flood depth map for the year 2006 with extra 20% inflow, the flood is evaluated at history point number 27, 28 and 29 as shown in Figure 6.15. The water depth was represented by a bar chart as shown in Figure 6.13. We found that Khartoum state at history point number 29, no flood, and at history point number 28, the flood depth is 1 meter, and in history 27 the depth is 2m. The flood at the left part of Khartoum as shown in **Error! Reference source not found.** is serious. This amount of water depth could be dangerous for the life of people and their goods. In history point number 3 it found that Bahri still not inundated. At history point number 74 Bahri still safe and no flooding.

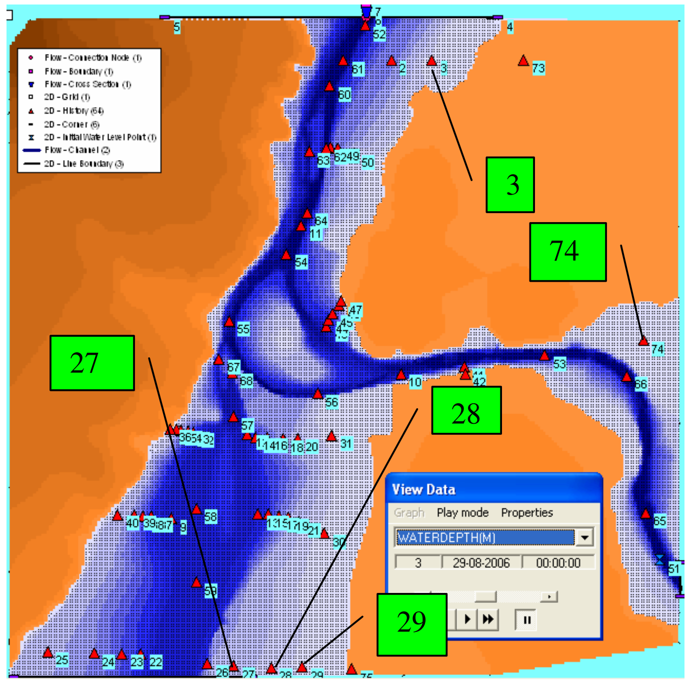


Figure 6.15: SOBEK result for flood extent and depth for 20% extra than29 of August 2006

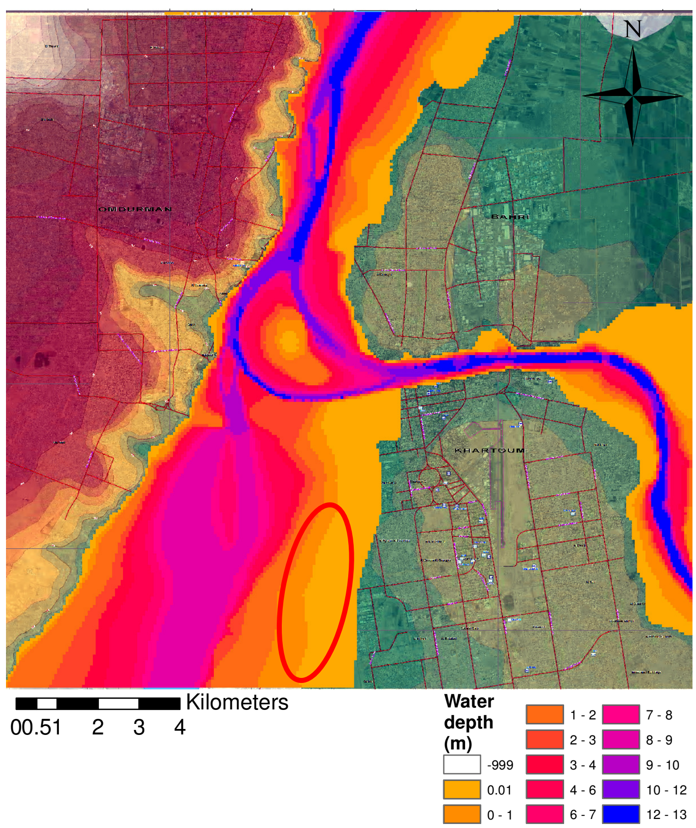


Figure 6.16: Flood extent and depth for 20% extra than 29 of August 2006.

