Remote Sensing for Mapping Wetland Floods in Kafue Flats, Zambia*

M. S. Aduah and S. Mantey

Aduah, M. S. and Mantey, S. (2012), “Remote sensing for mapping wetland floods in Kafue Flats, Zambia”, *Ghana Mining Journal,* pp. 33 - 40.

Abstract

Monitoring huge and dynamic floodplains such as the Kafue Flats in Zambia is critical to its sustainable use. This requires among other things accurate, past and current geo-referenced flood maps. The aim of this study was, therefore, to use remotely sensed data to generate flood maps for Kafue Flats. Flood maps were created by classifying seven cloud-free Landsat images of selected months in 2001 and the areas flooded computed. Further spatial analyses were performed to integrate the flood maps to generate a multi-temporal flood map and to compute flood durations. The results indicate that 2001 was an extremely wet hydrological year with a maximum flooded area of 31%. Also, approximately 2% of study area remained flooded for six months while permanent open water bodies covered an area of approximately 4%. Statistical analysis showed that the flood extent is significantly related to water levels and discharge when water levels are high. Therefore, prediction equations were generated to estimate flood areas with respect to water flows. However, it has been revealed that rainfall within the flats has little influence on flooding. Rather, the most critical factor in controlling the flooding is water releases from the ltezhi-tezhi dam located upstream. This study has demonstrated that remote sensing is suitable for operational mapping and monitoring of tropical floodplains.

1 Introduction

Floods are critical in the existence of wetland ecosystems and maintain the fertility of soils by distribution of nutrients and sediments. This ensures the growth of many plants and animals species and provides fertile lands for flood recession agriculture. The inter-dependency between wetland plants and animals is essentially influenced by availability and quantity of water. For this reason there has been a reduction in the size and biodiversity in many wetlands due to river regulation, climate change and poor management (Junk, 2002). The reduction mainly caused by economic development is due to regulating rivers for electricity generation, irrigation and drinking water supply. Consequently, flooding regimes which sustain many wetlands have been altered severely.

The reduction and change in flood regimes have resulted in both economic and environmental losses in many floodplain communities worldwide. Plains that use to be dominated with grasslands have been encroached by bushes. Livestock farmers for instance have lost quality grazing lands in many parts of Africa. Also since floods are no longer natural, the quantity of fish catch has reduced in many places. Some animal and bird species have disappeared with the loss of wetlands and the invasion by alien species. In response to these challenges, many approaches to wetland flood restoration have been developed. The schemes are aimed at re-establishing the natural flooding regimes by controlling water flow in rivers. Water releases from dams are managed in a manner to achieve the objective of optimizing economic and environmental gains. These schemes have been tested in Africa in the Tiga and Challawa Gorge Dams in Nigeria, the Waza-Lagone floodplains in Cameroon (Scholte, 2005; Schelle and Pittock, 2006) and the Manantali Dam in Senegal. Results indicate successful restoration of flood regimes and increased biodiversity.

Furthermore, to be able to control flooding and restore wetlands, there is the need for information on the current and past flooding regimes. Maps showing the location and dynamics of floods are invaluable in this regard.

Traditionally, mapping and monitoring floods was based on ground surveys and hydrological modelling. However, due to the dynamic nature of floods and the complexity of many wetland areas, ground-based mapping and monitoring is limited to small areas. On the contrary, Satellite remote sensing has the capability to capture the spatial and temporal patterns of floods over large areas. Therefore, the constraint of spatial and temporal coverage associated with ground survey methods is reduced. Consequently, satellite remote sensing has been used to map floods in a variety of landscapes for decades (Birkett, 2000; Sheng *et al.*, 2001; Shaikh *et al.*, 2001; Hudson and Colditz, 2003;

---

* *Manuscript received December 20, 2010*
Revised version accepted November 5, 2011

Sandholt *et al.*, 2003; Shamsedddin et al., 2006). Flood maps derived from satellite images can serve as validation tools for distributed hydrological models. In this regard, remote sensing has become one of the most important technologies for the production of spatially referenced base line environmental data needed for the protection of wetlands.

The aim of this paper is to use satellite remote sensing to map and analyse floods of Kafue Flats in order to provide information to support effective water management.

2 Methodology

2.1 Study Area

Kafue Flats is a large wetland in Southern Zambia located between longitude 26° - 28° E and latitude 15° 20′ - 15° 55′ S (Fig. 1). Originally, the Flats were used for farming, animal grazing and small scale fishing. The Kafue Flats wetlands have been changed by the construction of the Kafue Gorge in 1972 and the Itezhi-tezhi dam in 1978. The Itezhi-tezhi dam located upstream was built to control flow of water into the Kafue Gorge downstream especially in the dry season (Mumba and Thompson 2005). This has resulted in a change in the duration, timing and extent of floods. The effects include wetland vegetation succession, loss of fertile lands for farming and reduction in fish catch. Many studies have been undertaken since 1982 and the need to restore the natural state of the wetlands has been proposed (Minderhoud, 1982; Balasubrahmanyam and Abou-Zeid, 1982; Mumba and Thompson, 2005; Munyati, 2000; Alvar and Haugstetter, 2005).

