Determination of The Extent of Yala River Flood Flows in The Yala Basin , Kenya

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Abstract

In Kenya, hazards caused by river floods are a common phenomenon in most parts of the country. Areas of Kano plains in Kisumu County, Budalang`i in Busia County and Coastal areas are prone to floods. Flooding of the lower reaches of the Yala River has been occurring for a long time causing havoc in the basin. The basin has experienced loss of lives, destruction of property, outbreak of water borne diseases and siltation of arable lands that have followed flood events. In the recent past, the frequency and intensity of the floods has increased, partially attributed to climate change. The extent of Yala river flood flows, the damage they cause in the basin have not been known in order to propose proper mitigation measures. The lack of information on the flood extent has been due to difficult conditions to measure discharge in the lower Yala basin because of channel instability, high silt content and presence of weeds in the swamp. The main objective of the research was to carry out mapping of Yala river flood extent in the lower basin using Satellite imagery technique as a suitable alternative in obtaining information where traditional discharge measurement methods were not possible. The results show a change in the flood extent of about 34.2km^2 from 1984 to 2010. The mapped area extent resultsmay be used for future flood management planning in the basin. The quantification of the extent of flood waters in the basin is very critical for future water resources planning and design of infrastructure such as reservoirs upstream of Yala River. This research forms anew basis for research on the extent and impacts caused by the Yala river flood flows in the basin using satellite imagery analysis technique.

Keywords: flood extent, Satellite imagery, flood early warning, Yala River

1. INTRODUCTION

Flood is a natural phenomenon that occurs when the volume of water flowing in a system exceeds its total water holding capacity. United Nations defined flood as excess flowing or overflowing of water, especially overland which is not normally submerged (ESCAP/UN 1997). Floods have several sources such as: prolonged rain with considerable intensity, dam or dyke break, river blockages, storm surges, abnormally high tides and tidal waves or *tsunami* (Badilla, 2008)

Floods have occurred in the world throughout recorded history and as a natural phenomenon affect mankind and his/her activitiesparticularly the poor who lack resources to mitigate their effects (BIAB, 2007). There are many different types of floods, namely; coastal floods, giant tidal waves floods, flash floods, river (or fluvial) floods, urban floods, ponding (or pluvial flooding) from tsunamis and earthquakes or volcanic eruptions in the ocean (Xuan, 2006). Floods are natural hazards that regularly occur due to changes in climatic conditions and exacerbated by human activities as a result of environmental degradation. Floods become disasters when they interact with the society, and result in death and destruction of property, thus requiring outside assistance in order to cope.

Although natural factors are the main causes of floods, anthropogenic factors, such as occupation and settlements in the flood plains, extensive urbanization, basin-wide land-use changes, structural measures (flood levees and walls, cutting river meanders, river training) have modified the natural characteristics of extreme floods worldwide. Proper knowledge and information on extent of impact of flood is therefore necessary. When this information is poorly known, communities with a limited capacity to respond experience increased scale of devastation (Masibayi, 2011). Riverine floods are the most dominant floods in Kenya. River floods mostly occur along floodplains as a result of exceeded stream flow capacity leading to over spilling of the natural banks or artificial embankments (Smith and Ward, 1998). River floods affect both the rural and urban areas in form of flash and urban floods. Flash floods have a characteristic short duration and steep rises and rapid falls of flood levels. In Jamaica for instance, flash floods were experienced with insufficient lead time to effect adequate mitigative response in Cave River, Rio Cobre and Rio Grande Valleys (Errol, 2003). To mitigate the effects of these floods, information on the magnitude and extent of impacts was mapped out in order to develop a low cost early warning system. Therefore, national and county planning should have proper information on the magnitude and extent of impacts of floods in order to develop reliable intervention measures whenever floods occur. Floods in Yala river basin are caused by intense storms upstream (Nandi Hills) of the catchments that produce more runoff than the catchment can store or the main Yala river can carry within its normal channel (Kiluva, 2010).