From the result of the flood depth map for the year 2006 with extra 30% in flow, the flood is evaluated at history point number 27, 28 and 29 as shown in Figure 6.15 in Khartoum province. Moreover, the flood is evaluated also at history point number 3, 73 and 74. The water depth was represented by a bar chart as shown in Figure 6.13. We found that Khartoum state at history point number 29 the flood depth is 0.5m, and history point number 28, the flood depth is 1.5 meter, and in history 27 the depth is 2.5m. This amount of water depth could be dangerous for the life of people and their goods. In this scenario Bahri province started to drown as shown in Figure 6.12 and in Figure 6.14. In history point number 3, 73 and 74 the flood is 0.5 meter. The flood covers large areas at Bahri in this scenario, but the flood is not serious. However, still Omdurman at the left part of the river is not inundated.

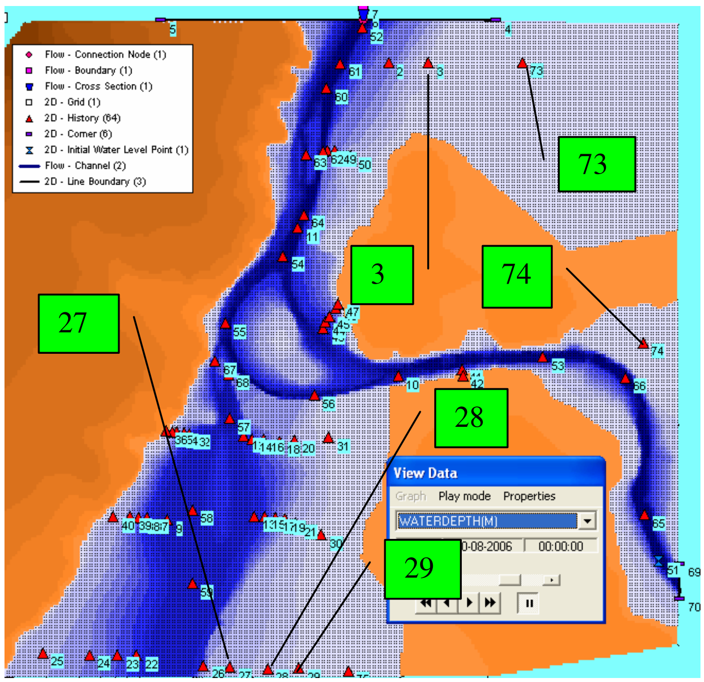


Figure 6.17: SOBEK result for flood extent and depth for30% extra than29 of August 2006

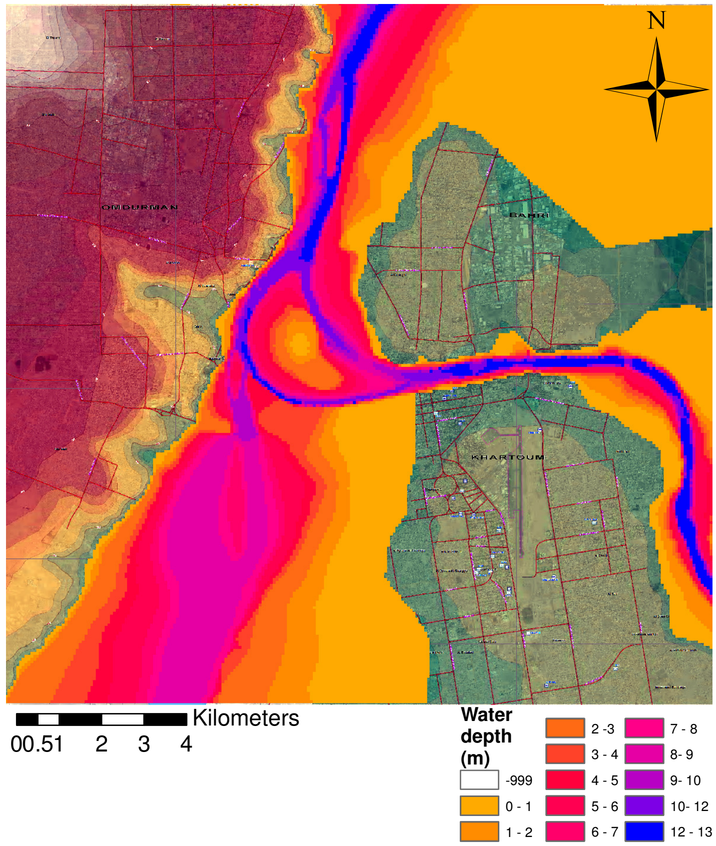


Figure 6.18: Flood extent and depth for 30% extra than 29 of August 2006.

