LAND COVER CHANGES AND ITS EFFECTS ON STREAMFLOWS IN THE MALEWA RIVER BASIN, KENYA

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ABSTRACT

Vegetated landscapes are transformed by both natural and human causes. This is thought to influence river flow regimes. It is argued that restored and reforested landscapes increase stream flow. However, studies done to date have been inconclusive on whether or not trees on restored or reforested landscapes increase stream flow. This study aimed to examine the effects of land cover changes on streamflow of the Malewa River Basin in Kenya. Satellite imagery based spatial change detection using ArcGIS 10.1 and ERDAS IMAGINE software was deployed to estimate the land cover changes. Based on projected land cover change data, a multiple regression technique was used to establish the relationship between land cover and streamflow. The results show that at Gauge 2GB01, area under wetland significantly predicted stream flows (b=0.134, t(488) =1.978, p=0.049), with an overall model (R^2=0.018, F(3, 488)=2.976, p=0.031). Area under grassland (b=0.108, t(488)=2.325, p=0.02), shrubland (b=0.112, t(488)=1.976, p=0.049) and amount of rainfall (b=0.533, t(488)=14.048, p=0.000) combined significantly predicted stream flows. Rainfall alone significantly predicted stream flows (b=0.531, t(488)=13.885, p=0.000). Overall, the gains in forest restoration did not specifically influence streamflow except in combination with other vegetation and rainfall. There is need to increase soil cover rather than woody biomass alone in the regulation of stream flows. A systematic response to address the drivers of change in land cover is also needed.

Key words: landscape, streamflow, restoration, land cover

INTRODUCTION

Vegetated landscapes are thought to influence river flow regimes, but there is lack of clarity about how forests contribute to water yield. The lack of clarity is informed by several forest-interaction studies (Beck *et al*., 2013; Ellison *et al*., 2012; Zhou *et al*., 2010; Silveira *et al*., 2006) under different contexts suggesting inconclusiveness on the relationship between forests and stream flows. It is argued that forests at larger spatial scales contribute to increased evapo-transpiration and precipitation (Ellison *et al*., 2012). Also, while forests may be net consumers of water and competitors for other downstream users, reduced forest cover could increase stream flows (Price *et al*., 2010). Generally, land use changes and their associated effects are known to impact the hydrology of the catchment area (Tang *et al*., 2005; Foley *et al*., 2005; Ott and Uhlenbrook, 2004; Bronstert et *al*., 2002). Vegetation cover is thought to increase the capacity of catchments, conserve moisture and increase water yield (Lal, 1997). There seems to be a relationship between altered flows and ecological change (Poff *et al*., 1997); however no evidence existed to show that ecological change was dependent on hydrological change (Poff and Zimmerman, 2010). Surface runoff and river discharge are generally thought to increase with clearance of natural vegetation, especially forests. This was evidenced, for example, in the Tocantins River Basin in Brazil (1960-1995) where an approximately 25% recorded increase in river discharge was attributed to expanding agriculture and not a change in precipitation (Costa *et al*., 2003). Elsewhere, stream flows of once degraded areas under large-scale land rehabilitation showed improved base flows (Wilcox and Huang, 2010). On the contrary, findings from 12 meso scale catchments (23-346 km^2) in the island of Puerto Rico do not show influence of changes in urban or forest cover on stream flow trends (Beck, 2013).

In the Mara River, Kenya, it was shown that higher flood peaks and faster travel times were experienced in an area that had undergone increased land use pressure (Mutie *et al*., 2006). In the Nzoia river catchment, it has been observed that forests reduce runoff with increased flows in croplands compared to forests. The findings show that as a result of an increase in agricultural area of between

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39.6 and 64.3% and reduced forest land from 12.3 to 7.0% (1973-2001), runoff increased by 119% (1970-1985). The authors noted that climatic factors being constant, land cover changes was responsible for the difference in run-off ranging from 55-68% (Githui *et al*., 2009). In another study in this catchment, arising from agricultural expansion, stream flow was found to increase during rainy seasons but decreased during the dry seasons. Stream flow generally increased with increase in forest cover. However, when the cover reduced to almost zero, increased peak and mean discharge was noted (Odira *et al*., 2010).

Despite the extensive literature on responses of baseflow and recharge to various human impacts (Price, 2011) these findings are inconclusive. Effects of regenerating forests on stream flow is still little known. This study was designed to address the problem of limited understanding on how forests and trees sustain stream flow in a human modified landscape. It contributes to a body of knowledge on land cover classes – water yield relationships. The objective of this study was to analyse the land cover changes and its effects on streamflows in the Malewa River Basin in Kenya.

