Evaluating Land Cover Change and its Impact on Hydrological Regime in Upper Shire River Catchment, Malawi

Lobina Palamuleni* [a], Prediskas M. Ndomba [b] and Harold Annegarn [c]

a) North West University, Mafikeng Campus, Department of Geography and Environmental Sciences, P/Bag 2046, Mmabatho, South Africa, 2735. lobina.palamuleni@nwu.ac.za
b) University of Dar es Salaam, Department of Water Resources Engineering, P.O. Box 35131, Dar es Salaam, Tanzania.
c) University of Johannesburg, Department of Geography, Kingsway Campus, P.O. Box 524, Auckland Park, 2006, South Africa.

ABSTRACT

A study was conducted to investigate hydrological impacts of land cover changes in the degradation of the hydrological on flow regimes of the Upper Shire River, Malawi. Remote sensing techniques were used to inventory temporal changes of land-cover changes in the catchment. The study revealed significant changes in magnitude and direction that have occurred in the catchment between 1989 and 2002, mainly in areas of human habitation. Trends in land cover change in the upper Shire River catchment depict land cover transition from woodlands to mostly cultivated/grazing and built-up areas. The land cover mapping showed that 23% of the land was covered by agricultural land in 1989. Subsistence agricultural area has increased by 18%, occupying 41% of the study area in 2002. The effects of the derived land cover changes on river flow in the Upper Shire River were investigated using the semi distributed Soil and Water Assessment Tool (SWAT) Model. River flows were found to be highly variable and sensitive to land-cover changes. Simulation results show that 2002 land cover data produces higher flood peaks and faster travel times compared to the 1989 land cover data. The changes detected indicate the effects of land use pressure in the catchment. The study highlights the importance of considering effects of land-use and land-cover changes on ecosystems and water resources for an informed decision on proper catchment planning and management.

*Corresponding author: lobina.palamuleni@nwu.ac.za

Key words: Hydrological regimes, Shire River, land cover change, subsistence agriculture, mass curves

INTRODUCTION

Recent studies in the Southern African region have revealed that climatic and land cover changes threaten to undermine the integrity of riverine habitats, the availability and quality of water, and agricultural productivity (IPCC 2008; IPCC 2001). The region has experienced floods and severe episodes of prolonged droughts in other places. With increasing human activities vis-à-vis water conflicts, it is important to understand the interactions between hydrological regimes and associated land use and land cover changes in catchments (Rockström et al. 2002). Such an understanding can be achieved by integrating land use planning and water resources management. Land cover and land cover change data represents a key variable in the management and understanding of the environment, as well as driving many environmental models such as hydrological models within large river basins or even for particular smaller catchments.

It has been widely accepted that climate change and human activities have imposed great impacts on the hydrological processes and water resources of basins (Schulze 2000, Stohlgren et al. 1998). Climate change is associated with rising temperatures and the increased frequency of extreme weather events such as droughts, floods and tropical cyclones (Arnell and Reynard 1996). Land use and climate changes may have both immediate and long-lasting impacts on terrestrial hydrology, altering the balance between rainfall and evapotranspiration and the resultant runoff. Changes in these hydrological variables may have implications for both large scale and local climatic characteristics. At the larger scale typified by orographic features such as mountains and valleys, topographic variation directly affects precipitation and surface temperature. At a smaller scale, topographic variation can modify surface and subsurface run-off through down-slope redistribution of soil water (Calder 2002).

In the short-term, destructive land cover change may disrupt the hydrological cycle either through increasing the water yield or through diminishing, or even eliminating the low flow in some circumstances (Croke et al. 2004). Ground disturbance not only affects the flow rates in the surface layers but subsurface as well. Thus, the subsoil flow rates under forests are greater than under other types of vegetation. However, once the ground has been disturbed, especially if the native organic matter is removed, the flow rates of the subsurface material decrease irrespective of the overlying vegetation. A study by Bonell et al. 2010 revealed that degraded forest shows a decline in saturated hydraulic conductivity at the surface as result of human impacts at decadal to century time scales.

The growing anthropogenic pressure on natural forest ecosystems disrupts the horizontal flux of air and water vapor from areas with weaker evaporation to areas with stronger evaporation. A reduced natural forest ecosystem simultaneously reduces leaf area index and evaporation from open water surface. Makarieva et al. 2007 suggests that water evapotranspired by forests is typically returned with interest, so one would expect a decline in rainfall, leading to lower runoff over a wider region, if forests are depleted. Thus, land use changes in a catchment can affect water supply by altering hydrological processes such as infiltration, groundwater recharge, baseflow and runoff (Lin et al. 2007).

A number of studies showed that changes in vegetation cover i.e., afforestation or deforestation lead to reduction or increase in water yield and such changes have been observed in catchments with different area ranging from less than 1 km^2 to over 1000 km^2 (Schulze 2000, Fohrer et al., 2001; Zhang et al., 2001 ; Brown et al., 2005). Tadele et.al (2007) reported an increase of mean monthly discharge for wet months by 12.5% while in the dry season a decrease of up to 30.5% during the 1992 – 2004. These changes in streamflow were particularly caused by the change to the forest cover to farmlands and settlements for the 182km^2 Hare River watershed, Southern Rift Valley Lakes Basin, Ethiopia. Costa et al. (2003) showed results from large-scale catchments (the upper Tocantins basin, 175 360 km^2) agree with the deforestation effects on streamflow from small catchments. Githui (2008) examined historical land use change and climate change in a large river basin in Kenya (Nzoia River, 12,709 km^2). The study revealed that without climate change, land cover changes would account for a difference in runoff of about 55-68%. On the other hand, change in climate without land cover change accounted for a difference in runoff of about 30- 41%. These separate effects of climate and land cover change can be further compared to the simultaneous effect of climate and land cover changes to reveal how interactions of climate and land cover may produce different impact on stream discharge of a catchment (Hu et al. 2005).