6.4.2 Velocity speed and directions

For the analysis of the velocities the model shows different velocities depending on the size of the cross section. For the narrow cross section at the history point number 53 the velocity was 0.26 m/sec, and for the wide cross section at the history point number 54 the velocity was 0.1 m/sec, which represent the reality (Figure 6.19). In the flood plain at the White Nile the modelled velocity is very low, and shows no clear flow direction.

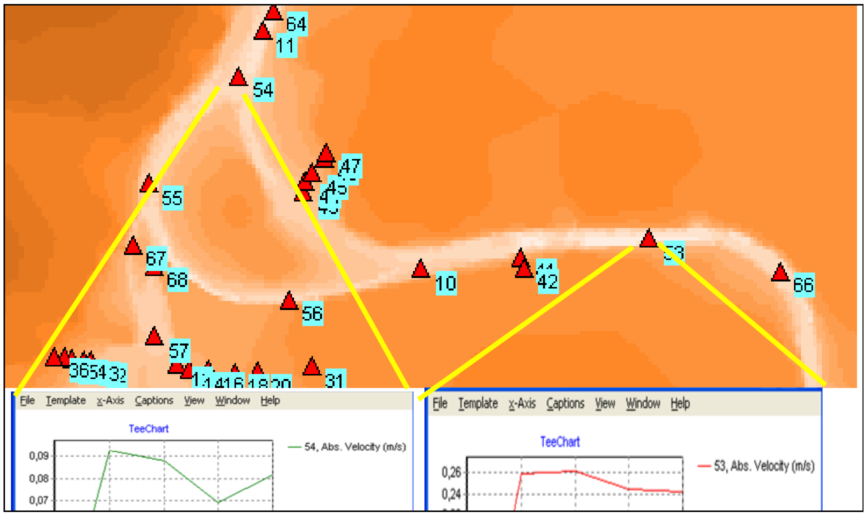


Figure 6.19: velocity magnitude.

6.4.3 Flood extent in Google Earth

Google earth is a friendly environment, many people nowadays using Google earth for different purposes. Almoradie, (2008) managed to export the shape file of flood extent to Google Earth Pro. The extent of the flood is shown in the Google earth environment as shown below.

From Figure 6.20 it found that for extra 10% amount the flood affects left part of Khartoum. But, Bhari and Omdurman still safe. In addition, from Figure 6.21 for extra 20% in the flow, the flood covers more area in Khartoum. However, still Bahri and Omdurman safe from the flood. For the worst scenario for extra 30% of the flow, the flood cover a large areas in Khartoum, many of these areas are important areas. Moreover, many parts of Bahri province start to drown. But, half of the drown areas are agricultural areas, and the other half is residential areas.

Figure 6.20 flood extent for 10% extra than 29 of August 2006 in Google earth

Figure 6.21 flood extent for 20% extra than 29 of August 2006 in Google earth

Figure 6.22 flood extent for 30% extra than 29 of August 2006 in Google earth

7 Contribution of the research to the DSS for Khartoum

7.1 Introduction

The river flood causes a lot of damages in Khartoum and in other cities in Sudan resulting in human and animal losses and extensive damages. Flood struck Khartoum frequently with different level of damages. Decision makers at different levels and stakeholders need to know the areas at risk, in order to take the right decisions.

