Journal of Geosciences and Geomatics, 2019, Vol. 7, No. 5, 237-244
Available online at http://pubs.sciepub.com/jgg/7/5/3
Published by Science and Education Publishing
DOI:10.12691/jgg-7-5-3

Determination of the Lukanga Swamps Flood Boundary using Landsat Imagery, Rainfall and Water Level Data

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Received October 12, 2019; Revised November 14, 2019; Accepted December 08, 2019

Abstract The Lukanga Swamp is a major wetland situated in the Central Province of Zambia. It is Zambia's fifth largest wetland whose flood boundary fluctuates with rainfall. Despite one of their many uses being that of flood control, they are no exceptions to this natural phenomenon - flooding. Hence, this study aimed at determining the most probable flood boundary of Lukanga swamps using Landsat images and rainfall data. Seasonal rainfall amounts received over the study area for the period 1972 – 2002, as well as the water level data of the swamp was used to determine wettest years as a means of selecting Landsat imagery which depicted flooding. Rainfall was determined by interpolating rainfall from adjacent meteorological stations as there is no such station in the study area. The selected Landsat imagery was used for delineation of the swamp's likely maximum flood extent using Remote Sensing and GIS software. The most likely maximum flood extent was found to be 11,891 km^2 at peak flooding.

Keywords: *Lukanga Swamps, Wetland, Landsat imagery, Geographical Information System, flood boundary, rainfall interpolation, image processing*

Cite This Article: Alick R Mwanza, Edwin Nyirenda, and Wilma Nchito, "Determination of the Lukanga Swamps Flood Boundary using Landsat Imagery, Rainfall and Water Level Data." *Journal of Geosciences and Geomatics*, vol. 7, no. 5 (2019): 237-244. doi: 10.12691/jgg-7-5-3.

1. Introduction

Flood monitoring using Remote Sensing and Geographical Information Systems technologies have become a need in the world. These technologies give quick and timely results. Knowing the extent of flooding and affected areas yields better risk estimates and preparedness for mitigation measures because despite floods claiming lives and causing property damage, humans have continued inhabiting areas threatened by floods. This has continued to be so because of the many benefits that the wetlands offer such as being very important livelihood sources and being habitats for a variety of flora and fauna.

The Lukanga swamps of Central Zambia with the Kafue River passing a distance away from the main swamp experiences considerable flooding during which time the swamps and the river become one water body. Hydrological studies carried out in the area have cited lack of data on the spatial extent of the swamps especially during floods as a drawback in accurate studies. Hence the need to contribute knowledge about the most probable maximum flood boundary of the Lukanga swamps by employing remote sensing, image processing and GIS technologies to feed into other studies such as climate change and variability, hydrological modeling, environmental modeling and socio-economic studies.

1.1. Study Disposition

The study commenced with the collection and analysis of rainfall and water level data for the period 1972 to 2002, from which the wettest years were ascertained. Landsat images [1,2] closely corresponding to the determined wettest seasons and months were then selected. But owing to the sparse availability of the Landsat imagery for the period of study only images for the years 1991, 2002 and 2005 were collected, hence used.

Thereafter, the most appropriate and relevant bands were identified that were used in the images for delineating the flood boundary. Flood boundary extents were extracted for each of the years 1991, 2002, and 2005 which were then merged to come up with the most probable maximum flood boundary for the Lukanga Swamp. Figure 1 shows the methodology as explained in the study disposition.

2. Data and Methods

Rainfall data [23] was collected for the period 1972 to 2002 for the study area and/or peripheral areas, information about when the swamp experienced floods, water level data of the swamps, a topographic map covering the entire swamps for reference, appropriate Landsat satellite images of the swamp and other adjuvant information useful in delineating the swamps' maximum flood boundary were also collected.