2.2 Data Acquisition

Landsat images (Jensen, 2000; Campbell, 2002; Skidmore, 2002) were used for this study due to two main reasons: (1) previous flood mapping studies that used Landsat images in similar environments were largely successful (Toyra *et al.,* 2002; Sandholt et. al., 2003) and (2) Landsat data were readily available and have relatively high spatial resolution. The data used are seven cloud-free time series images provided by Geovision Ltd, one of the partners of the Kafue Flats wetlands project. A subset of each image was created to cover part of the Flats most liable to flooding (i.e from Nyimba village to Blue Lagoon National park, Fig. 1). Though these images capture snap shots of flood conditions, studies show that water flows through Kafue Flats in approximately two weeks (Mumba and Thompson, 2005). Hence satellite images with approximately monthly interval would adequately capture the floods within the wet season. Also these images were selected because floods in the Kafue Flats take time to recede due to the abundance of poorly drained soils, flat topography and abundance of small lakes and lagoons. This is in contrast to other environments where flood durations range from few minutes to hours making it difficult to delineate floods with single images. Characteristics of the sensors and images used are presented in Table 1. In addition, hydrometric data for the Kafue River basin were obtained from the Zambia Electricity Supply Company (ZESCO). These included discharge and water levels at the Nyimba gauging station (Fig. 2) and rainfall at the Kafue Polder climate station (Fig. 3)