7.2 Set up of a Decision Support System for flood management

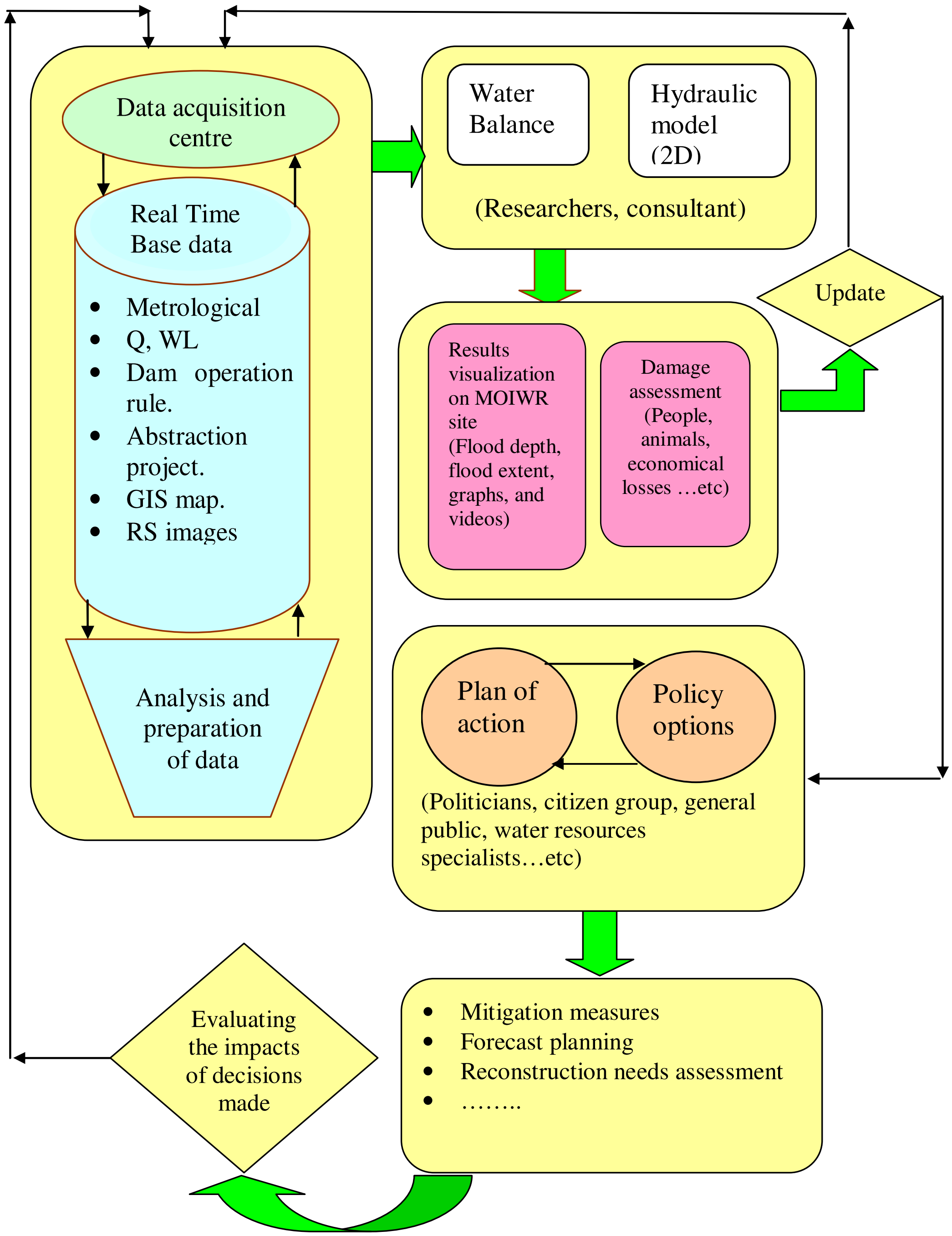
The most important things for the set up of any DSS model, is to have a data with good quality and reliability. Different governmental units should work together for supplying the data on time which is an important consideration to be taken into account. Data of various nature (topographic, and socio-economic, metrological, regulation rule of the dams, discharge and water level measurements and amount of water by abstraction projects) and different acquisition techniques (ground survey and satellite remote sensing) are integrated in specific bases data to be used. Flood simulation requires data processing for model setup (preparing input files).

The researchers, consultants or the experts should set up a water balance between Eddiem station and Khartoum station to predict the discharge at Khartoum. The water balance will be updated by the operation rules of the dams, rainfall along the Blue Nile, abstraction projects, etc. After that, a hydrodynamic model in SOBEK will be used to predict the water levels and water depth in Khartoum. The result from the water balance and the discharge at Jabal Awliya will be used as upstream boundary condition. Extensive analysis of the simulation results should be made available in GIS environment. Flood model results are translated to maps, diagrams, tables and extensive processing are provided in a GIS environment and Google Earth for further analysis. Flood scenarios could be generated also. From the flood extent map and flood depth map the damage of the buildings and affected people could be expected.

Extensive visualization capabilities should be implemented so that end users can visualize the results in terms of graphs or maps. The results should be downloadable from Ministry of Irrigation and Water Resources (MOIWR) site for the stake holders, decision makers, citizen group, and general public. All these people should cooperate to make a plan of action and evaluate policy options. Many conclusions could be drawn like: structural measures (temporary barriers), non structural measures (warning and evacuation of people in the affected areas).

