

Development of a hydraulic model for the Kavango river for improved disaster risk management in Namibia

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The impact of flooding can be effectively managed if scientists, policy makers and communities work together. Flood mapping provides an opportunity for geospatial scientists to engage society in disaster risk management. Namibia is experiencing persistent flooding events in the north and north eastern parts of the country since 2008, costing government millions of dollars on infrastructure and livelihood of the affected people. The objective of this research is to develop a static time series steady flow hydraulic model for the approximately 500 kilometers long Kavango river, which can subsequently be upscaled to other river basins in Namibia for improved disaster risk management. HEC RAS geometry is used to develop the model in an Arc GIS environment using a 50m DEM interpolated from LIDAR data. It is found that the flood line results have an average accuracy of 23.96 m when overlaid on GPS survey points. The study also reveals that at minimum river flow (100m³/s), the surface area covered by water is roughly 196.748 km². At 600m³/s, the surface area changes to 459.836 km², representing an increase of 263.088 km². At the highest flow rate of 1030m³/s recorded for the river, the surface area is 596.866 km². It is also found that the Kavango River is sensitive to changes in river roughness. In conclusion, the hydraulic model developed gives useful preliminary results and therefore could be upscaled to other river basins in Northern Namibia.

Key words: Flood mapping, steady flow hydraulic model, Kavango river, disaster risk management, GIS, HEC-RAS, DEM.

INTRODUCTION

Changes in regional and global hydrological conditions are among the major consequences of climate change that people have to cope with. One of the major challenges with climate change is its impact on water resources and extreme hydrological events (Andersson et al., 2011). The IPCC General Circulation Models (GCM) provides an overview of the current situation and validates increasingly refined forecasts of the possible changes in climate over the long term (IPCC, 2007). However it is difficult to incorporate the GCM results into hydrological analysis and modeling. Hydrological analyses rely on rainfall data whereas climate change models are based on temperature variations. This gives a discrepancy in translating the GCM to local variations in hydrological conditions such as flooding. Hydraulic models provide an opportunity to derive more accurate local hydrological forecasts. There are also barriers to societal use of geospatial data in adaptation to climate change and variability (Aron, 2006). Scientists could break these barriers by engaging policy makers and local

communities in geospatial data analysis.

Any hydrologic model is an abstract representation of a component of a natural process (Vieux, 2004). Models of river flooding are primarily based on hydraulics, representing water flow both within the channel and on the floodplain (Thomas & Nisbet, 2006). Flood mapping provides an opportunity for geospatial scientists and society to work together. This preliminary research is part of a national wide project to develop Namibia flood models of the three major catchment areas situated in northern and northeastern of the country, an initiative funded by the World Bank. It is the first time such models are developed in Namibia. The results from the study will be upscaled to cover other river basins of Cuvelai and Zambezi.

Study area

The study area covers the Kavango River in north-

eastern Namibia, starting from Katwitwi border post with Angola in the west to Mohembo border post with Botswana in the east. The total river length is approximately 500 kilometers. In Figure 1, the expanded river is shown with some of the social infrastructure.

Its headwaters originate from the highlands of Angola covering the Cuito and Cubango Rivers. The river supports livelihoods of communities living adjacent to it through subsistence farming, fisheries, livestock, and household water consumption. Increased frequent flooding events occur in the region since 2008. This results in shocks to the local communities who cannot cope with the flooding disaster, prompting the government of Namibia to redress their approach to disaster risk reduction and management. Figure 2 is the study area showing the location of the Kavango River and its catchments in Namibia.

MATERIALS

Hydraulic modeling

With the impact of climate change effects on the intensity of rainfall events, identifying the vulnerable areas and assessing the degree of impact for a higher magnitude flood risk event more clearly describes the potential risk at which the current developmental or infrastructural facilities are situated (Yerramilli, 2012). Models of river flooding are primarily based on hydraulics, representing water flow both within the channel and on the floodplain (Thomas & Nisbet, 2006). The HEC-Geo RAS products developed by US Army Corps of Engineers enable these flood simulation models to be compatible with Arc GIS environment and provide valuable tools to evaluate impacts associated with flood plains (Cameron, 2000). The HEC products are utilised in this study because of their simplicity to assemble and cost as they are freely available. A static time series steady flow hydraulic model is developed for the entire Kavango river.

Data collection and preparation

The basic spatial data requirements to build the Kavango hydraulic model were the Digital Elevation Models (DEM) and river geometry. The accuracy of the model depended much on the correctness and accuracy of the DEM used. Lidar data was obtained from the Directorate of Survey and Mapping in the Ministry of Lands and Resettlement. The data with a ground sampling resolution of 50m was interpolated into a DEM in an Arc GIS environment. The study area was then clipped from the generated DEM. Flow records for 2011 and 2012 were obtained from the Hydrology Division in the Ministry of Agriculture, Water and Forestry (MAWF). Three flow rates of 1030 m³/s, 600m³/s and 100m³/s were used. The 1030m³/s was the

extreme high flow recorded at Mukwe in March of 2012 while 100m³/s is the expected average low river flow (MAWF, 2012).