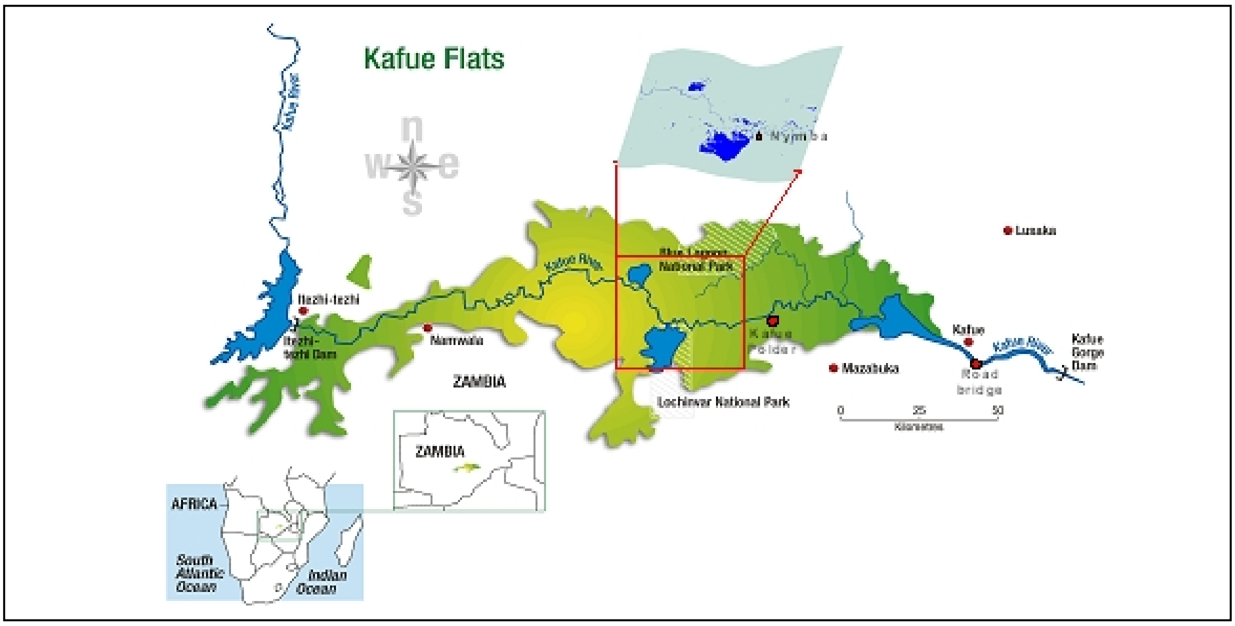


Fig. 1 A Map of the Study Area

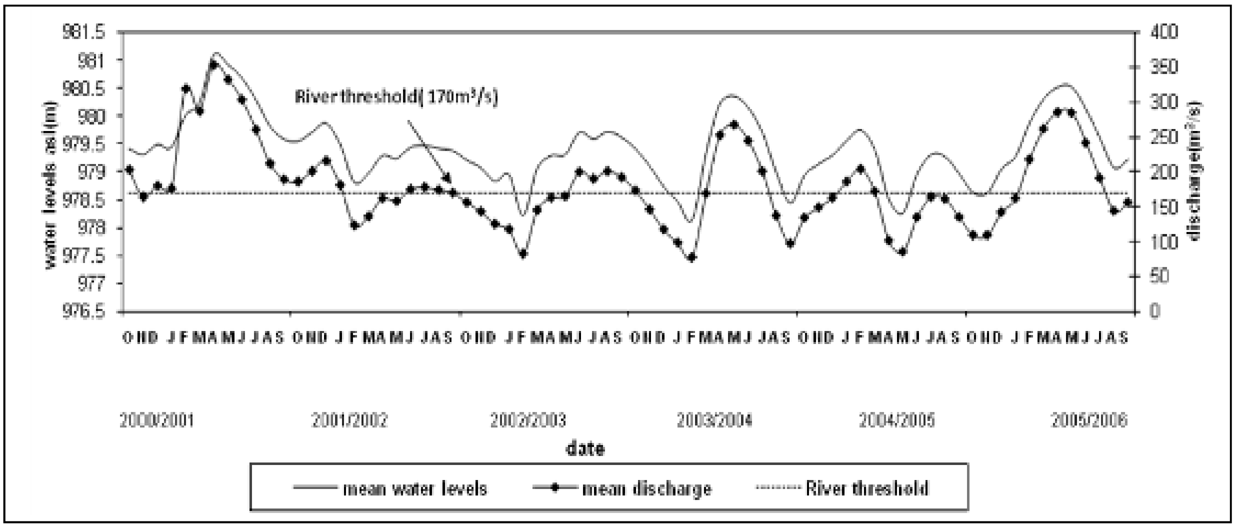


Fig. 2 Water Levels and Discharge at Nyimba Gauging Station between 2000 and 2006

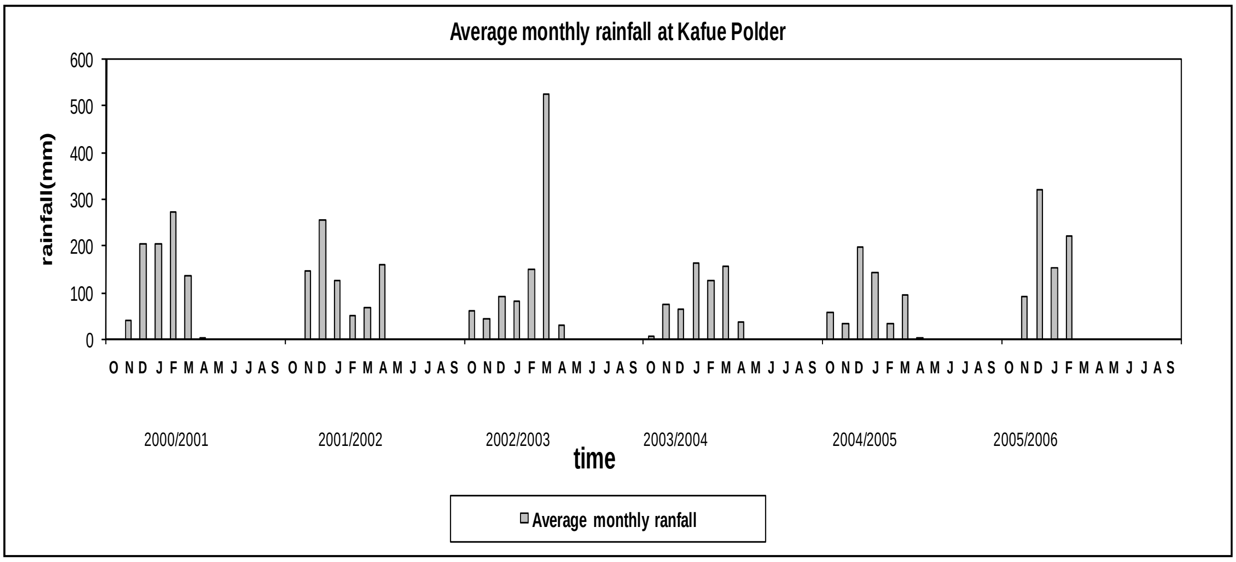
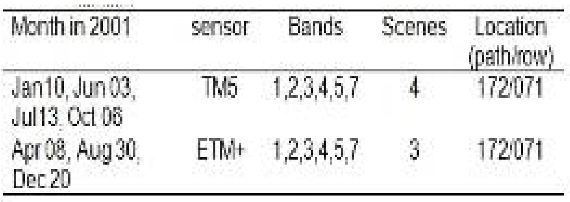