Flood Mapping using Satellite Imagery

Flood mapping based on satellite image provides useful information for disaster monitoring and assessment (Stancalie *et al*., 2012). There are different methods used for obtaining useful products for flood risk mapping such as: land cover/land use maps, hydrographic network characteristics and water accumulation, maximum flood extent, flood area classification, flood evolution and flood damage assessment (Stancalie *et al*., 2012).

Huizinga *et al*. (2005) proved that methods for deriving the water level directly from combining observed flood maps and digital elevation models (DEM) are very sensitive to small errors in geo-referencing of the maps and local errors in the inundation.

Flood maps derived from satellite imagery data can play an important role for improved flood modeling and forecasting. For example, when no gauging stations are available, gauging stations fail or unforeseen events (such as dyke breaches) happen. Geo-referenced and classified satellite data can provide information on flood extent as well as water levels for large flooded areas (Barneveld *et al*., 2008). Satellite data may provide near real-time information on the flood event, better flood predictions, a tool to detect flood detention areas and improve management of rivers and their catchments (Barneveld *et al*., 2008).

In recent years, different remote sensing techniques have been used to detect water bodies and their characteristics (water extent, height, variability, vegetation cover and sediment load) (Leauthaud *et al*., 2012). Synthetic Aperture Radar imagery is very popular because of its high spatial resolution and its capacity of mapping water under thick vegetation. However, the radar signals change continuously due to wind induced waves, especially in the C-band, limiting the use of this band for water detection (Alsdorf *et al*., 2007). L-band data are limited by their low orbital repeat cycles, cost and limited archives. Passive microwave data have been used to detect flooded surfaces (Sippel *et al*., 1998; Ticehurst *et al*., 2009), but are limited by low spatial resolution.

Thermal satellite data have been used to map inundated areas (Leblanc *et al*., 2011). An alternative solution is the use of passive optical/infrared sensors on board the Landsat, Moderate-Resolution Imagery Spectroradiometer (MODIS) and SPOT satellites. Differences in the spectral signature of land and water covers are used to distinguish water bodies from other surfaces (Leauthaud *et al*., 2012).

Many Water Indices have been developed using different spectral bands and deferent satellite data (Gao, 1996; McFeeters, 1996; Rogers and Kearney, 2004; Xu, 2006). However, they don't always distinguish between flooded and non-flooded vegetation. Oliesak (2008) used the Modified Normalized Difference Water Index (Xu, 2006) to map the open water bodies in the Inner Niger Delta and the Normalized Difference Water Index of Gao (NDWIGao) (Gao, 1996) to include the vegetated water.

The Landsat image was used to examine the impacts of land use activities in Budalangi and Yala Swamp Area in Western Kenya. It focused on the assessment of the land cover/use trend in the study area by collection of data and documentation on the status of encroachment into the wetland areas and therefore the level of their degradation (Onywere*et al.*, 2011).

The Tana Inundation Model (TIM) was used to quantify essential hydrological variables of ecological importance for 2002–2011 such as flood extent and duration, flood timing and frequency, flood peaks and water height in Tana River Delta (TRD), Kenya. The TRD is characterized by scarce hydrological data and a high cloud cover limiting the use of many remote sensing techniques. The methodology therefore combined a conventional water-balance analysis with the extraction of inundation extents from MODIS satellite imagery at a medium spatial and temporal resolution (Leauthaud*et al*., 2012). Although, there is frequent flooding in Yala basin, there is no information on flood extent from the flood flows. Flood extent in Yala river basin was mapped using satellite imagery technique since there are no stable controls in the lower reaches of the basin due to low gradients in the swamp where water spreads beyond the main channel making gauging or installation of measuring devices like staff gauges and area surveying difficult. During flood periods it is impossible to measure area extent directly because of weeds, excessive widths and silt. As an alternative to capture the flood area extent, this research study extracted and analysed the flood extent using satellite images for the years 1984,1990, 2000 and 2010. The Landsat images for 1980 could not be used due to poor resolution; hence 1984 data sets were used. The years were chosen to cover a period of at least 27 years to study change. This situation has created a gap in data collection, flow quantification and area surveying hence requiring use of Satellite imagery technique.