The river geometry was manually digitized from aerial photographs obtained from the Namibia Statistical Agency (NSA). These aerial photographs were acquired in 2011 during the preparation of the 2011 national population census.

METHODOLOGY

Conceptual model

The process started with data collection and ended with the overlay of social infrastructure data on the generated flood masks although the latter is not included in this study. For the purpose of this submission, no attempt is made to detail the flood effects as it relates to social impact. The field work was undertaken between 18 to 22 April 2012 and GPS points were surveyed along the flood and water lines on one river stretch on the extreme side of Popa falls. The methodology is outlined in figure 3 below.

Channel geometry in Arc GIS and HEC Geo-RAS

The river geometry used for simulation in HECRAS was generated from the digitized layer covering 490 kilometers. The geometry was digitized from upstream to downstream in Arc GIS software. The bank and flow path lines were also generated the same way starting with the left, channel and finally the right flow line. These geometries were then copied into the created RAS Geometry layers (centerline or river, bank lines and flow path centerlines). Attempts to use ASTER30 DEM for cross section generation died due to the poor vertical resolution of the data. The use of the Lidar DEM with 50m resolution from the DSM became apparent as it indicated better vertical resolution to properly simulate flow than the ASTER data. Figure 4 compares the cross sections generated on both DEMs.

The generated cross sections had to be manually aligned in Arc GIS software such that they are perpendicular to the flowlines over the entire length. Consequently, these cross sections must not be more than 18 degrees out of perpendicular for the flood simulation to work well in Hec Ras (Figure 5).

With the average river width of 200 meters, the DEM was artificially deepened along the channel by 2 meters. The deepened channel was the basis upon which the calculations of the longitudinal cross sections and floodplain maps took place. The 2-D and 3-DX Cut Lines with all the attributes were finally generated in RAS Geometry before exporting to HEC RAS for hydraulic simulation.



Figure 1. Kavango river, picture taken on 23 April 2012.

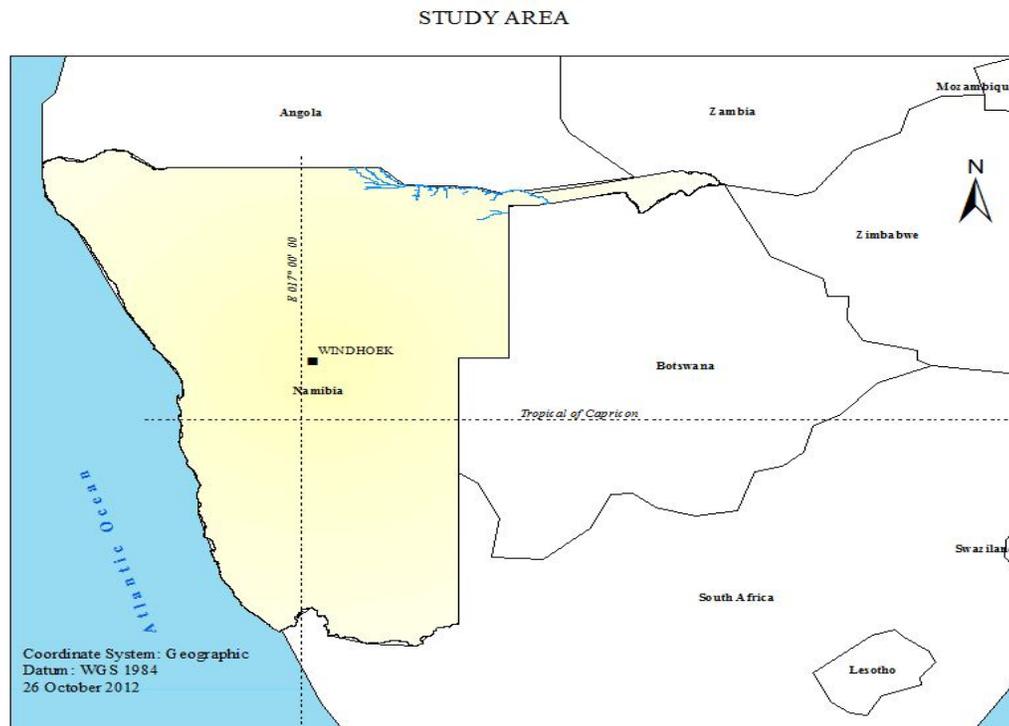


Figure 2. Study area showing the location of the Kavango river and its catchments.