Fig. 3 Average Monthly Rainfall at Kafue Polder between 2000 and 2006

Table 1 Landsat images for study



Month in 2001	sensor	Bands	Scenes	Location (path/row)
Jan10, Jun 03, Jul13, Oct 06	TM5	1,2,3,4,5,7	4	172/071
Apr 08, Aug 30, Dec 20	ETM+	1,2,3,4,5,7	3	172/071

2.3 Image Preprocessing

2.3.1 Geo-referencing

Topographic maps and the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) of Kafue Flats were obtained from the Survey Department of Zambia and the United States Geological Surveys (USGS) website respectively. These were used for image geo-referencing and GIS analysis. The topographic map was scanned and geo-referenced to the Zambian Transverse Mercator Projection. The Landsat7 ETM+ image of April 8th, 2001 was then registered to the geo-referenced topographic map. The rest of the images were co-registered to this image with a precision of less than one Landsat pixel. The nearest neighbour re-sampling algorithm was used.

2.3.2 Field Data

Fieldwork in the Kafue Flats was conducted in the dry season from September to October 2006. Training samples for image classification were collected in the area liable to flooding. The fieldwork consisted of: (1) visual identification of sample sites, their sizes and classes and (2) measurement of sample coordinates with a Garmin Etrex handheld GPS instrument. Conducting field work in the dry season made it possible to observe the flood gradient from the uplands to permanently flooded river banks. This is because during the rainy season the Kafue Flats is inaccessible (observation of Landsat images and personal communication from ZAWA park scouts) and difficult to collect ground data.

2.4 Image Classification

Prior to classification, field data and acquired local knowledge (Glasser and Reinartz, 2005) from field visits were used to create training data/signatures. The training signatures were created with at least 100 pixels per land cover class (Campbell, 2002). Accordingly, all the seven Landsat images were classified into four using the maximum likelihood classification algorithm described by Campbell (2002) and Jenson (2000) and used by Sandholt *et al.* (2003). The classes are open water, flooded lands, grasslands, and woodland/shrubs. These classes were merged to flooded and non-flooded classes. Though the four classes are broad, they are adequate for water management. Also these classes are enough for validation of predicted flood maps from the Kafue basin hydrological model (KAFRIBA) and for the creation of a digital elevation model of the Flats. The flood map classes are also adequate as inputs to biogeochemical models for assessing methane emissions from the wetlands. Accuracy assessment of the derived maps was not conducted since ground truth data at the time of satellite over pass was not available. However an indication of the flood map accuracies was based on the relationship between computed flooded areas and water flows, a known relation in similar floodplains (Toyra and Peitroniro, 2005).

2.5 GIS Analysis

The flood maps produced were exported into Environmental System Research Institutes' (Esri) ArcGIS9.1 and for each flood map its aerial extent was computed. The flood maps were reclassified and combined to generate a multi-date flood map. Furthermore, regressions between flooded areas, discharge and water levels at Nyimba gauging station were investigated. From this, a relation was developed and its significance tested. Finally, to understand the major influencing factor(s) of flows in the Kafue River, regressions between water flows and rainfall were carried out. The regressions were executed with the data analysis toolpark of Microsoft Excel. Therefore, the prediction equations developed through regression analysis were used to estimate flooded areas. The water level data used ranged from the year 1984 to 2000. Also, since flooding is controlled to some extent by terrain elevations; the multi-temporal map was crossed with an SRTM DEM to relate terrain elevations to flood duration classes. This was executed by extracting several randomly distributed elevation points on the SRTM DEM and intersecting them with the multi-temporal floodmap. The generated point data included the flood duration classes and their elevations.

3 Results

Flood maps generated are presented in Figs. 4 and 5 respectively. Also Table 2 shows the flooded areas for each flood map. The flooded areas increased from 279.051 km^2 in January 2001 to a maximum of 1893.338 km^2 in April 2001 and started reducing in June 2001. In October 2001, the beginning of the 2002 hydrological year, the area flooded was 200.416 km^2, a value almost twice the permanent water areas (Table 3). This is an indication that in 2001 the Flats received a higher volume of water than it does in a normal hydrological year (Table 4). Also the multi-date flood map, based on the monthly flood maps (Fig. 4) was used to generate flood durations for the wet season of 2001 (Fig. 5). Areas that flooded in all the months were assigned highest flood probability zones while those that did not flood were assigned as never flooded. The duration is categorised into eight classes representing zero to seven months.