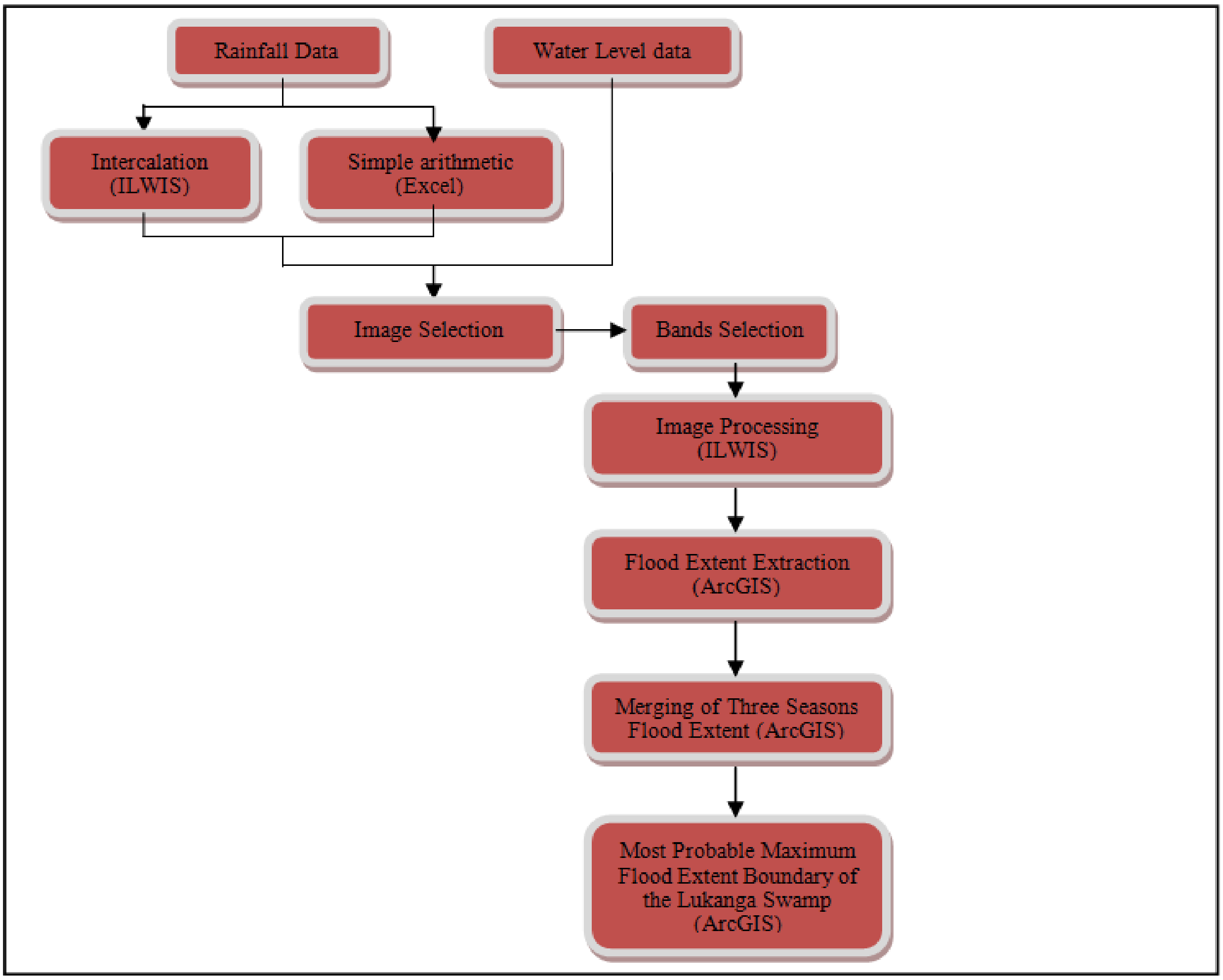

Figure 1. Flow chart of the methodology followed

2.1. Rainfall and Water Level Data

The swamp itself has no weather stations, therefore rainfall data from surrounding weather stations was used to ascertain the wettest and driest years experienced in the swamp through simple arithmetic mean and interpolation using ordinary kriging method [4,10,13,14,16,20,22]. The interpolated rainfall amounts (using all available stations country wide) and the measured water levels of the swamp were then cross referenced to determine which years were the wettest and the driest from which the appropriate Landsat images to be used were identified. Water level data that was used for the Lukanga Swamp was only for Station 4390 (Chilwa Island) (Table 1). These data were only recorded from 1959 up to 1987 when data collection ceased.

A thorough examination of the water level data showed that the Lukanga Swamp had the highest water levels among the months March, April and May interchangeably (Table 2) while the lowest water levels were in the months November and December (Table 3). Hence, it was deduced that peak flooding usually occurred in March and April, and sometimes in May.

Table 1. Gauging Station in the Lukanga Swamp at Chilwa Island (source: [3])

Stn. Name	Description	Long (°)	Lat (°)	Period of Data Collection
4390	Lukanga Swamp at Chilwa Island	27.650	-14.217	01/10/1959 – 30/09/1987

Table 2. Months and seasons with the Highest Water Levels

	Month with Highest Water Level	Number of Seasons between 1972 & 1987
1	March	Four (1972/73, 1981/82, 1982/83, 1983/84)
2	April	Six (1973/74, 1974/75, 1976/77, 1979/80, 1980/81, 1984/85)
3	May	Two (1977/78, 1985/86)
4	June	One (1975/76)

Table 3. Months and seasons with the Lowest Water Levels

	Month with Lowest Water Level	Number of Seasons between 1972 & 1987
1	November	Five (1974/75, 1977/78, 1982/83, 1983/84, 1985/86)
2	December	Six (1972/73, 1975/76, 1976/77, 1981/82, 1984/85, 1986/87)

Using the interpolated rainfall results it was determined that the wettest seasons were 1973/74 (1307mm), 1977/78 (1345mm) and 2000/01 (1379mm) whereas the driest seasons were 1991/92 (548mm), 2001/02 (560mm) and 2004/05 (628mm) and that the average rainfall in the swamps over a 33 year period (1972 – 2005) was 994mm.