Flood simulation and floodplain mapping

A steady flow hydraulic model of the river was assembled and simulated in HEC RAS 4.1.0. Three profile flows were determined for this study. The first flow rate was for $100 \text{ m}^3/\text{s}$ which represented the normal flow record of the Kavango river (MAWF, 2012). The second was $600 \text{ m}^3/\text{s}$ was put in to approximate the average of the

lowest and highest flows. The third was $1030 \text{ m}^3/\text{s}$ representing the highest flow rate recorded in March 2012.

The reach boundary conditions for upstream was set to known while a normal depth with average river slope of 0.003 was set for the downstream. Because of uniformity along the river, the roughness was made consistent. The left and right bank roughness was set at 0.02 while the

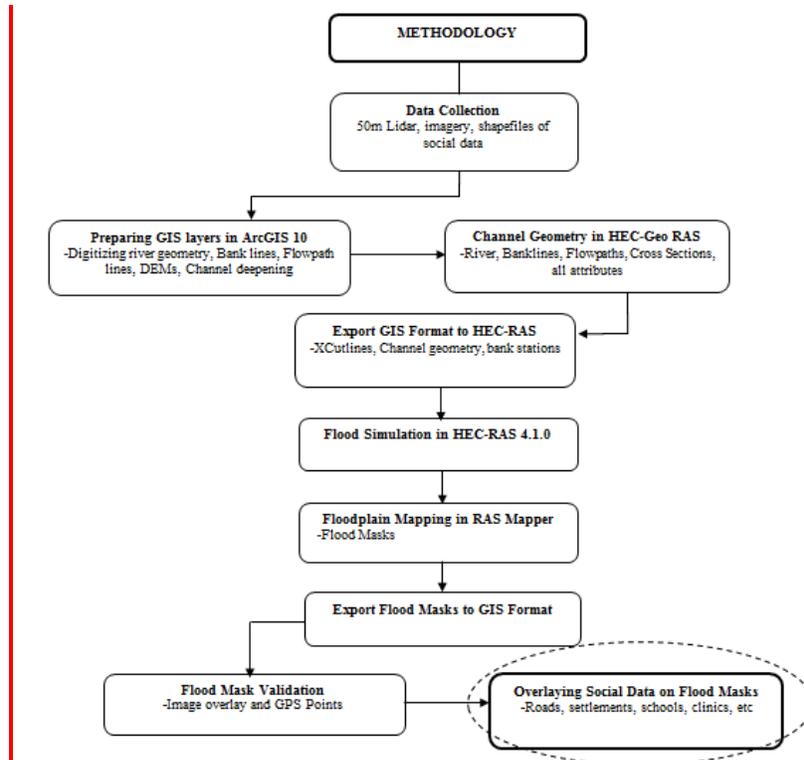


Figure 3. Hydraulic modeling methodology followed.

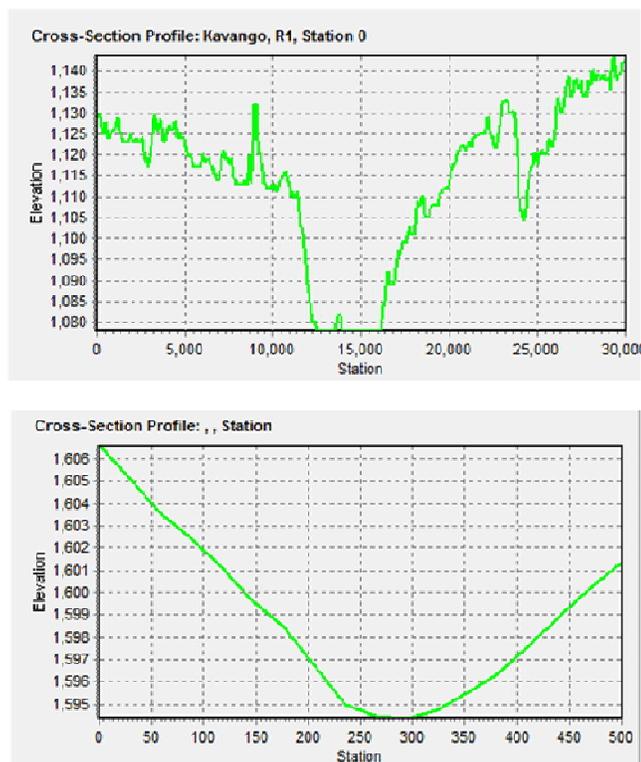


Figure 4. Comparison of cross sections of aster 30m DEM (Top) and 50m Lidar DEM (Bottom).