In Malawi, as in many other countries, the landscape is continually changing under the influence of several factors such as demographic trends, climatic variability, national policies, and macroeconomic activities. Land cover changes over the last two decades have adversely affected the condition of water resources in the upper Shire River sub-catchment, Malawi. Within the

Shire River catchment - two factors are the major driving forces: human population increases and rainfall variability (Malawi Government 1998). The high population growth has translated into rapidly increasing demands from land in terms of food, shelter, energy (fuelwood) and construction materials. Agricultural crops now replace some of the woodlands, while the grass-covered dambos have been either overgrazed or cultivated and are now bare. This trend is most likely to continue as evidenced by current agricultural practices and population growth[1] (National Statistical Office 2008). The modifications of natural vegetation cover and soil conditions usually lead to changes in rainfall-runoff characteristics of the catchment which consequently change the river flow regimes. Major environmental changes resulting from the catchment surface modifications observed in Shire River include high peak stream flows, reduced base flows, enlarged river channel, and silt build-up along the riverbed. The potential to predict the effects of land cover changes is very important for future use and management strategies in the Shire River catchment. The current study sought to quantify the magnitude and the pattern of land cover changes that have occurred over time. The effects of the derived land cover changes on river flow in the Shire River were investigated using the semi distributed Soil and Water Assessment Tool model (Arnold et al 1995).

Description of the study area

The Shire River lies in the southern part of the Great East African Rift Valley system and is the outlet of Lake Malawi. The river flows approximately 400 km from Mangochi on the southern extremity of Lake Malawi, to Ziu Ziu in Mozambique at the confluence with the Zambezi River. The entire Shire River catchment area is ~18,000 km^2 and consists of the upper, middle and lower sections. The Upper Shire River catchment is between Mangochi and Matope, with a total channel bed drop of about 15 m over a distance of 130 km. The river flows through Lake Malombe, which is 1.8 m below Lake Malawi, (Malawi Institute of Education 2001). The focus

---

[1] Over the last three decades, population density in the Southern Region of Malawi (Shire River catchment located within this region) has shown an upward trend. The population density is given as 139 people km^{-2}, 105 people km^{-2}, and 85 people km^{-2} in the period 2008, 1998 and 1987, respectively.

of this study is the uppermost reach from Mangochi to Liwonde, which is almost flat at 465 – 600 m above mean sea level over a distance of 87 km. It forms a catchment area of ~4,500 km^2, located between latitudes 14° 20' S; 15° 12' S and longitudes 34° 59' E; 35° 30' E (Figure 1).

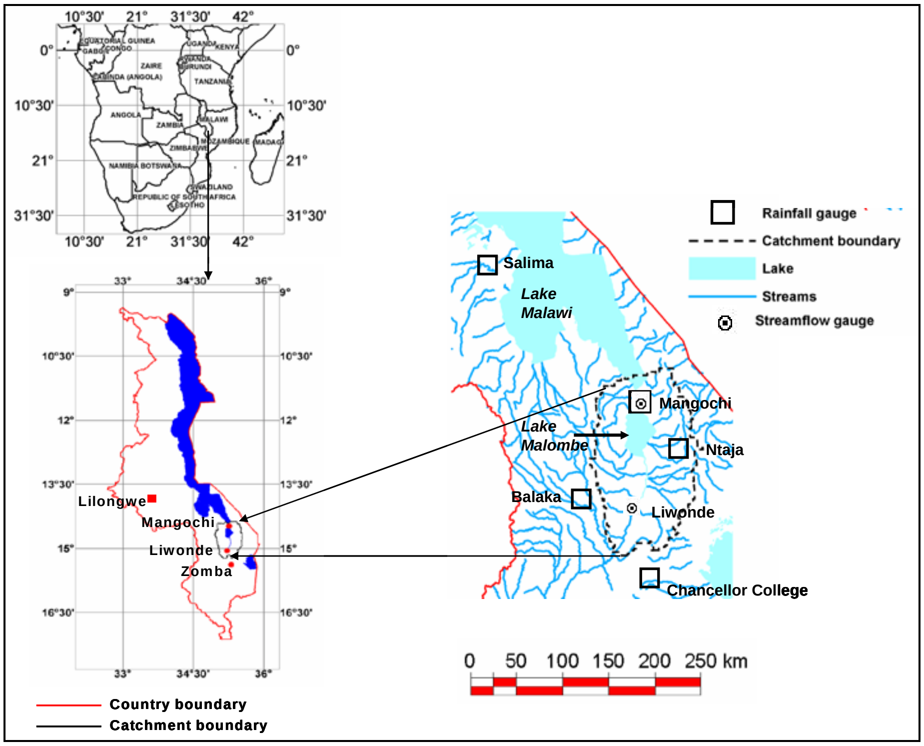

Figure 1: Location of the Upper Shire River Catchment in Malawi

The dominant vegetation in the study area is *mopane woodland,* which varies in density from tall open woodland to dense scrub. *Mopane woodlands* may form pure stands excluding other species, but are generally associated with several other prominent trees and shrubs such as *Kirkia acuminata, Dalbergia melanoxylon, Adansonia digitata*, *Combretum apiculatum, C. imberbe, Acacia nigrescens, Cissus cornifolia,* and *Commiphora* spp. Within the Shire highlands and the slopes along the catchment, lowland forest and *Brachystegia* woodland are found. Tall grasses are associated with low altitude woodland. For most rural communities, the woodlands are a primary source of energy in the form of fuelwood and charcoal and a crucial source of essential subsistence goods (Dewees, 1994; Morris, 1995). Households rely on woodlands to supplement their food supply through the collection of wild food plants, bushmeat, nuts, leaves and roots.

People living in towns and cities throughout the *Miombo* eco-region also depend on food, fibre, fuelwood and charcoal from miombo woodlands (Bradley and McNamara, 1993; Dewees, 1994). In addition, woodlands have an ecological role in controlling soil erosion, providing shade, modifying hydrological cycles and maintaining soil fertility (Desanker et al. 1997).