Table 4 shows the interpolated rainfall amounts over the Lukanga Swamp for the three rainfall seasons for which Landsat images were available. Figure 2 – Figure 4 illustrate the rainfall interpolation maps for the 1990/91, 2001/02 and 2004/05 seasons in which maps 1 and 2 show seasonal rainfall ranges and mean rainfall figures over the study area respectively..

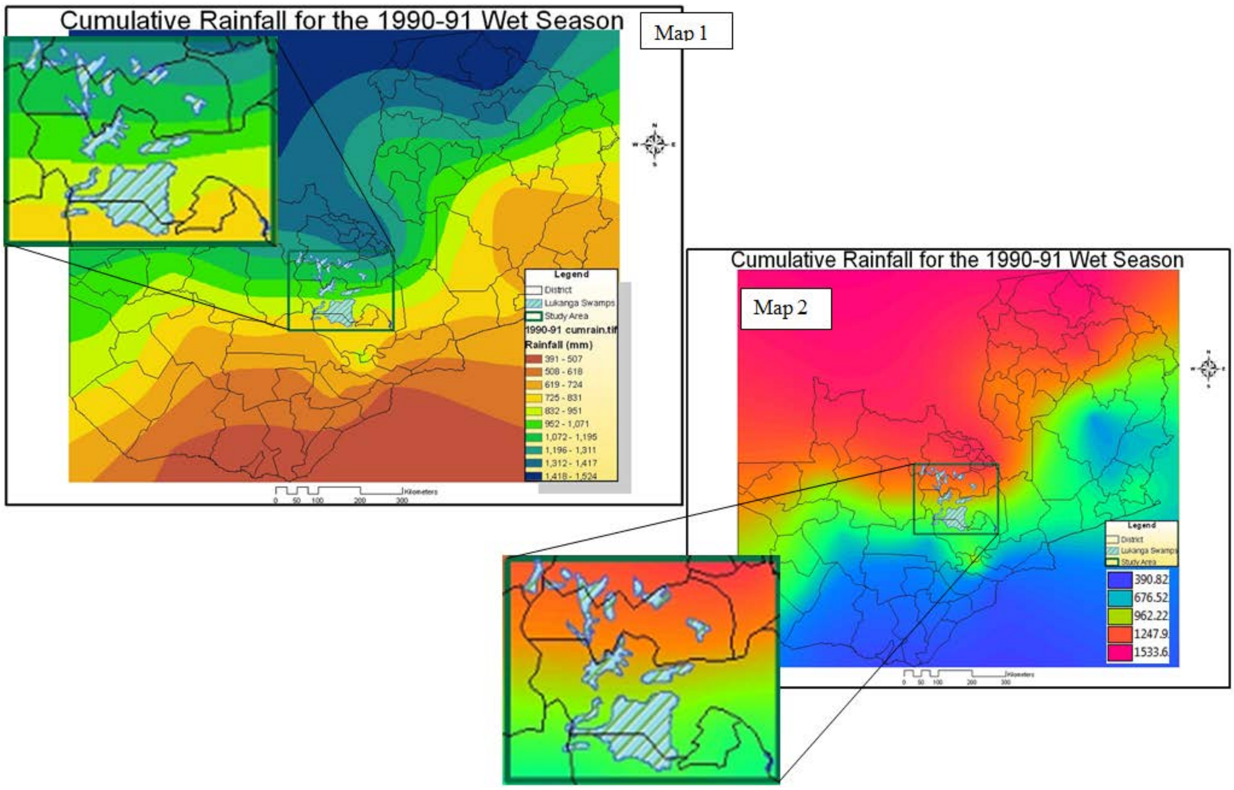

Figure 2. The interpolated rainfall map of Zambia for the 1990/91 season

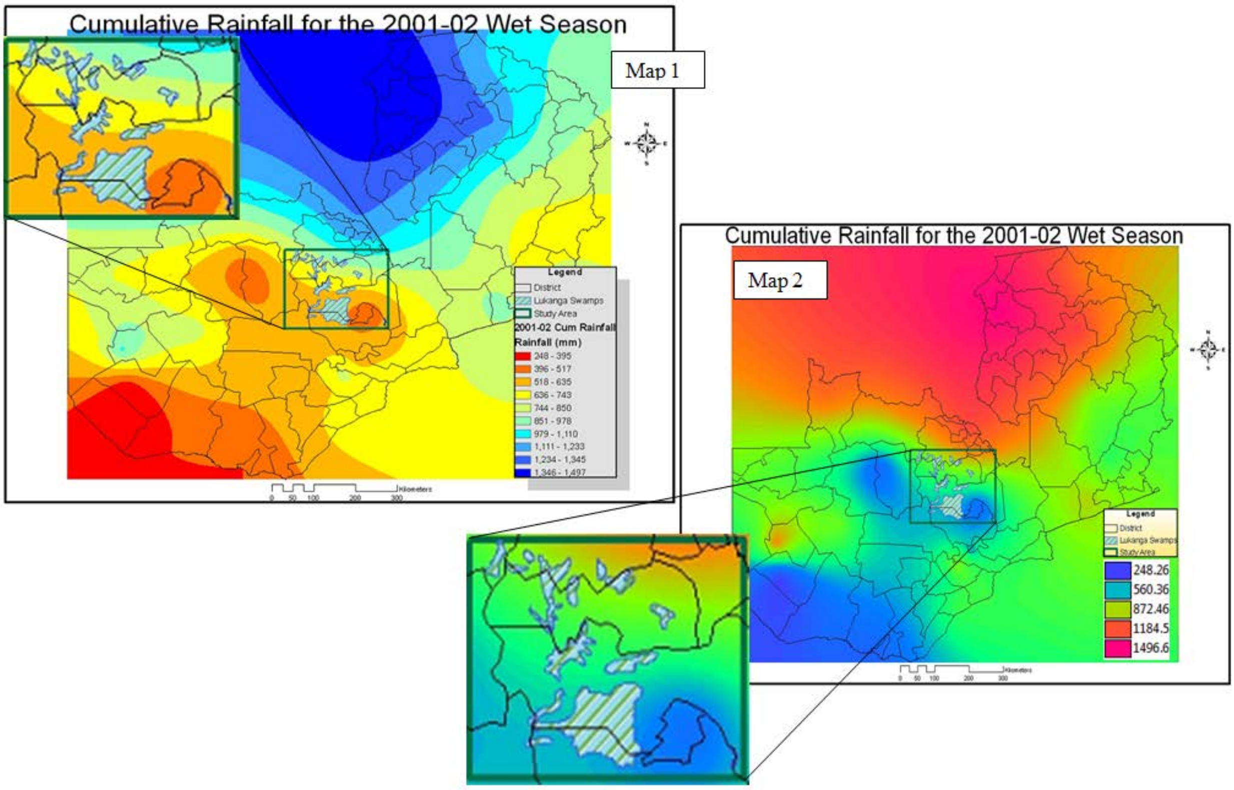

Figure 3. The interpolation rainfall map of Zambia for the 2001/02 season

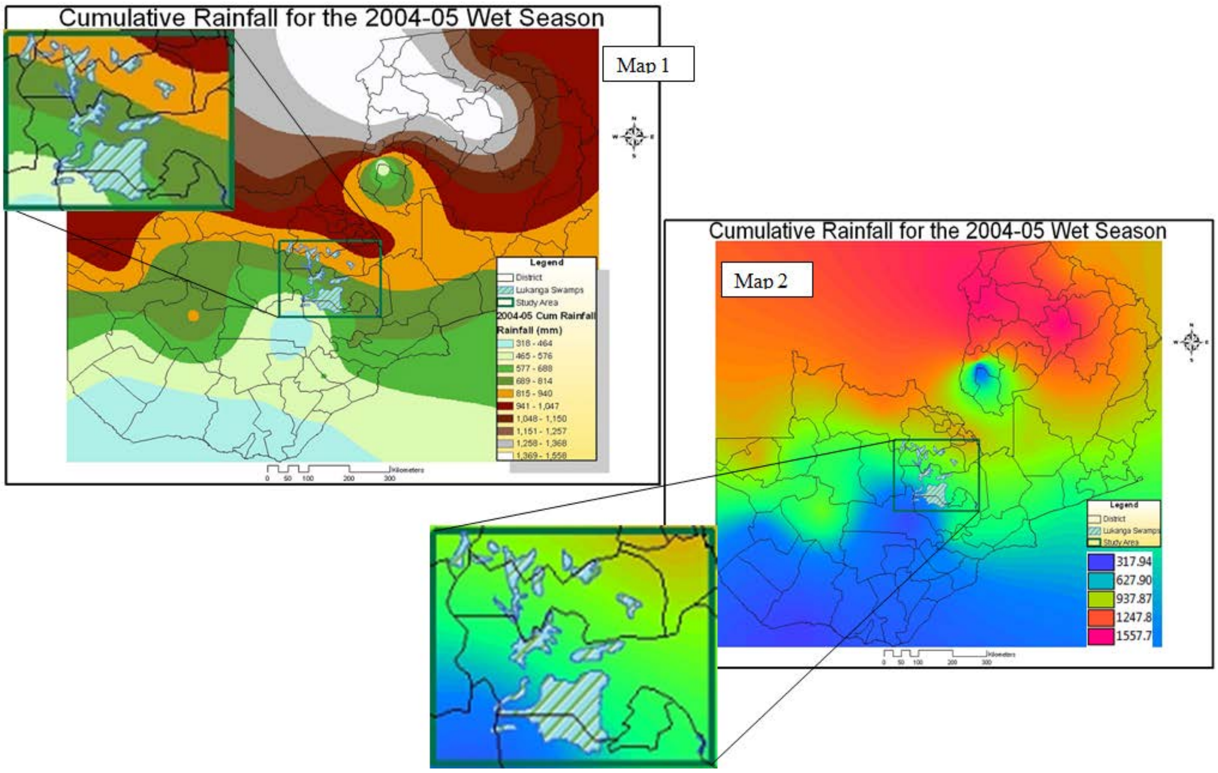

Figure 4. The interpolation rainfall map of Zambia for the 2004/05 season

Table 4. Interpolated rainfall amounts over Lukanga swamps

	Season	Mean Rainfall Range	Mean Rainfall
1	1990/91	832 – 951	962.22
2	2001/02	518 – 635	560.36
3	2004/05	577 - 688	627.90

2.2. Landsat Imagery

The Landsat TM/+ETM images used (Table 5) were already pre-processed and ortho-rectified [21]. They were acquired in GeoTIFF format (a format which utilizes geospatial tags embedded within the TIFF file), and in WGS84 UTM projection system. Essentially, GeoTIFF is a TIFF file with location.

Landsat images were selected for use in this study for the following reasons [12]:

a) their relatively high spatial resolution of 30 metres (15 metres for panchromatic);
b) a temporal resolution of 16 days (equivalent to 232 orbits) which is reduced to 8 days when the two operational satellites are considered together;