The final step is the self-assessment and improvement mechanism for the DSS. This mechanism starts with monitoring and evaluating the impacts of decisions made. These evaluations identify the need for improvements of the quality and completeness of the information generated by decision support system and processes. Georgakakos, (2006).

The diagram below explains the steps for DSS.



7.3 The challenges for implementing DSS in Khartoum

Challenges to be solved for the implementation of a DSS in Khartoum are:

- The gap between the advanced technologies and the implementation of management practices.
- Little communication and cooperation between governmental sectors which, contribute in water resources.
- Little participation of stakeholders in the process of decision making.
- Bureaucratic process for the exchange of data between governmental sectors.
- Increase the number of monitoring station along the Blue Nile, White Nile and Main Nile. Update the data about the abstraction projects.
- Lack of improvement mechanism.

7.4 Benefit of DSS in Khartoum

The flood extent map will provide the decision makers with information of areas at risk by defining flood risk zones. Moreover, it will help spatial planning, and public awareness could be raised of the areas at risk of flooding

7.5 Relevance of the research for the development of the regional NBI-DSS

Regional NBI would include many aspects at which flooding is one which, is important for Khartoum flood management. The umbrella of DSS includes other issues like drought, water allocation, and water management. Flood management is one of these important issues which will help in regional DSS. This research studied the flood in an important city (confluence of White Nile and Blue Nile).
Climate change Scenarios and studying their effects on the Blue Nile will have an impact on the Nile basin DSS. It's expected to improve the future DSS plans.

8 Conclusions and Recommendations

8.1 Conclusions

- **Sudan suffers frequently on average every two to three years from flood**. The current operational flood forecasting and early warning system -Flood Early Warning System (FEWS, Delft Hydraulics 1992) - suffers many problems, such as forecasting the time of the flooding.
- **Water balance for the reach Sinnar and Khartoum show good results**. The small differences between computed and monitored are expected to be the effect of rainfall and abstraction projects. From the results of the water balance between Sinnar and Khartoum dam it can be concluded that the data is of good quality and is probably sufficient to build a 1D hydrodynamic model in the future , upgrade of the flood early warning system, and for preparing models for the Nile DSS development. In addition, we may predict a discharge at Khartoum during the flood season by a water balance.
- **Water balance for the reach between Rosseries and Sinnar Dam gave good results,** but there is a little over estimation on the discharge from the water balance. This is expected to come from the rainfall and the change in storage at the filling period of the dam. From the results of the water balance between Rossieres and Sinnar dam it can be concluded that the data is of good quality and is probably sufficient to build a 1D hydrodynamic model in the future, upgrade of the flood early warning system, and for preparing models for the Nile DSS development. In addition, we can predict a discharge at Sinnar during the flood season by a water balance.
- **Flood occurs due to prolonged and high rainfall in the upper catchment Ethiopia. Sometimes, the situation is worse when it is accompanied by high local rainfall**.
- The most important factors which govern building a good 2D model is, a good digital elevation map and the boundary conditions for the model.
- From the **flood** analysis floods occur in **1999, 2000, 2001, 2006 and 2007**. The year 2000 is a river induced flooding. However, 2007 is a river flooding accompanied by local rainfall 120 mm. The peak of the rainfall at Khartoum occurred before the peak of the discharge in many years. The opinion of the experts about the effect of the local rainfall was contradicting. However, the majority believe there is an effect of local rainfall at the flood in Khartoum. Because the amount of water harvesting in a small sub catchment in ?Khartoum was big.
- **The difference between the SRTM digital elevation data and the elevation topographical map was big**. The differences in some areas along the river bank are more than **17 meters**, because the SRTM radars were unable to sense the surface beneath vegetation canopies and so produced elevation measurements from near the top of the canopies. Man-made objects, such as large buildings, towers, and bridges are often problematic targets for radar imaging. Thus, heights measured in cities will represent average building sizes in a cell rather than the height of the ground on which the buildings are built.

- **SRTM free source for DEM map is not recommended to be used for the extension of the flood in Khartoum**.
- The Arc Hydro Toolset is a suite of tools which facilitate the creation, manipulation, and display of Arc Hydro features and objects within the ArcGIS environment. It's useful in lowering the DEM, when the lowered cell is not varying and have a constant reduction.