MATERIALS AND METHODS

Study area

The Malewa River Basin (1,760 km^2) is located in Kenya (See Figure 1) and itcovers Nakuru and Nyandarua Counties. The Malewa River discharges about 153 million cubic metres (MCM) of water per annum (Arwa, 2001). The river has a dendritic drainage system, with several streams (including Turasha, Kitiri, Mkungi, Wanjohi and Malewa) emerging from the upper catchment. Rainfall ranges between 600 and 1,700 mm, with the Kinangop plateau experiencing a yearly rainfall ranging from 1,000 to 1,300 mm (Becht and Higgins, 2003). The climatic conditions mirror that of the semi-arid areas, with bi-modal rainfall distribution: longer rainy season (March to May) and short rainy season (October to November, February, July and December) as described by Kamoni (1988). The potential evaporation is about twice the annual rainfall (Farah, 2001). The mean annual temperature ranges between 16 ^{o}C and 25 ^{o}C. The daily temperatures range from 5 ^{o}C to 25 ^{o}C (Republic of Kenya, 2014). Soils have been influenced by extensive relief variation, volcanic activity and underlying bedrocks (Sombroek *et al.,* 1982); and developed from lacustrine deposits, volcanic and lacustrine-volcanic basements (Girma *et al*., 2001; Nagelhout, 2001). The soils are prone to erosion and compaction (Kiai and Mailu, 1998). Forests and cropland dominates the upper catchment (the Nyandarua range) while livestock grazing is done at the lower catchments (Muthawatta, 2004).

Study design

The study area was sub-divided into three sub-catchments, namely Turasha (Sub-catchment I), Upper Malewa (Sub-catchment II) and Malewa (Sub-catchments II and III combined). Sub-catchment I was mapped to Gauge 2GC04, Sub-catchment II to 2GB0708 and Sub-catchment II and III combined to Gauge 2GB05. The entire basin consisting of the three sub-catchments was mapped to Gauge 2GB01.

Data collection and analysis

Satellite imagery from Landsat MultiSpectral Scanner (MSS) (1973), Landsat Thematic Mapper (TM) (1986) and Enhanced Thematic Mapper Plus (ETM+) (2000) were obtained from the

Landsat database (orthorectified archives) (NASA, 2015). These images were geo-processed using ERDAS imagine 2015 and ArcGIS 10.1 software. SPOT image from Astrium was acquired courtesy of WWF Kenya office. UTM Projection Zone 37N and WGS 84 Datum were adopted in the registration procedures. DeltaCue software was used to perform image registration (ERDAS Inc, 2008). Threshold based segmentation technique where a multilevel image is converted into a binary image (Telgad *et al*., 2014) was applied. Image processing and enhancement was done using ERDAS imagine 2015. An object-based classification using a supervised maximum likelihood classification technique was used. A classification scheme based on Anderson *et al*. (1976) was adopted, with six distinct classes generated, namely cropland, forestland, grassland, shrubland; wetland and settlement. Interpreted raster was then converted into polygons using conversion tool in ERDAS imagine. The normalized difference vegetation index (NDVI) algorithm (Rouse *et al*., 1973) was used to detect vegetation health.

Daily stream flow data for gauges 2GB01, 2GB05, 2GB0708 and 2GC04 (see Figure 1) was sourced from the Water Resources Management Authority. Monthly rainfall data for six stations (9036243 - Dundori Forest Station, 9036029 - Kwetu farm, 9036002 - Naivasha Water Bailiff,