c) high value to cost ratio;
d) broad cross-application validation;
e) ability to concurrently use scenes from two dates for comparing pre-event, event, and post-event situations and;
f) lastly, ease of access as Landsat images have been a free data source since November 2008 downloadable from the GLCF website (ftp://ftp.glcf.umiacs.umd.edu/glcf/Landsat/WRS2/).

2.2.1. Landsat Image Band Selection

The best satellite image band combination should be based on knowledge of the individual band properties and their reflectance characteristics pertaining to wetland mapping [17,6]. [9] suggested that the best FCC RGB displays of ETM+ bands for separating wetlands from other land units were:

a) ETM+4/ETM+7, ETM+4/ETM+3, ETM+4/ETM+2,
b) ETM+4, ETM+3, ETM+5 and
c) ETM+3, ETM+2, ETM+1.

[19] added ETM+7, ETM+4, ETM+2 to the above list as the fourth combination. Similar suggestion was also made in 2007 by [11].

In this study, bands 7, 4, and 3, assigned to colors red, green, and blue, respectively, were selected. This combination was arrived at because it took into consideration the sensors that were able to discriminate wetlands by hydrophitic vegetation (high moisture content), hydric (water-logged) soils, and wetland hydrology (permanent or periodic inundation). Therefore band 7 was selected due to its sensitivity to vegetation moisture monitoring; band 4 for its good soil moisture and vegetation monitoring, and water body discrimination (it presents strong contrast between water bodies and other land features [5]; and band 3 for its ability to distinguish among plant species.