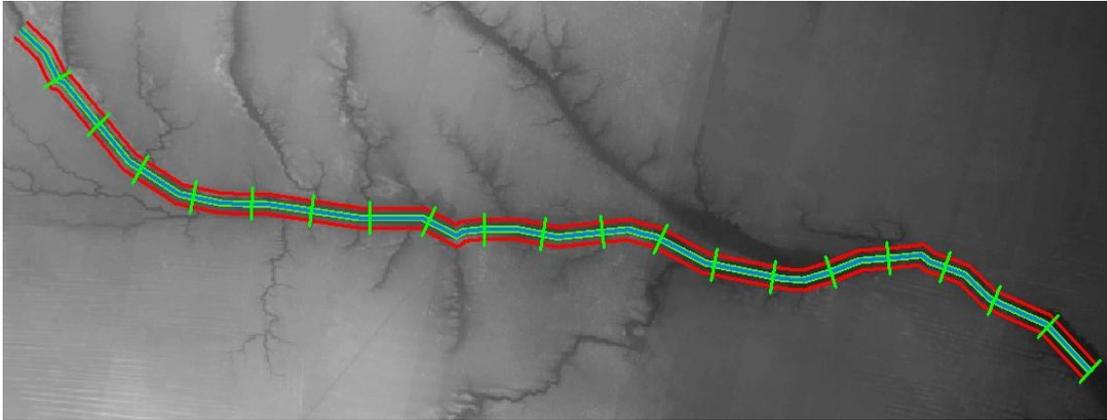


Figure 5. Aligning cross sections to the flow lines so that they are perpendicular.

channel was set at 0.01. These values are based on the recommendations from the Ministry. In figure 6, the geometric data of the Kavango River as exported from Arc GIS is shown including its direction of flow.

The three flow records of 100, 600 and 1030 were jointly simulated using the similar boundary conditions. Figure 7 shows one of the simulated profile flow based on the 1030 flow rate. The generated profile flow is visualized in figure 8 using the 1030 flow rate.

Floodplain mapping was conducted in RAS Mapper using a float DEM as backdrop to generate 2-D water surfaces (flood masks) for each profile flow (figure 9). The water surfaces were exported to GIS format for overlay with infrastructural data.

Flood model validation

The model needed validation before any analysis of vulnerability could take place to ensure that the calculated flood lines are reasonably accurate for the purpose of social economic data overlay. Two methods were used; firstly a field trip was conducted between 20 and 24 April 2012 to the study area.

GPS waypoints were collected on the right bank of the river along a distance of approximately 5 kilometers. This stretched from Popa falls to the east towards the Mohembo border post. Water lines and flood lines were collected while a boat ride approximately passing in the middle of the river was also conducted. Water line defines points collected at the edge of the water surface on 23 April. Flood line defines points marked for areas clearly showing maximum flood extent before receding. These points were all collected randomly. In order to analyze the overall shift from the measured points to the flood line, a distance calculation was made from each point to the 1030 m³/s flood mask line (Table 1). A maximum distance of 45.6 meters was calculated inside the flood line while 5.1 meters was the minimum distance

calculated.

The standard deviation calculated on the 1030 m³/s flood line was 12.2 meters while the mean distance was approximately 24 meters. The second method of validation was to overlay the flood masks generated on a specific flow rate date on the corresponding satellite imagery of that specific date. However due to lack of current satellite data, this validation method is still to be concluded.

RESULTS AND ANALYSIS

The hydraulic model developed was based on constant river flow and roughness. The left and right bank roughness was set at 0.02 while the channel was set at 0.01. The river slope was also constant at 0.003. Figure 10 shows part of the mask generated for the 1030 m³/s flow rate visualized in ArcGIS.

A comparison was made in terms of surface area covered by each flood mask on the three flow records. Figure 11 below shows the differences in flood lines when superimposed on each other. The study reveals that at minimum flow (100m³/s), the surface area covered by water is roughly 196.748 km² over the channel length of approximately 500 kilometers. At 600m³/s, the surface area changes to 459.836 km², representing an increase of 263.088 km². At the highest flow rate of 1030m³/s, the surface area is 596.866 km².

It was also possible to test the obvious influence of the hydraulic roughness values on flooding by changing the value to 0.25 from 0.20 on both left and right banks. This was experimented on the 1030m³/s flow record. The process of selecting the suitable hydraulic roughness is interactive and land cover / land use mapping and field observation are a requirement. Individual roughness-values can be entered on each cross section line. This was not done for this study. Figure 12 highlights the sensitiveness of changing roughness values. The