2. MATERIALS AND METHODS

2.1. Study area

This study focused on the Yala River Basin. Yala basin is located within Lake Victoria North Catchment in Kenya. The catchment is centered about 35^{o} E, 0.1^{o} N (Githui *et al*., 2005). The basin is divided into three zones; the upper, middle and lower based on regular gauging stations at the outlet of each sub-catchment. The upper catchment falls in Nandi County, middle catchment falls in Kakamega and Vihiga counties of Western region and the lower catchment is found in Siaya County in Nyanza region.

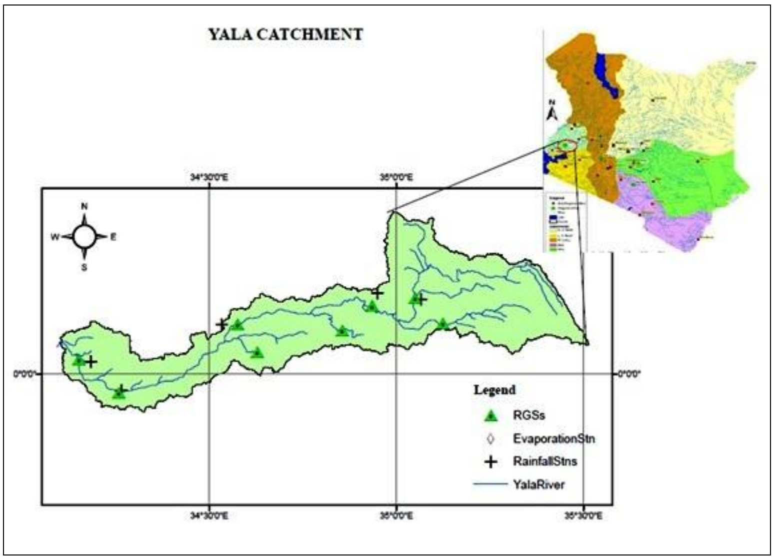


Figure 1: Map of Yala catchment in Western Kenya (Source: Researcher, 2014)

This study applied the use of satellite imagery technique to generate results of the flood extent for the years, 1984,1990,2000 and 2010.The Landsat images that were available for the year 1980 were of poor quality due to high cloud cover hence the 1984 data sets were used. Satellite imagery data was obtained from the Regional Centre for Mapping of Resources for Development (RCMRD) for the years 1984, 1990, 2000 and 2010. The LANDSAT images of TIFF format were sourced courtesy of U.S. Geological Survey, (http://eros.usgs.gov/products/satellite) with a resolution of 30mx30m.

2.2. Satellite Imagery Analysis

Multi-temporal LANDSAT Thematic Mapper satellite imagery was used to detect, delineate and map land cover change on lower Yala basin and its surrounding. The data was extracted, composed and developed into maximum likelihoods for determination of Yala flood extent. Emphasis was laid on; the extent of water mass on the land surface with time and changes in land area with time. The LANDSAT images obtained were clipped using lower Yala shape file in ArcGIS 10.1.