The combination of these three bands created a pseudo natural color composite which closely mimicked natural colors, i.e. water appeared blue, (bare) soil appeared red, and vegetation appeared green [7].

In order to delineate the flood boundary [8,18], the classified image (Figure 5*(a)*) was used in conjunction with false and pseudo color composites of bands 7, 4, 3 (Figure 5*(b)*) and 4, 3, 2 because flood-affected areas were very apparent alluvial wet soils around the swamp and along streams and rivers. The combination of bands 4, 3, 2 was also used because it brought out water affected areas clearer. In a False Colour Composite, green vegetation appears red, water bluish, and bare soil in shades of brown and grey. Digitizing of the flood boundary extent was done by interchanging views between the pseudo- and false- color composites.

Table 5. Landsat images used

No.	P/R	Acq. Date	Dataset	Producer	Attributes	Type	Location
1	173/070	24-May-89	TM	EarthSat	Ortho, GeoCover*	GeoTiff	Zambia
2	172/070	23-May-91	TM	EarthSat	Ortho, GeoCover*	GeoTiff	Zambia
3	173/070	4-May-02	ETM+	EarthSat	Ortho, GeoCover*	GeoTiff	Zambia
4	172/070	13-May-02	ETM+	EarthSat	Ortho, GeoCover*	GeoTiff	Zambia
5	172/070	5-May-05	ETM+	EarthSat	Ortho, GeoCover*	GeoTiff	Zambia
6	173/070	12-May-05	ETM+	EarthSat	Ortho, GeoCover*	GeoTiff	Zambia

*Landsat GeoCover refers to a positionally accurate orthorectified Landsat Thematic Mapper and Multispectral Scanner imagery covering the majority of the Earth's land mass.