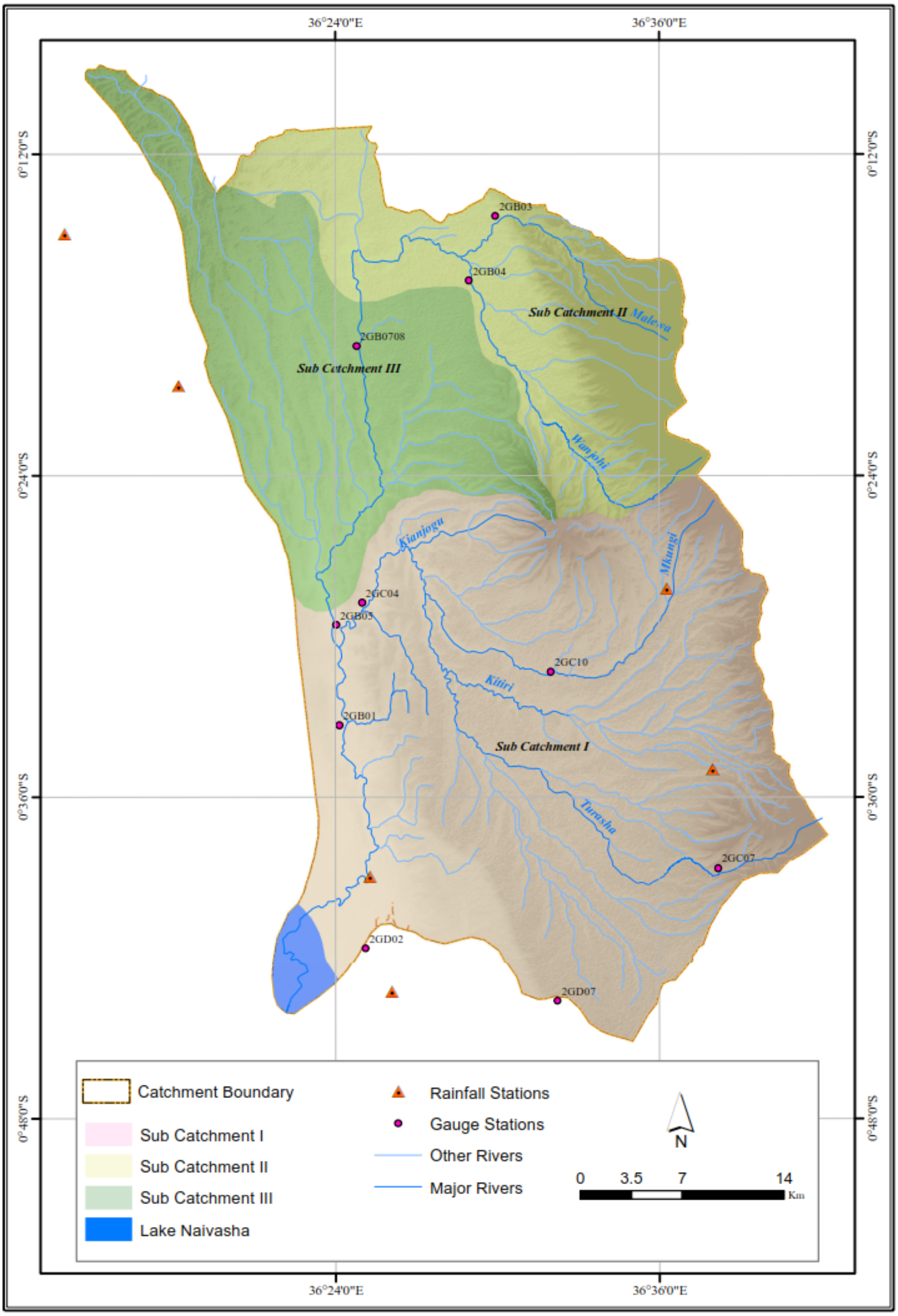

Figure 1.Study area showing location of the gauge and rainfall stations

9036081 - National Animal Husbandry Resource Centre, Naivasha, 9036025 - North Kinangop Forest Station and 9036241 - Geta Forest Station) was sourced from the Kenya Meteorological Service.

The land cover data generated for the years 1973, 1986, 2000 and 2013 were then projected using polynomial regression with the data fit achieved using a procedure described in Lutus (2013). It was assumed that area under settlement is part of cropland, and so five class projections was applied. The degree of regression was obtained by setting the number of data pairs minus one. The range was limited to 40 years to match with the study timeframe. To reduce possible bias, the polynomial regression order was set to two. Using XLSTAT software (https://www.xlstat.com/), multiple regression technique was run with the projected land cover class and NDVI against streamflow and rainfall data to establish statistical relationships. Regression equations were used to model the relationship between stream flow and the land cover classes (areas under cropland, forestland, grassland, shrubland and wetland) and rainfall amounts at four gauge stations for the years 1973 to 2013. These gauges represent runoff from four delineated catchments and the rainfall amounts assumed to fall in these areas. The significance level was set at 0.05.

The Pearson Product Moment Correlation (PPMC) (*r*) (Pearson, 1948) was used to establish the strength of relationship between any two variables: NDVI, land cover classes, rainfall and stream flows.

RESULTS

Rainfall amounts

The monthly rainfall amounts (1970-2013) ranged between 52 mm (2000) and 108 mm (1977) with a mean of 80 mm. The trend in monthly rainfall is provided in Figure 2. There was high level of rainfall variability over this period, and suggests a declining trend. Overall, the years 1977, 1978, 1988, 1998 and 2010 received the highest rainfall amounts while 1984, 2000 and 2009 had low amounts.

Annual rainfall totals ranged between 627 mm (2000) and 1 293 mm (1977) with an average of 960 mm. The annual trend in rainfall amounts is shown in Figure 3. This trend mirrors the monthly means, and is generally on a decline.