The main conclusions of this research are:

- **The results of the extension of the flood from SOBEK compared with the remote sensing images were almost same.**
- **Different scenarios for expected change in discharge as consequence of climate change have been modelled**. **Omdurman was almost not affected, and Bahri province more affected and Khartoum province was highly affected.**
- **The flood extent map will provide the decision makers with information of areas at risk by defining flood risk zones**. Moreover, it will help spatial planning, and public awareness could be raised of the areas at risk of flooding.

8.2 Recommendations

- For the preparation of the topographical map the street is not included in the map because the heights were not known, and for future work the researcher should contact Ministry of Engineering Affairs for the levels of the streets. The street will affect the extension of the flood and they work like a dike or a barrier for the flood.
- The topographical map should be extended through ground survey and the use of GPS.
- Optimization to Jabal Awliya dam may decrease the effect of the flood in Khartoum.
- A 1D/ 2D model should be made to improve the boundary condition locations.
- The local people fill sacks of sand and use it as a barrier in Toti Island and along the White Nile and in some low areas, these temporary local barriers are not included in the model.
- Expand the 1D/ 2D model to the upstream to include other cities.
- Culverts and pipes under the street also were not included in the SOBEK model. The culverts and the pipes below the street allow the water in the city to drain to the river. How they allow also the flood to inundate the city unless there are gates for them. Site visit should be made to those sites to know how they function and control.
- Create a shape file for the buildings near the river bank, and give them the exact height.
- Calculate damage functions for the expected inundated areas.
- A cost benefit analysis should be made for building of a dike along the river bank of Khartoum in the Blue Nile.
- Raised the 2D cells on the bank of the river and run the model for the worst scenarios.

- A rainfall runoff model for the upper catchment (Ethiopia) should be made for better forecasting of the flood. Moreover, satellite-based rainfall estimate could be used as an input for extra time.
- It's recommended to upgrade the existing FEWS with the lead time and flood extent.
- A code which will connect these entire model together for real time forecasting.
- Refine and improve the water balance.

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www.africanwater.org

Appendix

Appendix A: Abstraction projects

Data used for estimation of crop water requirement in agricultural projects in the Blue Nile.

Table 1: The area for each crop and each project.

Project	Total Area (km^2)	cotton 50% (km^2)	G.nuts 22.50% (km^2)	Dura 22.50% (km^2)	Vegetables 5% (km^2)
Wad Hashim	23200	11600	5220	5220	1160
El Safa	9420	4710	2119.5	2119.5	471
El Nayra	22400	11200	5040	5040	1120
Kassab	59600	29800	13410	13410	2980
El Busata	63400	31700	14265	14265	3170
Wad Reif	6620	3310	1489.5	1489.5	331
Karkoj	20270	10135	4560.75	4560.75	1013.5
El Suki	80000	40000	18000	18000	4000
NW Sennar	26000	26000	26000	26000	26000
Others	13725	6862	3088	3088	686

Table 1 The required water for each crop in a specific month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Cotton	539	0	0	0	0	0	707	0	609	1011	1055	674	4595
G. nuts	0	0	0	0	939	442	243	395	834	423	0	0	3276
Dura	0	0	0	0	0	0	939	307	815	366	0	0	2427
Veget.	765	0	0	0	0	0	0	59	544	508	787	865	3528

Table 2 The required water for project per month

Month Group	Total Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Wad Hashim	23200	7.14	0	0	0	4.90	2.31	14.37	3.73	16.30	16.44	13.15	8.82	87.16
El Safa	9420	2.90	0	0	0	1.99	0.94	5.84	1.52	6.62	6.67	5.34	3.58	35.39
El Nayra	22400	6.89	0	0	0	4.73	2.23	13.88	3.60	15.74	15.87	12.70	8.52	84.16
Kassab	59600	18.34	0	0	0	12.59	5.93	36.92	9.59	41.88	42.22	33.78	22.66	223.92
El Busata	63400	19.51	0	0	0	13.39	6.31	39.27	10.20	44.55	44.91	35.94	24.11	238.20
Wad Reif	6620	2.04	0	0	0	1.40	0.66	4.10	1.07	4.65	4.69	3.75	2.52	24.87
Karkoj	20270	6.24	0	0	0	4.28	2.02	12.56	3.26	14.24	14.36	11.49	7.71	76.16
El Suki	80000	24.62	0	0	0	16.90	7.96	49.56	12.87	56.22	56.67	45.35	30.42	300.57
NW Sennar	26000	33.90	0	0	0	24.41	11.49	49.11	19.79	72.85	60.01	47.89	40.01	359.48
Others	13725	4.22	0	0	0	2.90	1.36	8.50	2.21	9.64	9.72	7.78	5.22	51.57
TOTAL	324635	125.81	0	0	0	87.51	41.19	234.10	67.84	282.71	271.57	217.17	153.57	1481.47