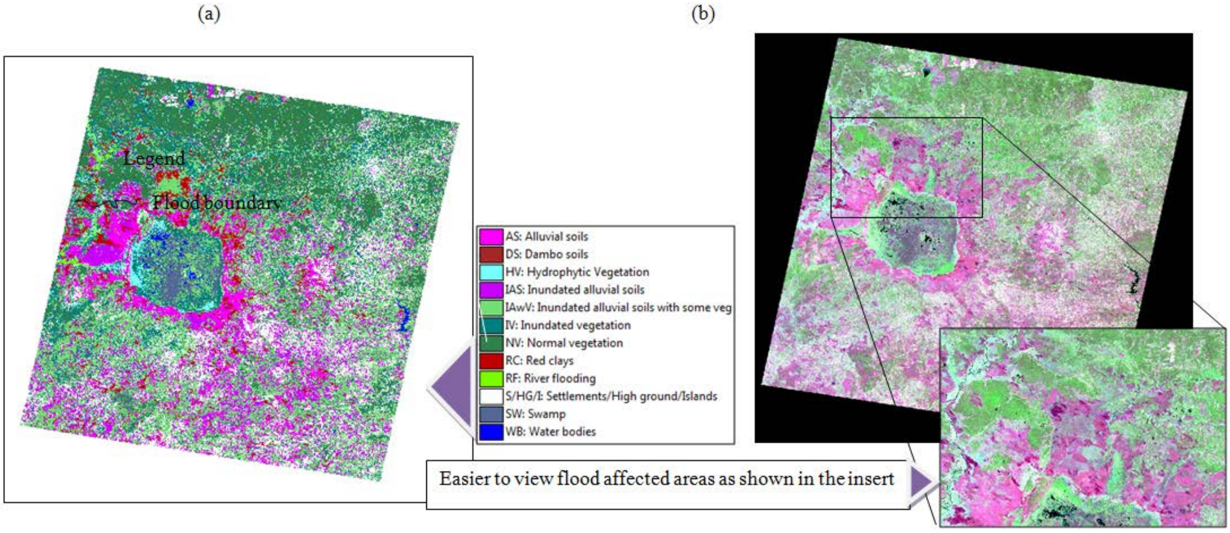

Figure 5. *(a)* Supervised classification of bands 3, 4, and 7 (majority filter) for the May 13, 2002 image, *(b)* color composite of bands 3, 4, 7 for the May 13, 2002 image