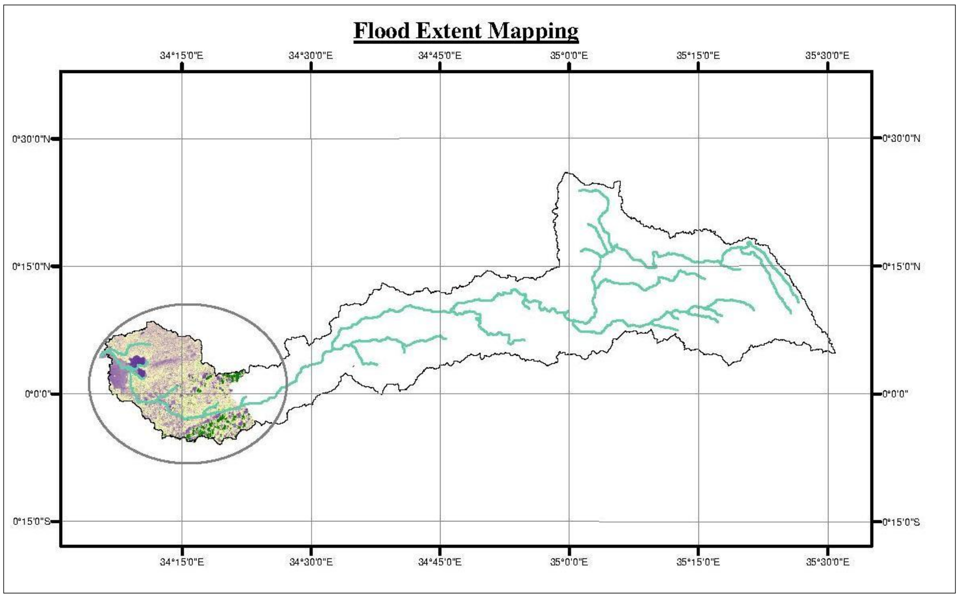


Figure 2: Circled part represents the Lower Yala used for Flood Extent Mapping

The resulting clipped images were loaded onto Adobe Photoshop software platform where they were rectified to improve the resolution and to separate colour bands along the river Yala channel. The images were then loaded back to ArcGIS platform where training samples were then created and grouped to either land or water for each of the images and their respective signature files saved. Maximum likelihood classification Method of Extraction was used according to the analysis procedure. Data on coverage area for each criteria of classification was obtained from the properties of the respective layers that gave the count of the number of cells and areas for each classification criteria (land or water) Maximum likelihood classification was carried out using the respective saved signature files and the results are as presented below. The methodology that was adopted is as shown below.

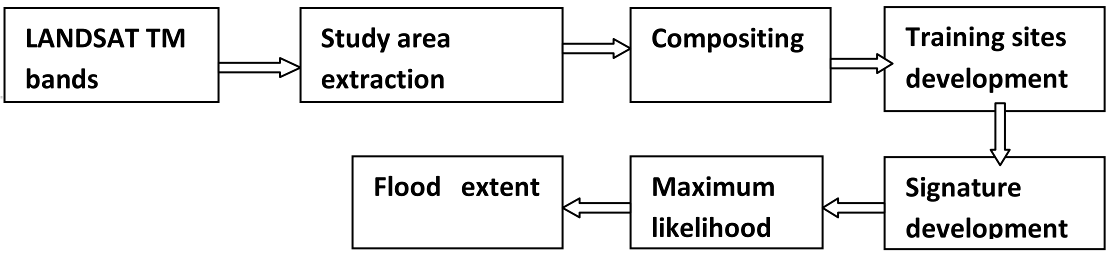


Figure 3: Methodology adopted

3. RESUL TS AND DISCUSSIONS

Land cover and water mass classes were mapped around lower Yala basin from the LANDSAT images. The flood extent extracted using the satellite imagery technique for the middle and lower sub-catchments covering an area of 1725km^2 that were considered for flood extent. An 8-bit false colour composite image (Figure 4) and flood extent maps of Yala basin were developed.