MATERIALS AND METHODS

Data Availability

Mapping of land cover change utilized available 30 m grid spatial resolution snapshots of Landsat TM and ETM, for the years 1989 and 2002, respectively. Image preprocessing was carried out using techniques described in Jensen (2005), and Lillesand et al. (2004). The topography of Shire catchment was mapped from the recently released Shuttle Radar Topography Mission (SRTM) data (USGS, 2006). Soils data were extracted and computed from the UN/FAO Digital Soil Map of the World Soil Map (scale: 1:1000000) (FAO/UNESCO 2003). Daily discharge readings of the Shire River at two stations were obtained from the Hydrology Department of the Ministry of Water Resources of Malawi for the period 1976-2006. There are only two flow-gauging stations on the Shire River within the study area, one at the inlet to the valley at Mangochi (1T1), and one at Liwonde (1B1), taken as the outlet (Figure 1).

Climatic input data (including daily precipitation, maximum/minimum air temperature, wind speed, and relative humidity) were collected from meteorological office based on their spatial distribution in the study catchment (Table 1, Figure 1). The macroclimate is characterized by a unimodal rainy season, where rainfall starts in October and end in April of the following year, reaching a peak between December and February. Rainfall distribution during the rainy season is variable, depending on the interplay between tropical and mid-latitude weather systems and convective variability. There are variations in the amount of rain, its onset, duration and intensity during the wet season. The annual average rainfall is 950 mm a^{-1}, with a standard deviation 274 mm a^{-1}. Significant features of the inter-annual variability in southern African seasonal rains are linked to the El Niño Southern Oscillation (ENSO). ENSO can manifest as either El Niño or La Niña episodes, associated with warm and cool sea surface temperatures respectively in the tropical Pacific. The inter-seasonal variability observed in Figure 2 for the years: 1988/89 and 2001/02 were associated with La Nina episodes depicting early onset of rains, all of which started in October. All the stations recorded rains above 100 mm in January and February. Total annual rainfall varied from average to wet. Above average annual total rainfalls of > 1 100 mm were recorded for 1988/89 and 2001/02. The graphical representation makes it clear that rainfall continued up to the end of April and beginning of May at all the stations. The stations that had missing data were filled using 'mean' method provided by the Excel spreadsheet. To show the rainfall and runoff pattern in the study area, the cumulative annual rainfall amounts and runoff volumes for the period 1977-2006 were plotted.

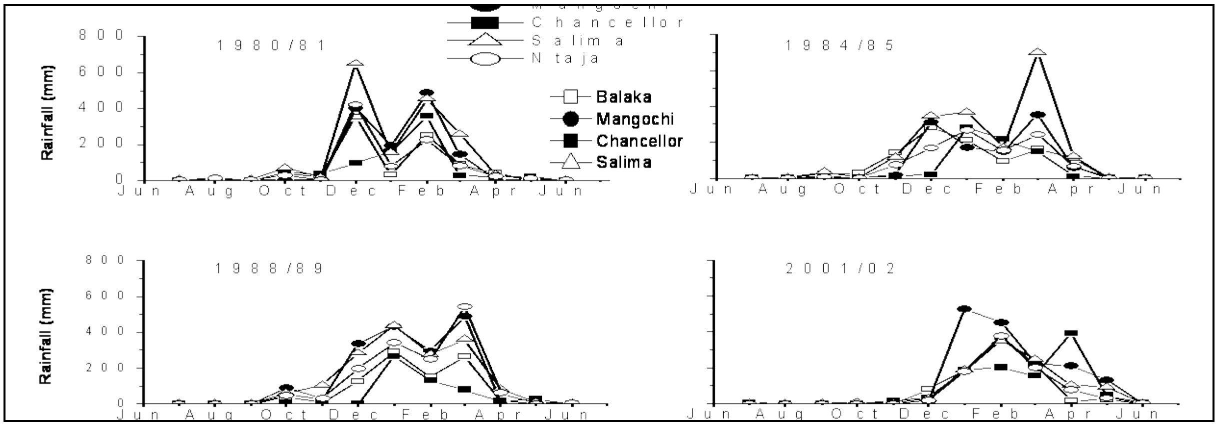

Figure 2: Rainfall variability in the Shire River catchment – 1988/89 and 2001/02 season (Data from the Department of Meteorology, Malawi)

Land Cover change mapping

The mapping of land use and land cover change over time began with mapping the 2002 satellite imagery, then looking back into history to map the 1989 satellite imagery. The image dates used were 1 July 1989 and 25 May 2002. Within the constraints of a limited number of suitable images in archive, a strategy for selecting Landsat imagery for development of land cover database for the Upper Shire River catchment was governed by cost-free available multi-temporal images, vegetation phenology and image quality (cloudiness, haze) (Palamuleni 2009). Besides, both images preceded La Nina episodes and the effects of differences in acquisition time were therefore acceptable (SADC: Drought Monitoring Centre 2004). As such, vegetation characteristics appeared comparable since similar rainfall conditions preceded both images. Supervised maximum likelihood digital image processing was employed by defining training sites, on the image, which are representative of each desired land cover category (Jensen, 2005).

Land Cover Reclassification

The derived land cover datasets were reclassified and adjusted to the SWAT land cover classification format so that the response coefficients used to compute excess precipitation could be associated (Table 1).

Table 1: Reclassification and association of derived land cover classes

LCCS Classification	SWAT Land/Plant cover classes	Interception (mm/hr)	Canopy (%)
Fresh water	Water	0.000	0.00
Built-up areas	Residential medium density	2.500	70
Cultivated/grazing	Agricultural Land Generic	0.500	10
Marshes	Wetland	2.000	50
Grasslands	Pasture	1.150	80
Savanna shrubs	Rangeland range brush	3.000	30
Woody open	Forest mixed	1.150	15
Wood closed	Forest Deciduous	1.150	65

The Soil and Water Assessment Tool Hydrologic Model

The Soil and Water Assessment Tool is a physically based semi-distributed geospatial hydrologic model. It operates as an extension within ArcView 3.2 and therefore requires data in GIS formats. The model uses remote sensed and ground observation data (soil, land cover, rainfall and evaporation), and digital elevation data sets describing the land surface to calculate the basin hydrologic water cycle (Arnold et al. 2005). It provides a continuous simulation of stream flow, on a daily time step. The model consists of two parts: a GIS-based module used for model data input and preparation, and the rainfall-runoff processing module.