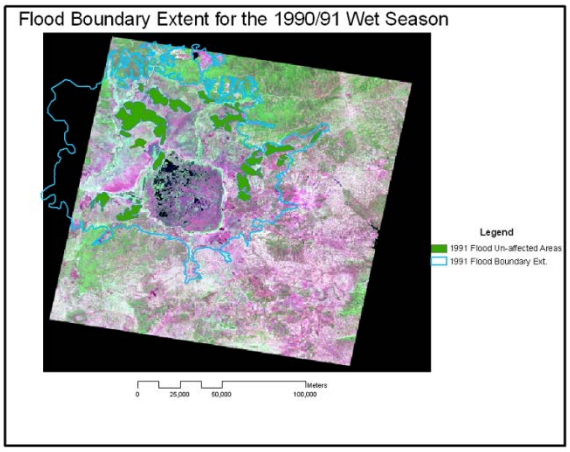

Figure 6. Flood boundary - 1990/1991 Wet Season

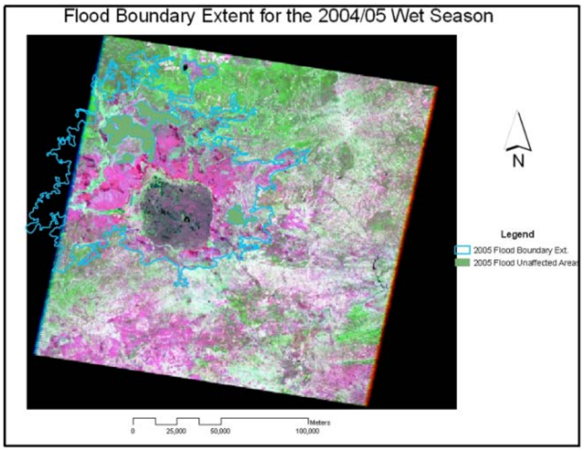

Figure 8. Flood boundary - 2004/2005 Wet Season

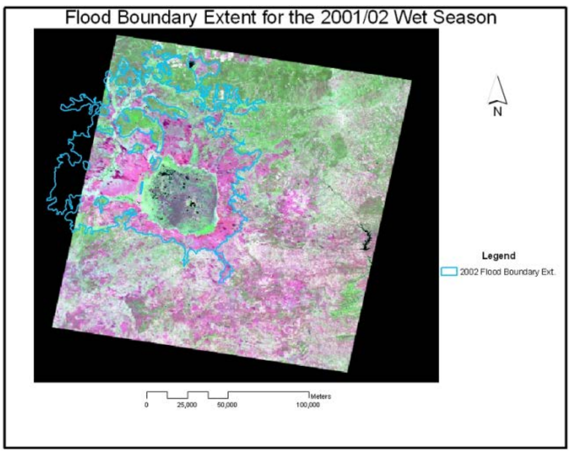

Figure 7. Flood boundary - 2001/2002 Wet Season

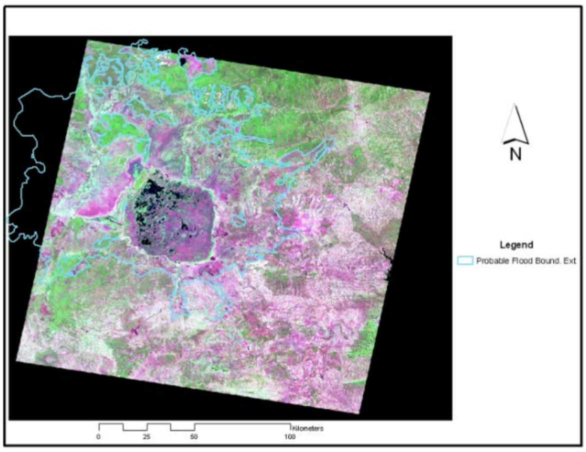

Figure 9. The most probable Lukanga Swamps flood boundary

2.3. Flood Boundary Delineation

Digitizing of the flood boundary was carried out at scales of between 1:50,000 and 1:250,000 to make viewing the flood-affected pixels easily. Areas unaffected by flooding (areas with normal vegetation) were digitized separately and were clipped out of the flood boundary extents afterwhich areas of flood boundary extents were calculated. Figure 6 – Figure 8 show the flood extent boundaries for the three wet seasons of 1990/1991, 2001/2002 and 2004/2005 as digitised.

3. Flood Boundary Extent

The area of the most probable flood extent of the Lukanga Swamp was determined as per Table 6:

a) each delineated flood boundary had its area computed.
b) all the areas unaffected by flooding within each flood boundary were computed and subtracted from the computed areas in (a).
c) The remainder was thus the approximate flood extent for the particular season.
d) The Lukanga Swamp's most probable flood extent was then obtained by merging the three flood boundaries. Figure 10(a) shows a merge operation being carried out while Figure 10(b) and Figure 10(c) show the boundary before and after the merge operation, respectively. In so doing the areas not inundated in one image but inundated in another were shown as inundated whereas the areas not inundated in all the images were shown as such in the merged image.

The flood extent area was then recalculated and found to be 11,891 km^2 as the most probable flood extent of the Lukanga Swamp. Figure 9 shows the most probable flood boundary superimposed on the color composite of the May 23, 1991 Landsat satellite image.

Table 6. Flood extent boundary areas

Season	Total Area Covered (km^2)	Uninundated Area (km^2)	Area of Flood Extent (km^2)
1990/91	12,051	1,049	11,002
2001/02	8,957	0	8,957
2004/05	10,139	639	9,500
Total boundary extent from the 3 seasons used			11,891