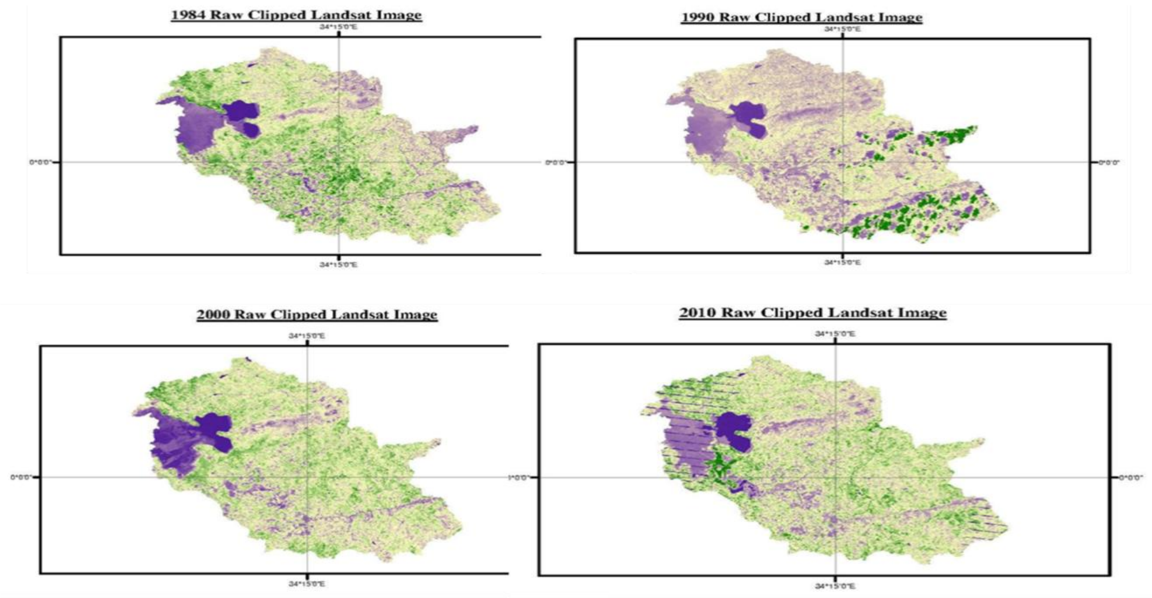
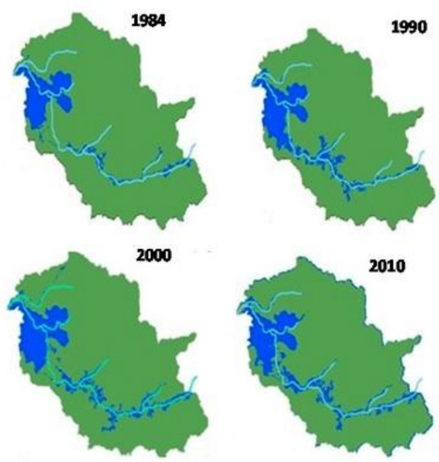


Figure 4: Flood extent mapping for selected years



Legend

	Color	Area(sq Km)				%age			
		1984	1990	2000	2010	1984	1990	2000	2010
Land		**528.85**	507.29	505.09	494.74	91%	87%	87%	85%
Water		52.54	74.13	76.33	86.77	9%	13%	13%	15%

Figure 5: Flood Extent Maps

Flood extent maps for the years, 1984, 1990, 2000 and 2010 (Figure 5) were generated to indicate changes in water mass and land cover changes.

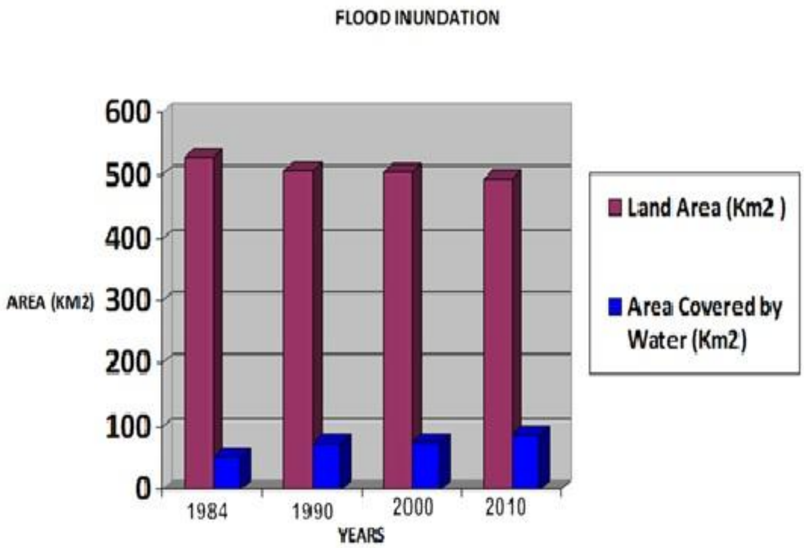


Figure 6: Variation in Flood Extent for the years 1984, 1990, 2000 and 2010

Variation in flood extent in the lower Yala basin has gradually increased in the past 27 years. The land area covered by the floods has increased by 34.23km^2 for the period between 1984 and 2010. The study noted that there is a strong correlation between water rise at 1FG03 and the extent of the floods as indicated by R2 (85%) as shown in Table 1 and Figure 7.