Calibrating and validating the model

Geographic information system (GIS) data for topography, soils and land-cover were used in the AVSWAT, an ArcView-GIS interface for the SWAT model (Di Luzio et al. 2001). A Digital Elevation Model (DEM) defined the topography of catchment. The generated stream flow is routed down the stream, guided by the terrain of the basin as defined by the DEM data. The soil data is required by the SWAT to define soil characteristics and attributes. The land-cover data provides vegetation information on ground and their ecological processes in lands and soils. Two simulations were made for the catchment, one with the 1989 land cover data and the other with the 2002 land cover data. The catchment was divided into several sub-basins based on the DEM, stream network and outlets, and each sub-basin was split into several Hydrological Response Units (HRUs) based on the land-cover and soil data. Annual and monthly stream flows were simulated from 1977 to 1981 using the SWAT model.

Observed daily rainfall and temperature data were needed to simulate streamflow, which was compared with the observed streamflow during calibration and validation processes. The calibration and validation was done at Liwonde gauging station (Figure 1). Calibration was done manually by varying the models most sensitive parameters. The sensitive model parameters are SCS run-off curve number (CN2), Soil evaporation compensation factor (ESCO), Soil available water capacity (SOL_AWC), Soil depth (SOL_Z), Surface run-off lag time (SURLAG), Saturated hydraulic conductivity (SOL_K), Baseflow alpha factor (ALPHA_BF) and Ground water “revap” coefficient (GW_REVAP) (Palamuleni, 2009). Each parameter was varied while holding the other parameters constant until the highest correlation between the simulated and observed was obtained. Care was taken when varying the parameters to make sure that the final basin parameters were within actual ranges. The resulting streamflow was compared with observed values qualitatively and quantitatively using plots and coefficient of determination, R^2, respectively.

Effects of Land Cover change on River Streamflow.

The objectives of the study were to identify the change of land cover pattern in two periods, 1980’s and 2000’s through two land cover maps for the years 1989 and 2002 representing each period, then to examine the effects of that change on rainfall-runoff relationships. The SWAT model was run separately with the reclassified land cover datasets (Table 1) of 1989 and 2002 as the only variables. Rainfall and evaporation data of five years 1977-1981 was used during the simulation. Rainfall, evaporation, and soils data sets were kept constant for the 1989 and 2002 land cover runs to eliminate their effects on the streamflow. The two simulated hydrographs were compared using daily values, monthly and annual means.

In addition, this study used double mass curve analysis to examine the effect of land-use changes on rainfall-runoff in the Upper Shire River sub-Catchment. The double mass curve is a useful method for detecting non-homogeneities in a record. The most significant information that a break in slope provides is an estimate of the time at which a change occurred (Searcy and Hardison 1960). A double mass curve is a plot of cumulative values of one variable against the cumulation of another quantity during the same time period (Searcy and Hardison 1960). The theory behind double mass curves is that by plotting the cumulation of two quantities the data will plot as a straight line, and the slope of this line will represent the constant of proportionality between the two quantities. A break in slope indicates a change in the constant of proportionality (Searcy and Hardison 1960).

Even though the double mass analysis is typically performed on precipitation data, this type of analysis can be performed on many types of hydraulic and hydrological data such as sediment transport (Hindall 1991), reservoir sedimentation (Yang et al. 2002), and effect of land cover change on runoff (Zhao 2004).

To perform the double mass curve analysis, the procedure involved plotting of successive cumulative annual rainfall collected with the cumulative annual runoff. Time-series of cumulative surface runoff as simulated using 1989 and 2002 land cover data were plotted. The change in the proportionality between the measurements on the periods of 1980’s and 2000’s are reflected in a change in the slope of the trend of plotted points. Divergence from a straight-line indicates a possible link to land cover changes.

RESULTS

Classification of land cover in the Upper Shire River catchment categorised eight major groups namely: woody closed, woody open, savanna shrubs, grasslands, marshes, cultivated or grazing areas, built-up areas and fresh water. The maps in Figure 3 indicate the land cover in the Upper Shire River catchment in 1989 and 2002.

Figure 3: Land cover maps - 1989 and 2002

Classification accuracy assessment and field verification

Based on the ground truth observations and the classification, the error matrix in Table 3 was constructed. A total of 228 reference samples were used for the calculation of the error matrix. The overall classification accuracy achieved for all land-cover classes was 87% and the overall kappa statistic was 0.8467. Besides, all user's and producer's accuracy for all classes were much higher than 77 %. These results generally suggest that a good agreement exists between the classification and the actual land-cover categories with few misclassifications occurring across nearly all categories. Within classes, the greatest accuracy occurred in grasslands and water.

Table 2: Error matrix of land cover classes

	Ground truth data									
Classification	**Fresh water**	**Built-up areas**	**Cultivated /grazing**	**Marshes**	**Grass-lands**	**Savanna shrubs**	**Woody open**	**Woody closed**	**TR**	**User's accuracy (%)**
Fresh water	11	0	0	0	0	0	0	0	11	100.0
Built-up areas	0	20	5	0	0	0	1	0	26	76.9
Cultivated /grazing	0	2	40	0	1	2	5	1	51	78.4
Marshes	0	2	0	23	0	0	0	0	25	92.0
Grasslands	0	0	0	0	29	0	0	0	100	100.0
Savanna shrubs	0	0	0	0	0	20	2	0	22	90.9
Woody open	0	0	1	6	0	0	31	1	39	79.5
Woody closed	0	0	0	1	0	0	0	24	25	96.0

TC	11	24	46	30	30	22	39	26	228
Producer's accuracy (%)	100	83.3	87	76.7	96.7	90.9	79.5	92.3	

where TD = sum of major diagonal, TC = column totals, TR = row totals. The overall classification accuracy was TD/TR (198/228) = 87%. kappa statistic = 0.8467

The decline of forest has been enormous and the cultivated area was increased. The area of the catchment covered by each land cover type for 1989 and 2002 are shown in Table 4.