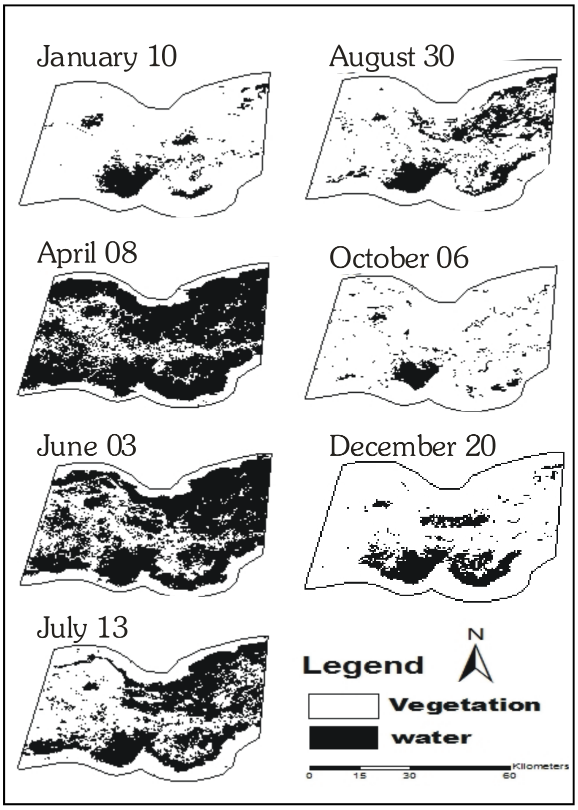


Fig. 4 Flood Maps of 2001

The seventh class- area of permanent water - was approximately 4% of study area while the longest flood duration covered approximately an area of 2%. Furthermore, an area of approximately 45% remained flooded from two to four months. Furthermore, the relation between terrain elevations and flood durations is presented in Table 3. It can be observed that as the terrain elevations decrease the flood durations increase indicating that the Kafue Flat is a concave floodplain. However, the average height of the permanent water bodies is slightly higher than those of the backswamps. This phenomenon ensures that the backswamps are always flooded since they only receive water when the river overflows its banks and are disconnected at low water levels.

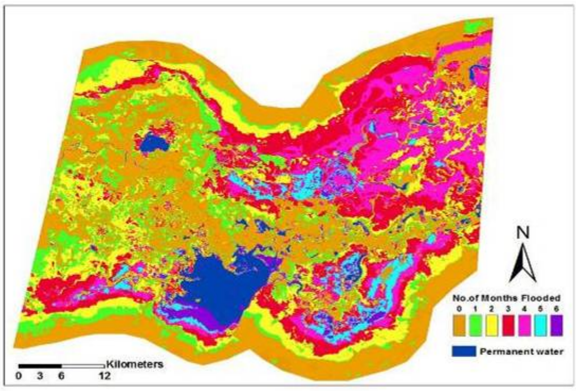


Fig. 5 Multi-date Flood Map of 2001

Table 3 Flood Duration and Average SRTM DEM Elevations

Date (2001)	Flooded area (sq. km)	% flooded area	Nyimba water levels (m)	Nyimba Discharge (m^3/s)	Kafue Polder Rainfall (mm)
January10	279.051	4.510	979.350	166.000	205
April 08	1893.338	30.570	981.120	356.000	2
June 03	1667.442	26.920	980.790	315.000	0
July 13	1141.803	18.440	980.370	267.000	0
August 30	580.397	9.370	979.640	184.000	0
October 06	200.416	3.240	979.520	167.000	0
December 20	430.972	6.960	979.910	220.000	255

Furthermore, linear regression analysis of flooded area and water flows at Nyimba gauging station produced significant results. The flooded area is significantly related to water levels ($F=100.39$, $R^2=0.95$, $\alpha=0.05$, $p<0.05$, $df=6$) and discharge ($F=102.56$, $R^2=0.95$, $\alpha=0.05$, $p<0.05$, $df=6$). However, it was found that this relation fails when water levels are low. In addition, rainfall at Kafue Polder (near Nyimba gauging station) is not significantly related to flooded area ($F=1.77$, $R^2=0.26$, $\alpha=0.05$, $p>0.05$, $df=6$). Using the above statistics the following prediction equations were generated.

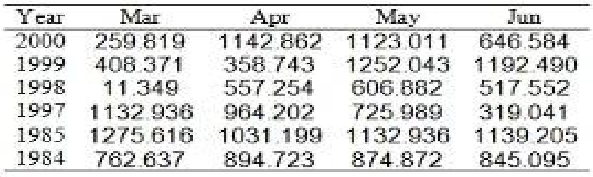
$$\mathbf{y} = -1242.234 + 8.889 \times \mathbf{D} \tag{1}$$

$$\mathbf{y} = -971918.358 + 992.555 \times \mathbf{WL} \tag{2}$$

Where y = flooded area in square kilometres, D = discharge in cubic meters per second and WL = water levels in meters above mean sea level.