Table 1: Change in flood extent vis a vis water levels for base year (1984) at 1FG03

Satellite imagery dates	Water Level at 1FG03	Area cover by water	Change in water level at 1FG03	Change in Flood Extent Area
09/08/84	3.09	52.54	0	0
07/02/90	3.32	74.13	0.23	21.59
06/03/00	3.5	76.33	0.41	23.79
29/01/2010	3.89	86.77	0.8	34.23

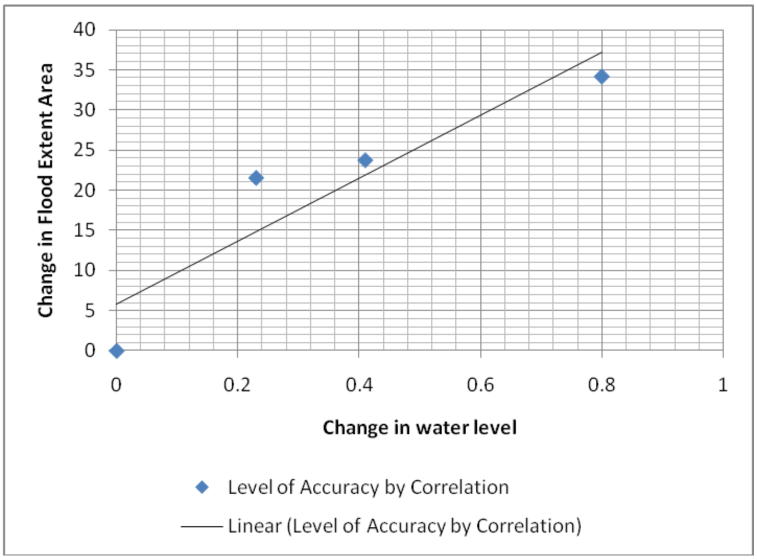


Figure 7: Correlation of flood extent with water level rise at 1 FG03

The overall inundation extent results from the satellite imagery are similar to remote sensing estimates from *Papa et al.* (2010) showing the seasonal variation of flood extent in Yala basin. This scenario is likely to continue based on the climate change projection in the western parts of Kenya (USGS, 2010) and human activities being carried out in the basin. With a population of 100 persons per square kilometer near the Lake Victoria area (KNBS, 2009), about 3,400 persons have been affected by the change. These people experience loss of lives, destruction of property, and outbreak of water borne diseases. The extent of Yala river flood flows has a significant impact in the basin requiring proper planning by government and other agencies to mitigate the vise

4. CONCLUSION

The extent of Yala river flood flows has a significant impact on the community in lower basin and future urban planning long beaches to develop resorts and tourist attractions. The mapped out flood extent change (34.23 km2) should therefore be planned for through appropriate flood intervention measures upstream of the Yala catchment to mitigate against potential urban development by Siaya county Government that is seeking increased in investment in hotel industry to attract tourism. The Yala Basin is important environmentally and economically and acts as a buffer to Lake Victoria in terms of sediment loading into the lake. More attention should therefore be given to the monitoring of water discharges upstream to mitigate against the flood area extent that give indication on the deteriorating health status of the basin in terms of water management.

4.1. Recommendations

From the foregone discussion, the following recommendations to improve flood extent mapping for management of Yala flood flows are advanced:

i. The performance of the developed flood extent maps to be enhanced through intensified real time data collection to complement Satellite imagery. This will assist to increase the lead time between the initial sensing of flooding and the moment of impact.
ii. The scope of the study was limited to seeking to determine the flood extent in the Yala river basin for more focus. However, to optimize interventions aimed at reducing the risk to flooding including investments to enhance lead agencies interventions, the socio-economic contributions caused by Yala flood flow extent on the affected community should be investigated through similar extensive research.