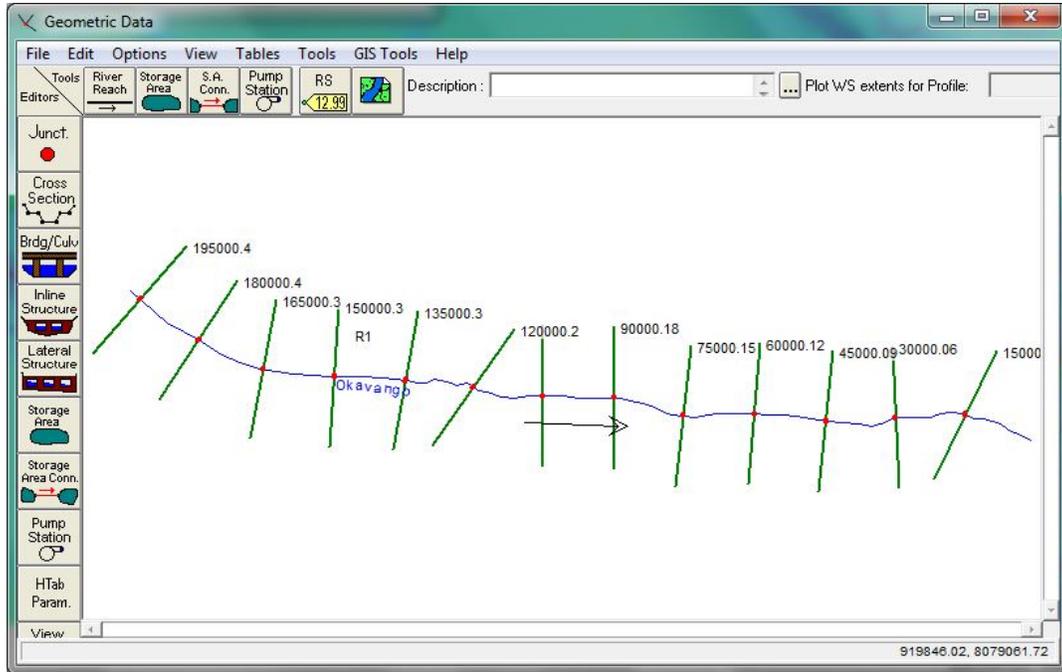


Figure 6. Visualising geometric data in Hec Ras.

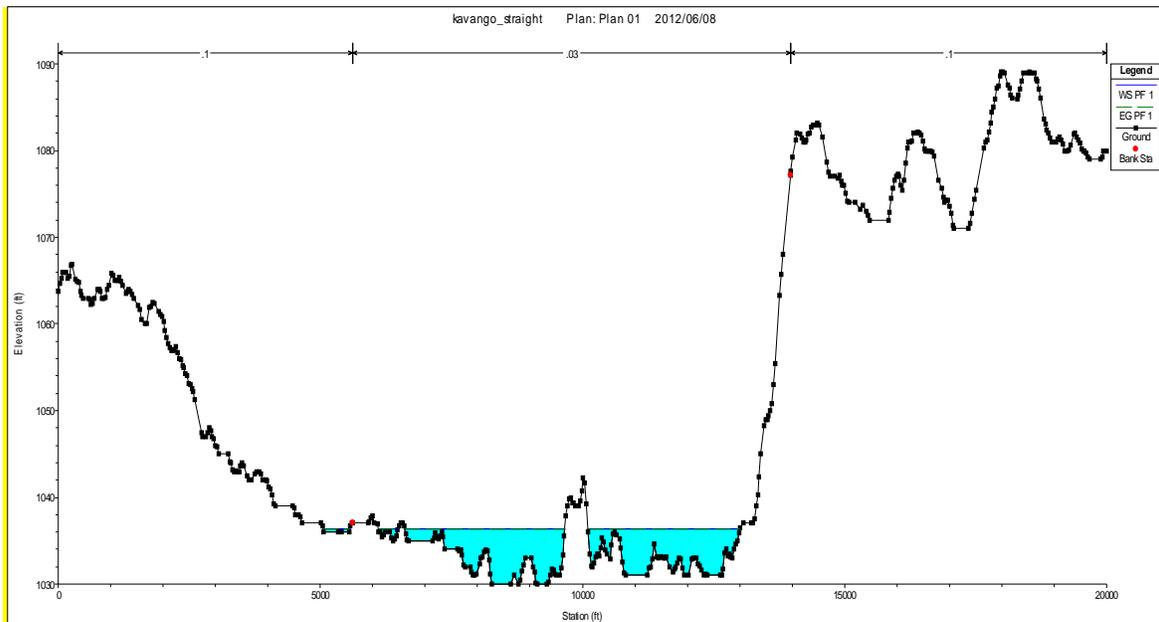


Figure 7. Simulated flow per profile on 1030 flow rate.

changes in area coverage are shown in red. A slight increase was observed in the flow pattern from 596 km² to 643 km² which is approximately 8% increase. This shows the sensitivity of changes in roughness in the river and the requirement for a detailed land use/cover mapping in future.