There are significant increases in the spatial extent of grasslands, cultivated or grazing areas, and built up areas; while savanna shrubs, woody open and woody closed areas decreased in extent. Between 1989 and 2002 there has been a decrease in closed forests of 52%. Rapid increasing demands from forest resources for food, shelter, energy (fuel-wood) and construction materials contributed to the decrease in woodlands. The clearing of closed woodlands has resulted in an increase in cultivated/grazing lands and built-up areas by 23% and 177% respectively. While the increase in grassland could be attributed to grass thriving best in areas previously occupied by woody closed forests.

Table 3: Land cover changes of the Upper Shire sub-Catchment

Class	1989		2002		Change 1989-2002	Change %
	Area (ha)	%	Area (ha)	%		
Fresh water	38 353	8	37 178	8	-1 175	-33
Built-up areas	14 326	3	39 813	9	25 487	+ 177
Cultivated/graz	95 428	21	117 071	26	21 643	+23
Marshes	6 444	1	29 490	7	23 046	+358
Grasslands	15 127	3	63 664	14	48 537	+321
Savanna shrubs	178 034	39	112 356	25	-65 678	-37
Woody open	70 612	16	38 446	8	-32 166	-46
Woody closed	37 930	8	18 480	4	-19 450	-52
Total	456 498	100	456 498	100		

The clearing of natural vegetation and the increase in agriculture has resulted in severe soil erosion in the catchment. Sediment deposition over the years in water bodies has reduced their area extent by 33%. The deposition of sediments has caused a rise in elevation of the river channel resulting in riverbank backflow during rain seasons. The overflowing water, rich in nutrient sediments originating from high fertiliser runoff from agricultural areas has led to an increase of the catchments' marshlands by 358% (Malawi Government, 2006).

The SWAT Model runoff component was calibrated for a period of five years, from 1977 – 1981. The R^2 and values obtained for monthly and daily calibrations were 0.83 (p-value =0.05; n= 60) and 0.65, respectively (p-value =0.05; n= 1808). The model accurately captured the hydrograph rising limbs and peaks but was unable to capture the recession limbs and low flows. Validation was done for 2 years from 1984 to 1985. Similar behaviour of the generated hydrograph as for calibrations was observed. For the monthly and daily, the R^2 was 0.72 and 0.63, (p-value =0.05; n= 24) and 0.65, respectively (p-value =0.05; n= 731). respectively.

Effects of Land Cover change on Streamflow.

Mass curves analysis: Figure 4 represents the relationship between cumulative precipitation and cumulative runoff for the period of study 1977-2006. Each curve exhibits the same general relationship with similar slopes in the early years but variations in the latter portions of the record. Variations in the slope are noted for the seasonal dry and wet rainfall.

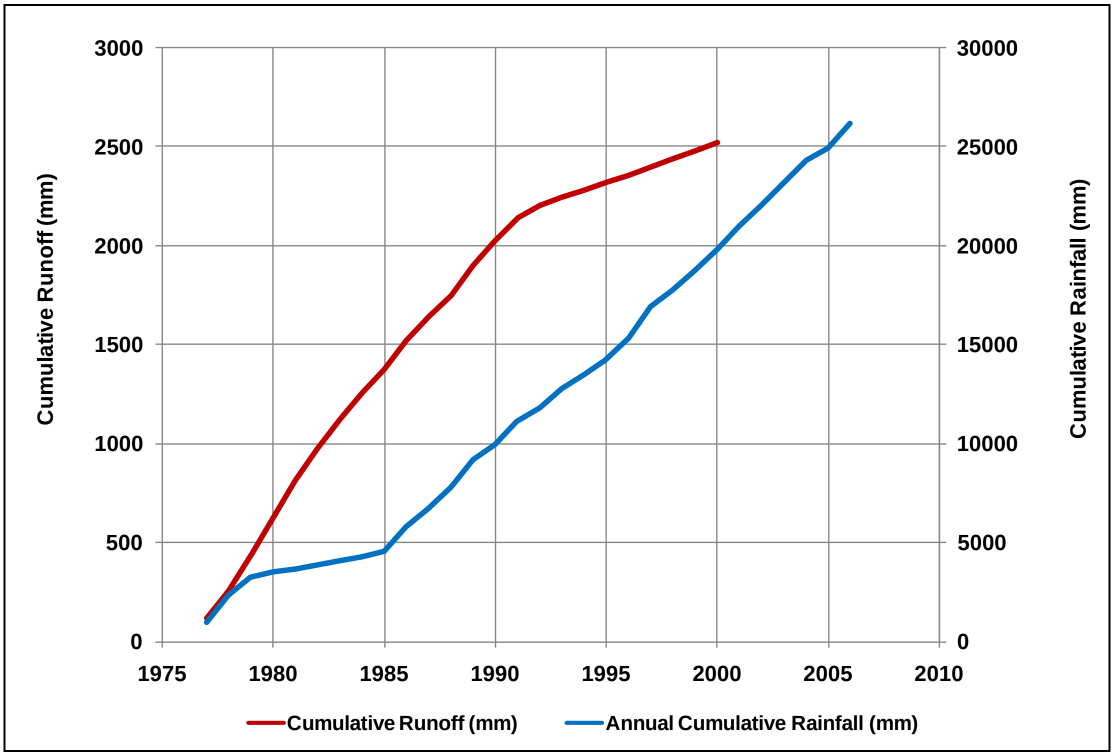

Figure 4: Time-series of cumulative rainfall and runoff for the period 1977-2006

Essentially the relationship should be linear if the catchment properties related to runoff have not been changed. Non-linearity between rainfall and runoff normally reflects a catchment disturbance if other factors such as abstractions are insignificant (Yanda and Munishi 2007). Any degradation in the catchment will create imbalances in the flow and the curve will deviate from a linear relationship. In the period between 1992 to 2002, the stream flow curve displays more persistent deviations implying more disturbances in the catchment than for the period 1986 and 1991. One will note that there is no shift in rainfall curve (Figure 4). The authors are attributing these shifts with land cover changes. An estimated 20-25 $m^3 s^{-1}$ of water is abstracted for irrigation in the Lower Shire valley and government sponsored smallholder schemes. In the middle Shire River catchment, Blantyre City abstracts 1 $m^3 s^{-1}$ of water for both domestic and industrial use (Malawi Government 2001). The slope of the runoff curve for the corresponding periods indicates a significant change in the overall runoff. This indicates that detectable change has occurred in the runoff process in the catchment.