Subsequently, flooded areas modelled with available water levels are presented in Table 4. It can be observed that a high flooded area of 1275.616 km^2 was recorded in March 1985; a value below the highest flooded area of 1893.338 km^2 recorded in 2001. This indicates that in the period 1984 to 2001, flood levels in 2001 were the highest.

Table 4 Modelled Flooded Areas in km^2*



Year	Mar	Apr	May	Jun
2000	259.819	1142.862	1123.011	646.584
1999	408.371	358.743	1252.043	1192.490
1998	11.349	557.254	606.882	517.552
1997	1132.936	964.202	725.989	319.041
1985	1275.616	1031.199	1132.936	1139.205
1984	762.637	894.723	874.872	845.095

*calculated with available average monthly water levels at Nyimba gauging station

4 Discussion

The results of this study indicate that optical and infrared satellite images are suitable for flood mapping and monitoring in Kafue Flats, a confirmation of other studies in similar environments (Birkett, 2000; Shaikh *et al*., 2001; Sheng *et al.*, 2001; Sandholt *et al*., 2003; Hudson and Colditz, 2003). Satisfactory flood mapping in this study is due to several factors. Firstly, the mapping was based on delineation of four broad land cover classes; open water, flooded land, grasslands and woodland/shrubs. Inspection of the spectral signatures of these classes shows a wide separability (Fig. 6). From field observations only the areas (termitaria zone) around the woodlands have tall grasses ranging from 1 to 2 m.

Also, the areas close to the river banks have vegetation such as Typha and Papyrus up to about 2 m tall. However, these areas cover a small percentage of the study area (Munyati, 2000). The abundance of short and weak stemmed grasses is important because when water level rises the vegetation is mostly submerged and appears spectrally differently from non-flooded grasslands on optical images. The near-infrared radiation is absorbed by the flooded surface while non-flooded surfaces emit it. Also the absence of dense woodlands and shrubs in the Flats improved the accuracy of flood delineation. From field observations the vegetation is sparsely distributed making it possible to detect water beneath most of the canopies. Also, the successes in flood mapping indicate that maximum likelihood classification algorithm have a potential operational use in Kafue

Flats. This is because the algorithm takes the variability of the land cover into account (Campbell, 2002; Toyra *et al*., 2002; Sandholt *et al.*, 2003; Kerle *et al.,* 2004). This study also shows that some field work is useful in acquiring local knowledge which is needed for accurate image interpretation.

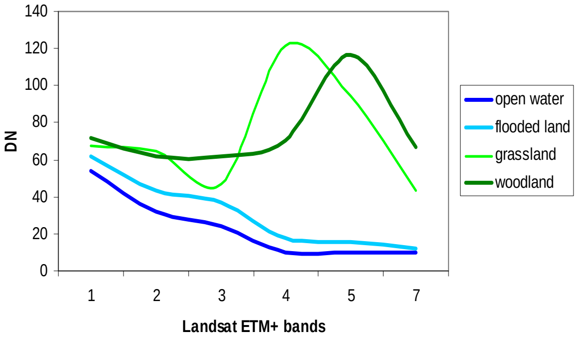


Fig. 6 Spectral Signature of Kafue Land Covers (ETM+ image 04 2001)

The study has also shown that 2001 was exceptionally wet hydrological year when approximately 31% of the study area was inundated. The flooded areas were very high such that even in October 2001, at the beginning of the 2002 hydrological year, about 3% of the study area was still flooded. The mapped flooded areas are consistent with what was revealed through field observations and interviews. The study has also revealed that flooding is significantly related to water levels and discharge at the 95% confidence level. The results of regression analysis are a reflection of the accuracy of the flood delineation, a relation that exists in many wetlands due to their flat topography and low infiltration capacity (Birkett, 2000; Temimi *et al*., 2005; Toyra and Peitroniro, 2005). However, the relation fails at low water flows. At low water flows the main water bodies are disconnected from the flooded areas (Toyra and Peitroniro, 2005). The prediction equations are thus statistically significant and were applied on previously recorded water levels to estimate flooded areas.

Furthermore, the Kafue Flats has zones that relate significantly to the flood frequency. The zones along the banks of the Kafue River have high elevations represented by both natural and artificial levees. Field observations and interviews showed that these zones do not flood. For instance the highest water levels and discharges recorded from 2001 to 2006 at Nyimba gauging station was on April 8 2001. The recorded values were above 981 m and 356 m^3/s respectively. Incidentally, the satellite image coinciding with this date (Landsat image of 8th April 2001) recorded the largest flood extent in 2001. The flood duration for these areas is up to one month (Table 3).