DISCUSSION

The overall results of this study uncover the sensitivity of the catchment areas of Kavango to flooding. Climate change is likely to trigger a wide range of secondary impacts, whereby efforts by people to mitigate and adapt

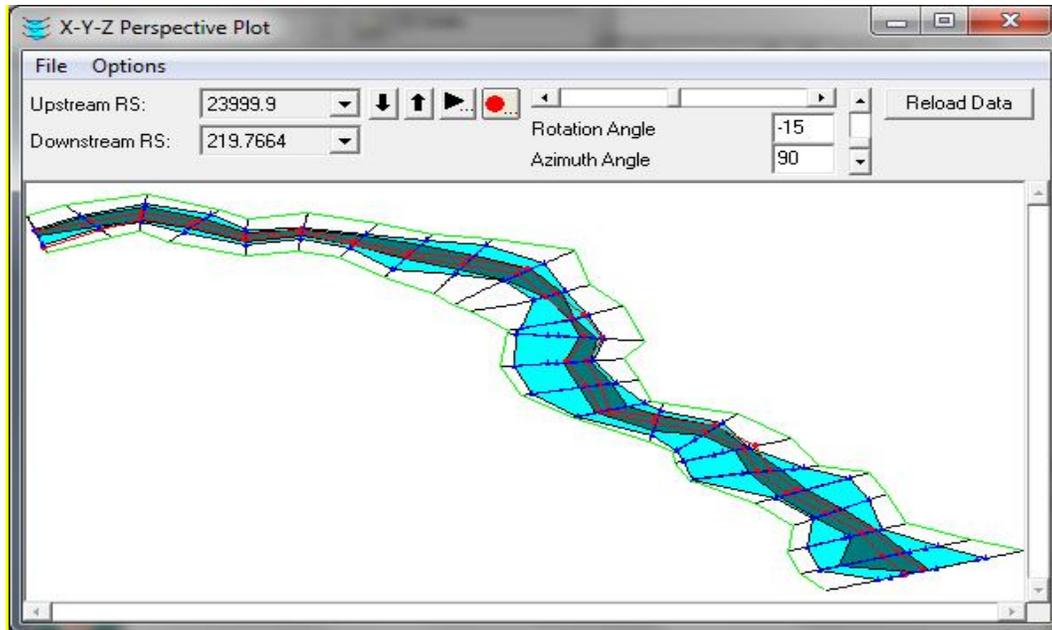


Figure 8. XYZ plot of the flow model generated.

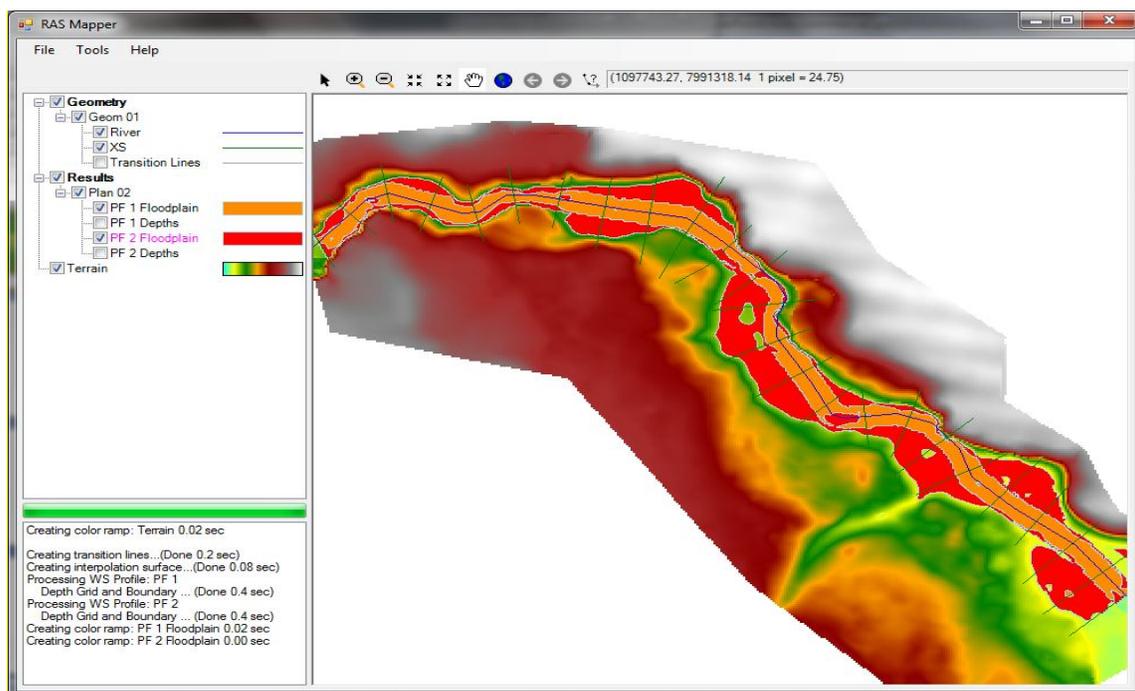


Figure 9. Generating 2D water surfaces in RAS mapper.

further compromise natural ecosystems (Bradley et al. 2012). Developing countries are particularly vulnerable because their economies are generally more dependent on climate sensitive natural resources, and because they are less able to cope with the impacts of climate change

(Agrawala and van Aalst, 2008). Climate is one phenomenon that has played and continues to play a major role in shaping the environment that serves as a source of livelihood for the majority of rural households (Assan et al., 2009). The combination of exposure to an

Table 1. Near distance table calculation.