The results in Figure 4 compare well with those of simulations as depicted in Figure 5.

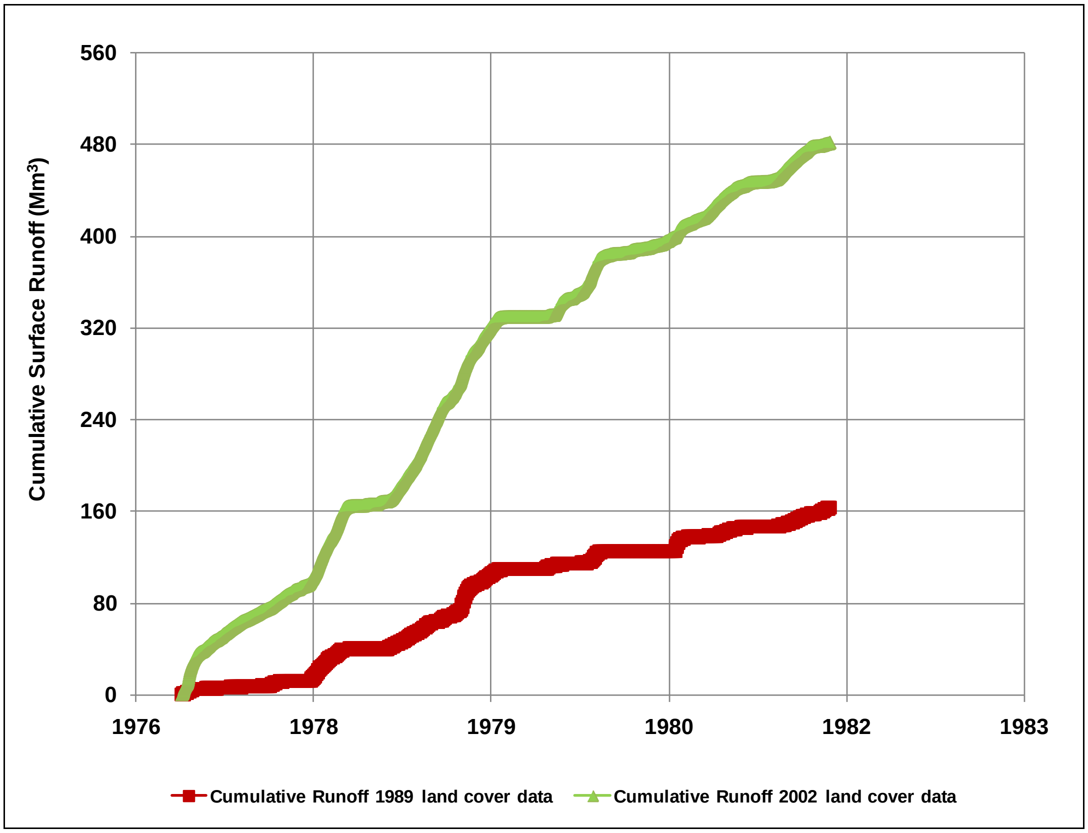

Figure 5: Time-series of cumulative surface runoff as simulated using 1989 and 2002 land cover data

However, it should be noted the former figure uses total stream flows of the entire basin whereas the latter plot uses simulated surface runoff (i.e. overland flow). In Figure 5, time-series of cumulative surface runoff for the period of 1977–1981 for the study area catchment are presented. The simulations were based on 1989 and 2002 land cover data. As depicted, the curve for 2002 land cover data simulated surface runoff plots above that of 1989 curve. Such increase in surface runoff is attributed to land cover changes.

DISCUSSION

As land cover changes from forest to rural built-up lands, and subsistence agriculture, surface runoff increases while surface and groundwater quantity and quality deteriorates. In the study area, subsistence agricultural areas have increased between 1989 and 2002, with most of the increase occurring in previously vegetated areas of savanna and forest. Agricultural land has the highest potential for runoff because the land is bare at the beginning of the rainy season. SWAT simulates surface run-off volumes and peak run-off rates for each HRU. Surface run-off is estimated with a modification of the SCS curve number method (USDA-SCS 1972). In this study, subsistence agricultural land has a curve number of 86 compared to 79 and 68 for savanna and forest, respectively. The curve number is a dimensionless parameter indicating the runoff response of a drainage basin. Changing land cover results in a different run-off curve number, which could result in changes in rainfall run-off responses. High curve numbers signify high surface run-off and low infiltration. Increase in storm runoff is mainly due to the reduced infiltration rate when other land cover classes convert to previously forested areas (Kiersch 2000; Allan 2004). These changes in runoff generation are in agreement with the state of knowledge that reducing forest cover results into an increase in surface runoff. Besides, in catchments, which were traditionally cultivated, or grazing areas that have been changed to woodland, increases in evaporative loss and decreases in discharge to the outlet have been observed (Dagnachew et al. 2003; De Roo et al. 2001; Robinson 1990).

Further, from the modelling process, savanna woodlands dominate HRUs from the 1989 land cover, while subsistence agriculture dominates HRUs from the 2002 land cover. Subsistence agricultural land is characterised by scattered grasslands, used for communal grazing during the dry season. At the beginning of the rainy season, most of these fields are bare soil that have been prepared for planting, or denuded by grazing. The majority of subsistence farmers in Malawi practice traditional methods of cultivation. Soil and water conservation technologies are not practised, and generally the adoption rate for most land husbandry technologies is low (Malawi Government 2001). If vegetation clearing is followed by land use practices that compact soils and expose them to erosion, decreased percolation to groundwater can result (Bonell 2004; Bruijnzeel 2004; Schulze 2000). Most of the run-off generated in the cultivated and grazing lands constitutes storm flow, especially at the beginning of the rainy season between November and January. According to Kiersch (2000), the impacts of land use practices on surface water can be two-folds: (i) on the overall water availability or the mean annual runoff, and (ii) on the seasonal distribution of water availability. With regard to the latter, impacts on peak flows and impacts on dry season flows are of importance. Studies in other countries (Siberia, Botswana Tanzania, and South Africa) have also shown the influence of land use changes on runoff generation and reduced baseflows (e.g. Onuchin et al. 2009; Masamba 2008; Kashaigili 2008; O'Keeffe and Davies1991). It is apparently clear that, land cover changes influence the flow regimes and have implications on the sustenance of dry season river flows (Kashaigili 2008).