Finally, majority of the flooding occurred within the first half of the year in Kafue Flats. Flooding starts in January after heavy rains in November and December and peaks around April-May. By June, flood recession begins as it does not normally rain from May to September. In August and September, the end of the hydrological year in Zambia, only permanent open water bodies remain, a confirmation of observations made by Mumba and Thompson (2005) and Balasubrahmanyam and Abou-Zeid (1982). This further shows that there is a time-lag between rainfall and flooding (Figs. 2 and 3). The local rainfall moistens the soil after the dry season. Therefore when the river overflows its banks in January-May as water from the upper catchment reaches the Flats; there is rapid overland flooding given that the generally clayey soils are already wet. Therefore, the flooding in Kafue flats is mainly caused by high water flows in the Kafue River. The controlling factor to the changed flood regime is therefore the operation of the two hydropower dams. This was observed by Balasubrahmanyam and Abou-Zeid (1982) when hydrological data before and after the construction of the two dams were analysed.

The relationships between the hydrological variables obtained in this study and *in situ* measurements provide a useful insight into how water passes through Kafue Flats ecosystem over the course of one hydrological year. These variables on the timing, extent, location and duration of floods vital for water management and wetland flood restoration activities have been provided.

4.1 Potential Application for Environmental Management

Flood maps generated by remote sensing image analysis in this study could be used for effective management of Kafue Flats. For instance it has been shown that the transition zones between grasslands and woodlands rarely flood. Also areas with low elevations adjacent to the levee system of the river system have long flood durations. The effect of these flood scenarios on the environment is evident. The areas with long flood durations are dominated by vegetation such as water reeds, Typha and Papyrus while those areas with short duration floods are dominated by grass species (Munyati, 2000). Also the flood maps can be used together with the water levels measured at the five gauging stations to develop an accurate digital elevation model (DEM). The integration of flood extent, time of occurrence, duration, location and DEM with water management at the two dams, vegetation composition and results of studies on wildlife distribution should allow important relationships to be derived and studied. For instance, it would be interesting to determine the relations between Kafue Lechwe, bird populations and flood extents. This could be used to assess the impact of flood extent when the new operational rules for the dams are finally implemented. Also, the flood maps could be used in validating the results of the KAFRIBA model. In this way the necessary understanding of the hydro-ecological functioning of the Kafue Flats would be generated to allow sustainable utilisation of the natural resources.

5 Conclusion

This study has demonstrated that satellite remote sensing is suitable for operational flood mapping and monitoring of Kafue Flats. The study has shown that there exist flood durations of one to six months in the study area and statistically significant relations exist between flooded areas, water levels and discharge respectively. Also the spatial and temporal distribution of floods is such that floods start around January when the river channel threshold of about 170 m^3/s is exceeded. The floods peak in April and May. In June flood recession starts and during the period August to October only permanent water bodies remain. Also the flood maps from this study can be used to generate DEM of Kafue Flats.

Acknowledgement

The work reported here is part of an Erasmus Mundus MSc thesis undertaken at the International Institute for Geo-information Science and Earth Observation (ITC), the Netherlands, University of Southampton (UK), Lund University (Sweden) and Warsaw University (Poland) by the corresponding author in 2007. The authors wish to thank Mr Marco Gylstra of Geovision, Netherlands, WWF-Zambia, the Zambia Electricity Supply Company (ZESCO) and the Zambia Wildlife Authority (ZAWA) for logistics and data support. Many thanks also go the reviewers for their comments/ suggestions.

References

Alvar, G. and Haugstetter, J. (2005), "Hydro-electric power production at the Kafue River, Research seminar, the politics of large dams", online material, available: *http://www.eawag.ch/research_e/apec/seminars/Case%20studies/2005/Kafue%20Case%20Study.pdf,* accessed: December 10, 2006.

Balasubrahmanyam, S. and Abou-Zeid, S. M. (1982), "Post-Itezhi-tezhi flow pattern of the Kafue Flats region", *proceedings of the National seminar on environment and change: the consequences of hydroelectric power development on the utilization of the Kafue Flats,* Lusaka, 1978, The Kafue Basin Research Committee of the University of Zambia, pp. 63 - 67.

Birkett, C. M. (2000), "Synergistic remote sensing of Lake Chad: variability of basin inundation", *Remote Sensing of Environment*, 72, pp. 218-236.

Campbell, J. B. (2002), "Introduction to Remote Sensing", 3rd Edition, London: Taylor and Francis, 621pp.

Glasser, C. and Reinartz, P. (2005), "Multitemporal and multispectral remote sensing approach for flood detection in the Elbe-Mulde Region", *Acta Hydrochim. hydrobiol*. 33, 5, pp. 395−403.

Hudson, P. F. and Colditz, R. R. (2003), "Flood delineation in a large and complex alluvial valley, lower Panuco basin, Mexico", *Journal of hydrology*, 280, pp. 229-245.