IN_FID	NEAR_FID	NEAR_DIST
16	224	45.608421
0	224	39.079866
19	224	36.586912
14	224	36.334061
9	224	34.193717
12	224	33.275217
11	224	32.628733
4	224	31.670593
7	224	22.099919
6	224	21.035609
3	224	20.620275
15	224	20.518094
2	224	15.758447
5	224	11.240602
1	224	8.650746
8	224	8.613475
18	224	8.236609
10	224	5.144635



Figure 10. Example floodplain map generated from using 1030 m³/s flow rate.

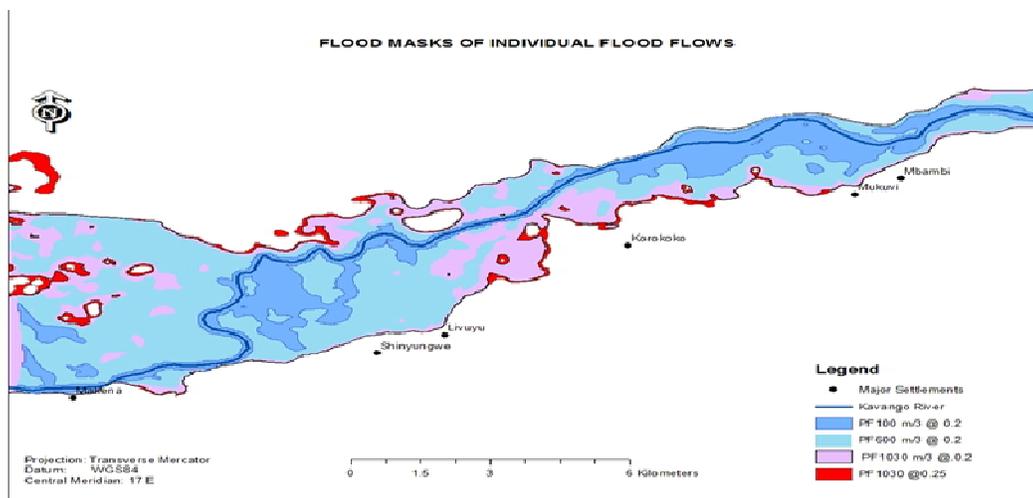


Figure 11. Comparing the flood effect of different flow rates.

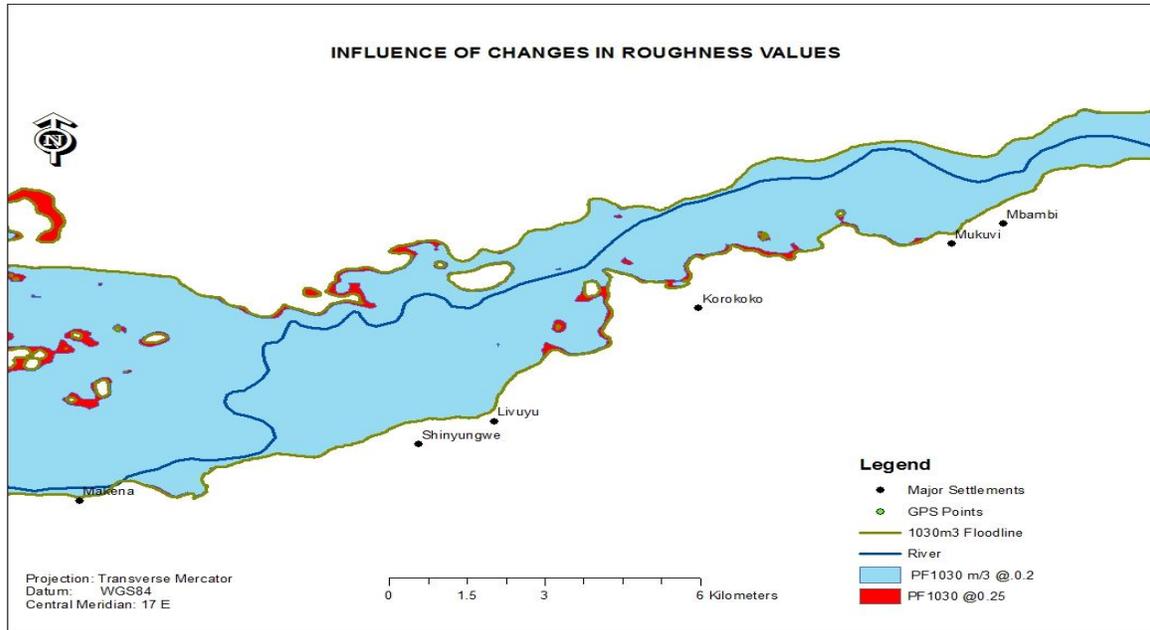


Figure 12. Comparing the influence of different roughness values.