5. REFERENCES

1. Alsdorf, D. E., Rodriguez, E., and Lettenmaier, D. P. (2007), *Measuring surface water from space*, Rev. Geophys., 45, RG2002, doi: 10.1029/2006RG000197, 2007. 11272
2. Badilla A R,(2008) : *Flood modelling in Pasig- Marikina River basin*. International Institute for Geoinformation Science and Earth Observation ESCHEDE, Netherlands.
3. Barneveld H. J, Silander J. T, Sane M, and Malnes E, (2008), *Application of Satellite data for improved Flood Forecasting and Mapping*. 4th International Symposium on flood Defence. Managing Flood Risk, Reliability and Vulnerability, Toronto, Ontario, Canada.
4. Errol D, (2003),*Institutional challenges of flood warning systems in Jamaica* unisdr.www.unisdr.org/Errol-Douglas.doc
5. ESCAP/UN, (1997), *Guidelines and Manual on land use planning and practices in Watershed Management and Disaster Reduction*.
6. Gao, B., (1996),*NDWI – a normalized difference water index for remote sensing of vegetation liquid water from space*, Remote Sens. Environ., 58, 257–266, doi:10.1016/S0034-4257(96)00067-3. 11273, 11313
7. Huizinga H.J., H.J. Barneveld, C.J.M. Vermeulen, I. Solheim and S. Solbø (2005), *On-line flood mapping using space borne SAR-images, water level deduction techniques and GIS-based flooding models in the river Rhine*. ISFD-Conference, Nijmegen, the Netherlands.
8. Kiluva V.M, Mutua F.M , Makhanu S.K and Ong'or B.T.I, (2010),*Rainfall runoff modeling in Yala River basin of Western Kenya*. Journal of meteorology and related sciences, vol 5.
9. Leauthaud C., Duvail S., Belaud G., Moussa R, Gr¨unberger O, and Albergel1 J .,(2012),*Floods and wetlands: combining a water-balance model and remote-sensing techniques to characterize*

hydrological processes of ecological importance in the Tana River Delta (Kenya). Hydrol. Earth Syst. Sci.

10. Masibayi E.N., (2011), *Hydrologic and Hydraulic Flood Forecasting for Nzoia River Basin, in Western Kenya*. Doctor of Phylosophy thesis. Pp 131
11. McFeeters, S., (1996), *The use of the normalized difference water index (NDWI) in the delineation of open water features*, Int. J. Remote Sens., 1425–1432.
12. Onywere, S M, Gitenga Z.M, Shadrack S. Mwakalila,S.S.Twesigye, C, and Nakiranda, JK.., (2011) : *Assessing the Challenge of Settlement in Budalangi and Yala Swamp Area in Western Kenya Using Landsat Satellite Imagery*. The Open Environmental Engineering Journal.
13. Sippel, S., Hamilton, S., Melack, J., and Novo, E., (1998), *Passive microwave observations of inundation area and the area/stage relation in the Amazon River floodplain*. Int. J. Remote Sens., 19, 3055–3074, doi:10.1080/014311698214181. 11272
14. Stancalie,G, Graciunescu,V., Nertan, A., Mihailescu,D., (2012),*Contribution of satellite data to flood risk mapping in Romania*. Geoscience and Remote Sensing Symposium (IGARSS),IEEE International.
15. Ticehurst, C. J., Dyce, P., and Guerschman, J. P., (2009),*Using passive microwave and optical remote sensing to monitor flood inundation in support of hydrologic modelling*, in: 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation With Mathematical and Computational Sciences, edited by: Anderssen, R., Braddock, R., and Newham, L., Australia, combined IMACS World Congress/Modelling and Simulation Society-of-Australia-and-New-Zealand (MSSANZ)/18th20 Biennial Conference on Modelling and Simulation, Cairns, Australia, 3747– 375. 11272
16. USGS, (2010), *Famine Early Warning Systems Network - Informing Climate Change Adaptation Series.* A Climate Trend Analysis of Kenya—August 2010. Fact Sheet 2010–3074 August 2010
17. Xu, H., (2006), *Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery*, Int. J. Remote Sens., 27, 3025–3033. 11273
18. Xuan, S.P. (2006), *Flood Control Measures in River Red Delta, The new Country Side*, Journal: (Tap ChI Nong Thon Moi) Issue 178: 3-4.