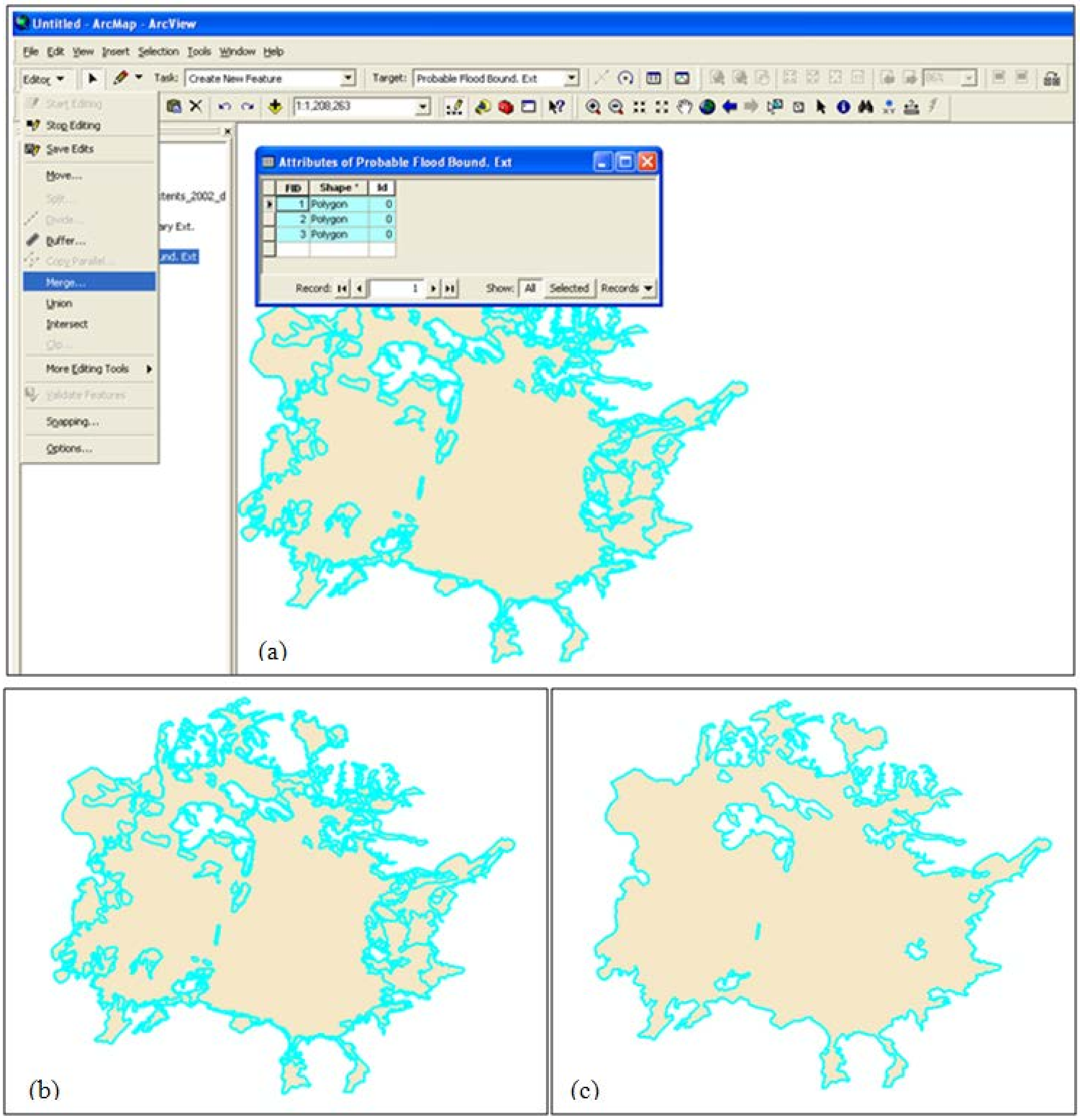

Figure 10. *(a)* merging the three flood boundaries, *(b)* before merging, *(c)* after merging

4. Discussion and Conclusion

4.1. Discussion

Although satellite imagery is unparalleled in mapping and analyzing flood events, availability of suitable images in terms of date and resolution is very vital. This study was somewhat affected because the images well limited. There were also significant gaps in rainfall and water level data such that the results were affected as such gaps were not filled at all.

Auxiliary data was also hard to come by especially that this study was carried out without a funded research budget such that field visits were limited and data that need to be bought could not be bought at all. Image classification was thus largely based on secondary knowledge.

It was also noticed that image enhancement carried out before supervised classification rendered the enhanced image unusable in ILWIS as its domain was changed from image to value domain. As a result FCC images were finally used in delineating the flood boundaries.

4.2. Conclusion

The most probable maximum flood extent of the Lukanga Swamps was determined to cover about 11,891km^2 using the three seasons' imagery that was processed. It is possible, though, that the determined extent could increase or decrease depending on the amount of precipitation in a particular season.

The determined most probable maximum flood extent thus covers about 60% of this wetland's catchment area increasing the swamp area during such maximum flooding by 4.5 times from the normal 2,600km^2. This is as a result of flooding covering the environs of both the Kafue River and the Lukanga swamp and the area in between them.

[15] estimated the mean rainfall in the swamp at 952mm. This study found 994mm from rainfall interpolation with the 2000/2001 as wettest season at 1,379mm and the 1991/1992 as the driest with only 548mm of rain. From the simple arithmetic mean the mean rainfall in the swamps was found to be 879mm with the 2000/2001 as the wettest season at 1321mm and the 2001/2002 as the driest at 577mm of rainfall.

Acknowledgements

This study would not have been possible without the kind support from the University of Zambia and many others who assisted in one or another, materially or financially, physically or morally. You are all acknowledged individually and severally.

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