Table 3 The required water for Gezira and Managil projects

	JAN			FEB			MAR			APR			Total
	Ji	Jii	Jiii	Fi	Fii	Fiii	Mi	Mii	Miii	Ai	Aii	Aiii	
Gez/Managil Canals	206.80	212.10	207.80	214.10	189.62	189.30	168.40	123.00	85.60	22.40	28.50	25.00	1672.62
	MAY			JUN			JUL			AUG			
	Mi	Mii	Miii	Ji	Jii	Jiii	Ji	Jii	Jiii	Ai	Aii	Aiii	
Gez/Managil Canals	25.00	36.80	36.90	68.60	101.90	113.10	200.50	188.70	160.60	163.50	243.00	214.00	1552.60
	SEP			OCT			NOV			DEC			
	Si	Sii	Siii	Oi	Oii	Oiii	Ni	Nii	Niii	Di	Dii	Diii	
Gez/Managil Canals	115.20	152.50	234.90	299.40	321.60	327.40	291.40	322.60	321.00	264.40	213.80	200.70	3064.90
													6290.12

Appendix B: Accumulated rainfalls and water levels at Khartoum

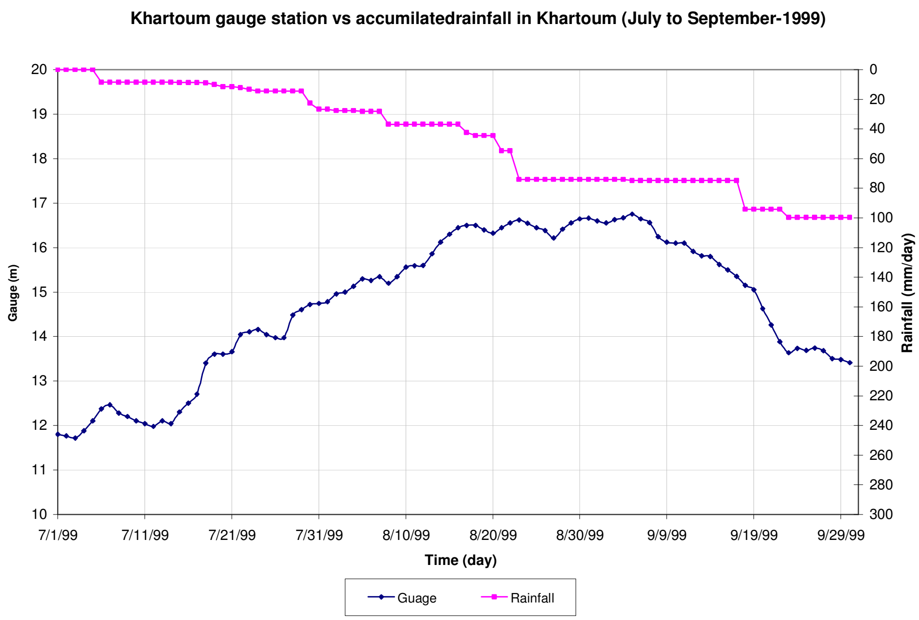

Figure 0.1 : Accumulated rainfalls and water levels at Khartoum from July to September 1999.