Jensen, J. R. (2000), "*Remote Sensing of the Environment: an Earth Resource Perspective*", New Jersey: Prentice-Hall, 544pp.

Junk, W. J. (2002), "Long-term environmental and future of tropical wetlands", *Environmental Conservation*, 29, 4, pp. 414-435.

Kerle, N., Janssen, L. L. F. and Huurneman, G. C. (2004), "*Principles of Remote Sensing*", 3rd edition, Enschede, The Netherlands: ITC educational textbook series, 250pp.

Minderhoud, P. (1982), "Kafue Flats hydrological studies"; *proceedings of the National seminar on environment and change: the consequences of hydroelectric power development on the utilization of the Kafue Flats, Lusaka, 1978,* The Kafue Basin Research committee of the University of Zambia, pp. 59-62.

Mumba, M. and Thompson, J, R. (2005), "Hydrological and ecological impacts of dams on the Kafue Flats floodplain system, Southern Zambia", *Physics and Chemistry of the Earth*, 30, pp. 442-447.

Munyati, C. (2000), "Wetland change detection on the Kafue Flats, Zambia, by classification of a multitemporal remote sensing image dataset", *International Journal of Remote Sensing*, 21, 9, pp. 1787-1806.

Sandholt, I., Nyborg, L., Fog, B., Lô, M., Bocoum, O. and Rasmussen, K. (2003), "Remote sensing techniques for flood monitoring in the Senegal River Valley", *Danish Journal of Geography*, 103, 1, pp. 71-81.

Schelle, P. and Pittock, J. (2006), "Restoring the Kafue Flats, A Partnership approach to environmental flows in Zambia", online material, available: *http://assets.panda.org/downloads/restoringkafueflatsschellepittockriversymposium3sept05.pdf,* accessed: November 2, 2006.

Scholte, P. (2005), "Floodplain Rehabilitation and the future of Conservation and Development, Adaptive management of success in Waza-Lagone, Cameroon", *Tropical Resource Management Papers,* 67, Wageningen University and

Research Centre, Department of Environmental Sciences, Resource Ecology Group.

Shaikh, M., Green, D. and Cross, H. (2001), "A remote sensing approach to determine environmental flows for wetlands of the Lower Darling River, New South Wales, Australia", *International Journal of Remote Sensing*, 22, 9, pp.1737 – 1751.

Shamsedddin , M. A. H., Hata, T., Tada, A., Bashir, M. A. and Tanakamaru, T. (2006), "Estimation of flooded area in the Bahr El-Jebel basin using remote sensing techniques", *Hydrology and Earth System Sciences Discussions*, 3, pp. 1851-1877.

Sheng, Y, Gong, P. and Xiao, Q. (2001), "Quantitative dynamic flood monitoring with NOAA AVHRR", *Journal of Remote Sensing*, 9, pp. 1709-1724.

Skidmore, A. (2002), *"Environmental Modelling with GIS and remote sensing*", London:Taylor and Francis, 260pp.

Temimi, M., Leconte, R., Brissette, F. and Chaouch, N. (2005), "Flood monitoring over the Mackenzie River basin using passive microwave data", *Remote Sensing of environment*, 98, pp. 344-355.

Toyra, J, and Pietroniro, A. (2005), "Towards operational monitoring of a northern wetland using Geomatics-based techniques", *Remote Sensing of Environment*, 97, pp. 174-191.

Toyra, J., Pietroniro, A., Martz, L. W. and Prowse, T. D. (2002), "A multi-sensor approach to wetland flood monitoring", *Hydrological processes*, 16, pp. 1569-1581.

Wang, Y. (2006), "Mapping the extent of a flood: what we have learned and how we could do better", Department of Geography, East Carolina University, Greenville, online material, available, *http://www.ncem.org/mitigation/Library/Research/wang.pdf,* accessed: July 8, 2006, pp. 1 -9.

Authors

Michael S. Aduah is a Lecturer at UMaT-Ghana. He specialises in remote sensing, GIS, GPS Surveys and their applications in surface water hydrology, urban infrastructure and utilities, climate change and land use studies. He obtained BSc degree in Geodetic Engineering from KNUST, Kumasi and two Msc degrees in Geo-Information Science for Environmental Modelling from Lund University (Sweden) and ITC (Netherlands).

Saviour Mantey is a Lecturer at UMaT-Ghana. He was awarded BSc (Hons) in Geodetic Engineering at KNUST-Ghana. He obtained MPhil degree in GIS and Remote Sensing from Cambridge University-UK. He has skills in using Erdas, ArcGIS9.x and Spectrum-Survey. His research interest includes applications of Web-GIS, Remote Sensing and GIS in Environmental Analysis. He is a Member of IEEE-GRSS and AARSE.