Currently within the Shire catchment, there is a steady recognition that surface and groundwater sources are declining. Higher surface run-off and less infiltration are not conducive of sustainability of rural agriculture as they erode fertile surface soils and make areas more vulnerable to periods of drought. Lack of perennial water flows may hamper the use of small-scale agriculture to combat cyclical food insecurity. In addition, water in the Shire River is almost totally allocated to hydro-electric power stations in the mid-catchment, irrigation schemes in the lower-catchment and domestic purposes (Malawi Government 2001). Water shortages during drought periods may therefore increase water contestation among different users.

CONCLUSION

A critical aspect of this study has been to establish the links between extensive land cover change and hydrological responses. The major land cover changes during the study period were the reduction in forested area, savanna woodlands and increase in cultivated and grazing land. Deforestation, land fragmentation, cultivation of wetlands and rapid increase in human settlements have had negative impacts on water sources resulting in reduced groundwater recharge, increased run-off and dry season water shortages. Simulation results revealed that surface runoff patterns in this catchment have been strongly influenced by the land cover changes that have occurred over the relatively short period of thirteen years.

Hydrological processes are an integrated indicator of catchment conditions, and changes in land cover may affect the overall health and functioning of a catchment. An understanding of temporal changes and trends in the proportion of surface flow and baseflow is critical for directing efforts in managing land cover and improving agricultural practices. Within the Upper Shire River catchment, the study proposes exploration different catchment management options, which conserve the water resource base while upgrading the socio-economic status of the population. Therefore, diverse development scenarios be investigated and the best alternative effected for the Upper Shire River catchment. An active management strategy aimed at the conservation and regeneration of the natural vegetation is recommended to improve the distribution of water throughout the entire Shire River catchment during both dry and wet periods.

Acknowledgements: This research was facilitated by a grant from Deutscher Akademischer Austausch Dienst (DAAD) through the African Network of Scientific and Technological Institutions (ANSTI) for collaborative University level training and research in the fields of science and technology. Besides, the authors wish to express their gratitude to the anonymous reviewers, who helped to improve this paper through their thorough review.

REFERENCES

Allan JD (2004) Landscapes and Riverscapes: The influence of land use on stream ecosystems. Annual Review Ecology Evolution System, 35:257–284

Arnell NW, Reynard NS (1996) The effects of climate change due to global warming on river flows in Great Britain. J of Hydrol183 (3-4): 397-424

Arnold JG, Williams JR Srinivasan R King KW Griggs RH (1995) SWAT: Soil Water Assessment Tool, U. S. Department of Agriculture, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, TX

Arnold JG, Fohrer N (2005) SWAT 2000, current capabilities and research opportunities in applied watershed modeling. Hydrological Processes 19:563-572

Bonell M (2004) Selected issues in mountain hydrology of the humid tropics. IHP-VI technical document in hydrology No. 70. UNESCO Working series SC-2004/WS/51

Bonell M et al. (2010) The impact of forest use and reforestation on soil hydraulic conductivity in the Western Ghats of India: Implications for surface and sub-surface hydrology. J of Hydrol 391:47–62

Bradley PN, McNamara K (1993) Living with trees: Policies for forestry management in Zimbabwe. World Bank Technical Paper Washington DC

Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. J of Hydrol 310: 28–61

Bruijnzeel LA (1990) Hydrology of moist tropical forests and effects of conversion: A state of knowledge review. UNESCO International Hydrologic Programme, Amsterdam: Humid Tropics Programme, Free University

Bruijnzeel LA (2004) Hydrological functions of tropical forests: Not seeing the soil for the trees? Agric Ecosyst Environ 104:185–228

Calder IR (2002) Forests and hydrological services: Reconciling science and public perceptions, Land use and water resources research 2, 2.1-2.12.

Costa MH, Botta A, Cardille JA (2003) Effects of large-scale changes in land cover on the discharge of the Tocantins Rivers, Southeastern Amazonia. J of Hydrol 283: 206-217

Croke BFW, Merrit WS, Jakeman AJ (2004) A dynamic model for predicting hydrologic response to land cover change in gauged and ungauged catchments. J of hydrol 291:115-131

Dagnachew L, Vallet-Coulomb C, Gasse F (2003) Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. J of Hydrol 275:67-85

De Roo A, Odijk M, Schmuck G, Koster E, Lucieer A (2001) Assessing the effects of land use changes on floods in the Meuse and Oder catchment. Phys Chem Earth (B) 26:593-599

Dewees PA (1994) Social and Economic aspects of Miombo woodland management in southern Africa: Options and Opportunities for research. Center for International Forestry Research, Bogor, Indonesia

Desanker PV, Frost PG, Justice CO, Scholes RJ (1997) The Miombo Network: Framework for a terrestrial transect study of land use and land cover change in the Miombo ecosystem of central Africa. International Geosphere- Biosphere Programme, Stolkholm

Di Luzio M, Srinivasan R, Arnold JG, Neitsch S (2001) ArcView Interface for SWAT 2000 User's Guide. Texas Water Resources Institute, College Station, Texas

Githui FW (2008) Assessing the Impacts of Environmental Change on the Hydrology of the Nzoia Catchment, in the Lake Victoria Basin. PhD dissertation, Vrije Universiteit Brussel, Belgium

Hu Q, Wilson GD, Chen X, Akyuz A (2005) Effects of climate and land cover change on stream discharge in the Ozark Highlands, USA. Environmental Modelling and Assessment, 10: 9-19 DOI 10.1007/s10666-004-4266-0

FAO (Food and Agriculture Organization) (2004) Shuttle Radar Topographic Mission (SRTM) Technical Guide. University of Advanced Computer Studies, University of Maryland, Department of Geography

FAO/UNESCO (2003) Digital Soil Map of the World and Derived Soil Properties, Version 3.6. CD-ROM, Information Division, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy

Fohrer N, Haverkamp S, Eckhardt K, Frede HG (2001) Hydrologic response to land use changes on the catchment scale. Phys Chem of Earth (B**)** 26**:** 577–582

Hindall SM (1991) Temporal Trends in Fluvial-Sediment in Ohio, 1950-1987. Journal of soil and Water Conservation 46(4):311-313

IPCC (2001) Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of the Working Group II to the Third Assessment Report of Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

IPCC (2008) Climate and Water Technical Paper VI eds Bates BC, Kundzewicz ZW, Wu S, Palutikof JPIPCC Secretariat, Geneva, 210 pp

Jensen JR (2005) Introductory digital image processing: A remote sensing perspective. Prentice Hall, USA, USA

Kiersch B (2000) Land use impacts on water resources: a literature review. FAO E–workshop on Land-Water Linkages in Rural Watersheds. http://www.fao.org/ag/agl/watershed/ watershed/en/mainen/index.stm. Accessed on 22/07/2008

Kashaigili JJ (2008) Impacts of land-use and land-cover changes on flow regimes of the Usangu wetland and the Great Ruaha River, Tanzania. Phys Chem of the Earth 33: 640–647

Lillesand TM, Kiefer RW, Chipman JW (2004) Remote sensing and image interpretation, 5th edn. Wiley, New York

Lin Y, Hing N, Wu P, Wu C, Verburg PH (2007) Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. Landscape and Urban Planning 80: 111-126

Makarieva AM, Gorshkov VG (2007) Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. Hydrol. Earth Syst. Sci., 11:1013–1033

Malawi Government (2006) Malawi's National Adaptation Programmes of Action (NAPA) under the United Nations Framework Convention on Climate Change (UNFCCC) 1st edition Environmental Affairs Department, Lilongwe Malawi http://www.unfccc.int/resource/doc/napa/mwi01.pdf

Malawi Government (2001) State of the Environment Report for Malawi. Likuni press, Lilongwe, Malawi

Malawi Government (1998) State of the Environment Report for Malawi. Likuni press, Lilongwe, Malawi

Malawi Institute of Education (2001) Malawi Senior Secondary Atlas. Simbeye EK (ed), MacMillan Malawi Ltd, Blantyre

Masamba WR Mazvimavi D (2008) Impact on water quality of land uses along Thamalakane-Boteti River: An outlet of the Okavango Delta. Phys Chem of the Earth 33:687–694

Morris B (1995) Woodland village: Reflections on the "animal estate" in rural Malawi. Royal Anthropological Institute, 1

National Statistical Office (2008) Malawi Population and Housing Census 2008: Summary of preliminary results. N. S. Office (ed), Government printer, Zomba

O'Keeffe J, Davies B (1991) Conservation and management of the rivers of Kruger National Park: Suggested methods for calculating instream flow needs. Aquatic Conservation: Marine and Freshwater Ecosystems 1: 55–71

Onuchin A, Burenina T, Gaparov K Ziryukina N (2009) Land use impacts on river hydrological regimes in Northern Asia. Hydroinformatics in Hydrology, Hydrogeology and Water Resources (Proc. of Symposium JS.4 at the Joint IAHS & IAH Convention, Hyderabad, India, September 2009). IAHS Publ. 331:163-170

Palamuleni LG (2009) Land Cover Change and Hydrological Regimes in the Shire River Catchment, Malawi. University of Johannesburg. Unpublished PhD thesis

Pereira HC (1992) Keynote paper. In 10th World forestry congress, Proceedings 3 Paris, 1991: 139-150

Robinson M (1990) Impact of improved drainage on river flows. Institute of Hydrology, Oxon, UK

Rockström J, Barron J, Fox P (2002) Rainwater management for increased productivity among small-holder farmers in drought prone environments. Phys Chem of the Earth 27:949-959

SADC: Drought Monitoring Centre, Special bulletins: El Nino/La Nina update, http://www.sadc.int.dmc. Accessed June 2008.

Schulze RE (2000) Modelling hydrological responses to land use and climate change: A Southern African perspective. AMBIO: A Journal of the Human Environment 29: 12–22

Searcy JK, Hardison CH (1960) Double mass curves. Manual of hydrology: part 1 general surface water techniques. Geological Survey Water Supply Paper, p 66

Skaggs RW, Amatya DM, Chescheir GM, Blanton CD, Gilliam JW (2006) Effects of drainage and management practices on hydrology of pine plantation. In Proc. Intl. Conf. on Hydrology and Management of Forested Wetlands, 3-14. St. Joseph, Mich.: ASABE

Stohlgren TJ, Chase TN, Pielke RA Sr, Kittel TGF, Baron J (1998) Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. Global Change Biology 4:495-504

Tadele K, Förch G (2007) Impact of Land Use / Cover Change on Streamflow: The Case of Hare River Watershed, Ethiopia. Catchment and Lake Research, Proceedings 2nd Lake Abaya Research Symposium (LARS), Arba Minch, Ethiopia 7th -11th May, 2007.

USDA-SCS (1972) Soil Conservation Service, Urban Hydrology for Small Watersheds, U.S. Government Printing Office, Washington, DC

USGS (2006) United States Geological Survey Digital Elevation Model Data http://edc2.usgs/geodata. Accessed 26/11/2006

Yanda PZ, Munishi PKT (2007) Hydrologic and Land Use/Cover change analysis for the Ruvu River (Uluguru) and Sigi River (East Usambara) watersheds. http://www.easternarc.or.tz/downloads/Uluguru/final report.pdf.

Yang S, Zhao Q, Belkin IM (2002) Temporal Variation in the Sediment Load of the Yangtze River and the Influences of Human Activities. J of Hydrol. 263: 56-71

Zhang L, Hickel K, Dawes WR (2001) A rational function approach for estimating mean annual evapotranspiration. Water Resources Research 40: W02502

Zhao, WW, Fu BJ, Meng QH, Zhang QJ, ZhangYH (2004) Effects of land-use pattern change on rainfall-runoff and runoff-sediment relations: a case study in Zichang watershed of the loess plateau of China. Journal of Environmental science 16(3):436-442.