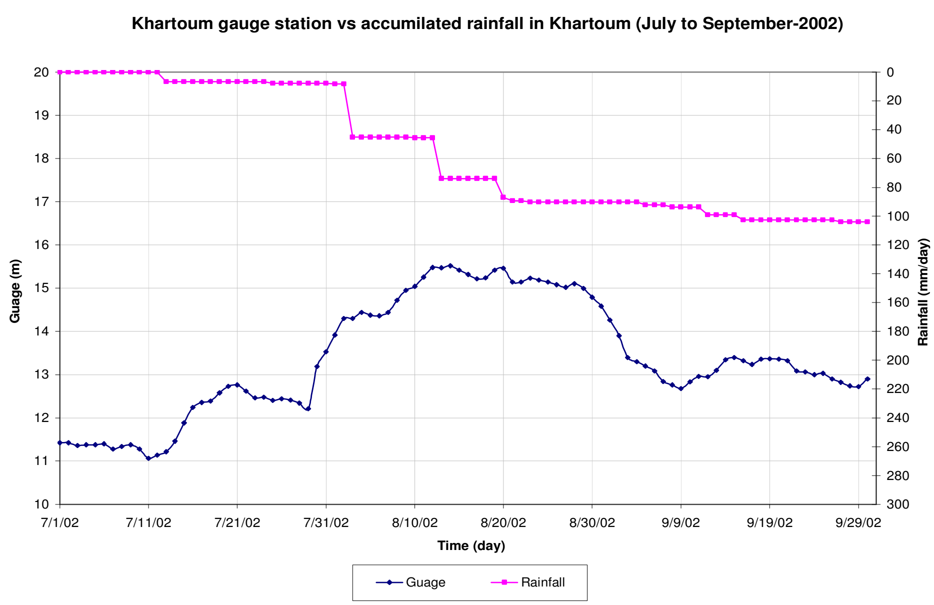

Figure 0.2: Accumulated rainfalls and water levels at Khartoum from July to September 2002.

Appendix C: Water balance

Table 4: Water balance between Sinnar and Rossieres dam for the year 1999 only.

Date	Roseries release from rating curve 10^6 m3	Gazera and managil abstraction from sennar 10^6 m3	Abstraction remaining projects 10^6 m3	Rainfall	Evaporation losses from sennar lake	increased storage is not included Sinnar Balance	Sinnar release from rating curve	Differences	Accumulated series Sinnar release	Sinnar release estimated from water balance
1-Jan-1999	45.4	20.7	4.1	0.0	2.5	18.1	10.4	7.8	10.4	18.1
31-Dec-1999	45.7	18.2	5.0	0.0	2.5	20.0	30.4	-10.4	55065.5	50958.0
31-Dec-2000	44.7		5.0	0.0	2.5	37.3	21.6	15.7	104643.9	96753.8
31-Dec-2001	39.5	18.2	5.0	0.0	2.5	13.9	8.8	5.1	154951.8	144450.8
31-Dec-2002	32.0	18.2	5.0	0.0	2.5	6.3	8.0	-1.7	170172.8	159278.4
31-Dec-2003	33.0	18.2	5.0	0.0	2.5	7.3	7.0	0.3	208437.8	193641.4
31-Dec-2004	31.6	18.2	5.0	0.0	2.5	5.9	8.1	-2.2	240928.0	224359.4
31-Dec-2005	22.9	18.2	5.0	0.0	2.5	-2.8	8.8	-11.6	279951.7	264802.2
31-Dec-2006	40.5	18.2	5.0	0.0	2.5	14.8	10.9	3.9	334026.6	317436.1
28-Oct-2007	99.2	32.7	8.8	0.0	2.5	55.2	42.3	13.0	388996.2	369978.1

Table 5: Water balance between Sinnar and Khartoum dam for the year 1999 to 2007

Date	Sinnar release from rating curve 10^6 m3	Rahad releases 10^6 m3	Dinder release 10^6 m3	Khartoum W.B 10^6 m3	Khartoum estimated 10^6 m3	Difference	Khartoum discharge from water balance	Accumulated series Khartoum estimated
1-Jan-1999	10.37			10.37	15.33	-4.96	10.37	15.33
31-Dec-1999	30.41		4.47	34.88	29.82	5.07	59265.44	57513.54
31-Dec-2000	21.58			21.58	31.07	-9.49	111180.57	106641.61
31-Dec-2001	8.81			8.81	31.63	-22.81	165894.95	160528.36
31-Dec-2002	8.00			8.00	22.74	-14.74	181569.52	176271.40
31-Dec-2003	7.00			7.00	14.58	-7.58	219856.76	221937.52
31-Dec-2004	8.08			8.08	20.93	-12.85	254217.41	255727.40
31-Dec-2005	8.76			8.76	25.28	-16.53	295735.46	297912.69
31-Dec-2006	10.92	0.00	0.00	10.92	29.41	-18.49	352931.68	362405.14
30-Sep-2007	220.66	14.99	42.96	278.61	435.90	-157.29	409220.54	429666.65