already fragile environment, dominance of climate-sensitive sectors in economic activity and low autonomous adaptive capacity in these regions entail a high vulnerability to the harmful effects of global warming on agricultural production and food security, water resources, human health, physical infrastructure and ecosystems (Arndt et al., 2010).

The IPCC (2012) predicts that it is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe especially the case in the high latitudes and tropical regions and in winter in the northern mid-latitudes. Projected precipitation and temperature changes imply possible changes in floods, although overall there is low confidence in projections of changes in fluvial floods (IPCC, 2012). This prediction implies that any small change in average rainfall upstream the Kavango in Angola will have an influence on the livelihood of the people especially those living along the river. This will require accurate local prediction and forecasting models that will inform decision makers in time before a major extreme flood event.

In the assembled preliminary model for the Kavango, we must state here that because of the observed channel landscape, the future selection of hydraulic roughness values must be done carefully based on a land use/cover classification map. The river has small outcrops of islands that influence the uniform flow of water. The cross section lines cutting these islands in principle must receive higher roughness values than those areas where uniform flow can be predicted. For an improved Kavango flood model, the islands need to be mapped and land use and land

cover alongside the channel must be incorporated. The accuracy of flood simulation depends much on the accuracy of the river geometry. Elevation data possibly LIDAR data with high accuracy will be acquired. The 50 meter DEM used has some inaccuracy as observed from the interpolated surface. The validation of the model must cover a longer distance by randomly mapping points on the flood lines or using satellite images acquired on the same date as the flow rates.

In conclusion, the preliminary hydraulic model developed establishes useful preliminary results that are of help in decision making. The maximum error offset of 46 meters on the flood lines on a 500 kilometer channel is acceptable as impacts to socio-economic infrastructures can be predicted with certainty. By overlaying infrastructure data on the flood masks, it is possible for decision makers to initiate different development scenarios. The preliminary model can be upscaled and tested on other river basins in Northern Namibia.

REFERENCES

- Agrawala S, Maarten van Aalst M (2008). Adapting development cooperation to adapt to climate change. *Climate Policy* 8: 183-193.
- Arndt C, Robinson S, Willenbockel D (2010). Ethiopia's growth prospects in a changing climate: A stochastic general equilibrium approach. *Global Environmental Change*. doi:10.1016/j.gloenvcha.2010.11.004.
- Andersson L, Samuelsson P, Kjellstrom E (2011).

- Assessment of climate change impact on water resources in the Pungwe River basin. *Tellus* 63(A):138-157.
- Aron JL (2006). Barriers to use of geospatial data for adaptation to climate change and variability: case studies in public health. *Geospatial Health* 1: 11-16.
- Assan JK, Caminade C, Obeng F (2009). Environmental variability and vulnerable livelihoods: minimising risks and optimising opportunities for poverty alleviation. *J. Int. Dev.*, 21: 403–418.
- Bradley BA, Estes LD, Hole DG, Holness S, Oppenheimer M, Turner WR, Beukes H, Schulze RE, Tadross MA, Wilcove DS (2012). Predicting how adaptation to climate change could affect ecological conservation: secondary impacts of shifting agricultural suitability. *Diversity and Distributions*: 1–13
- Cameron A (2000). Hydraulic modeling of the Salt River, Arizona using HEC-Geo RAS. In: 20th Annual ESRI International User Conference. June 26-30, San Diego, CA: ESRI.
- IPCC (2012). Summary for Policymakers. In: *Managing the risks of extreme events and disasters to advance climate change adaptation*. A special Report of the working groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.
- IPCC (2007). *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.
- MAWF (2012). *Personal Communication*. Guido van Langenhoven, Deputy Director, Hydrology Division. April 2012.
- Thomas H, Nisbet TR (2006). An assessment of the impact of floodplain woodland on flood flows. *Water and Environ. J.*, 1747-6585.
- Yerramilli S (2012). A hybrid approach of integrating HEC-RAS and GIS towards the identification and assessment of flood risk vulnerability in the City of Jackson, MS. *American J. Geographic Information System* 1(1): 7–16.
- Vieux BE (2004). Distributed Hydrologic Modeling Using GIS. 2nd Ed. Water Science and Technology Library.