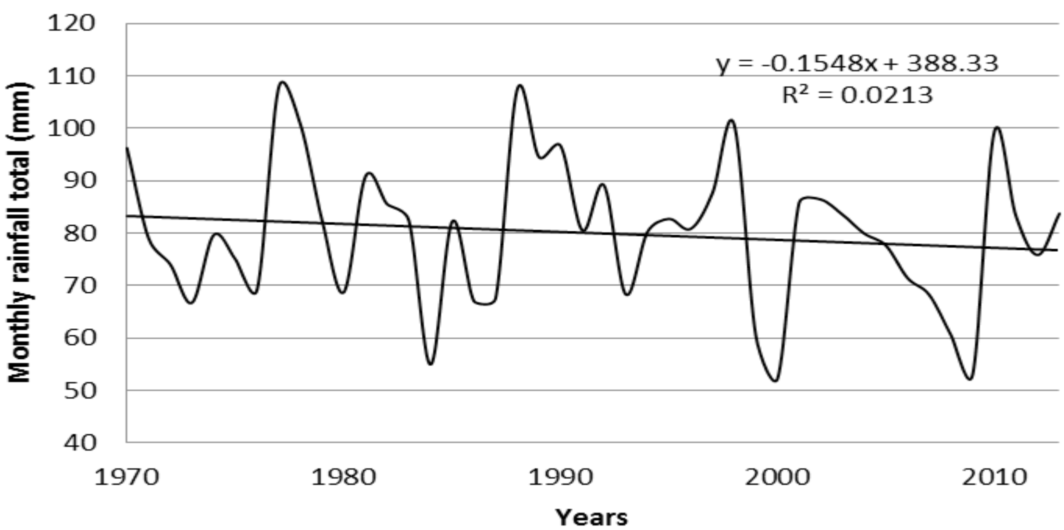

Figure 2. Monthly rainfall trend (1970-2013), **Source:** Kenya Meteorological Service

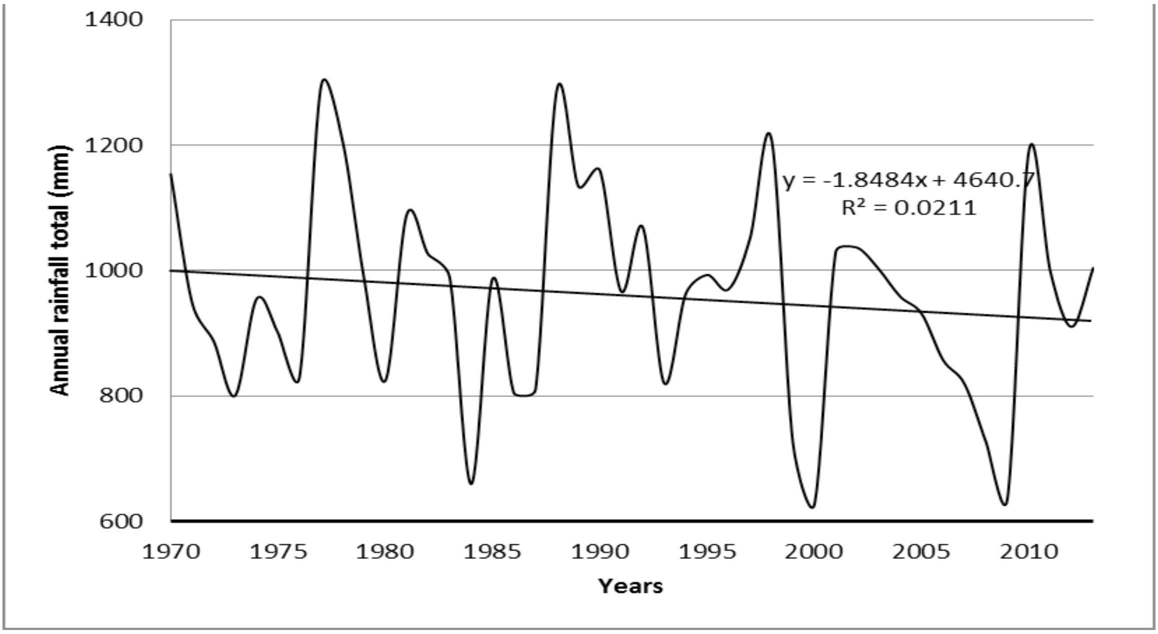

Figure 3. Annual trend in rainfall amounts,**Source:** Kenya Meteorological Service

Streamflow

On average, the Malewa River at gauge 2GB01 discharges (excluding abstractions) about 191 MCM of water annually. There were wide variations in minimum and maximum diurnal and annual flows recorded in all the four gauges. The daily and annual stream volumes and flow for the four gauges stations (1960-2013) are shown below (Table I).

Notes: Daily data in m^3/s; Annual data in MCM

Spatial extents of the three sub-catchments by cover class

Over the years 1973 to 2013, area under cropland increased by 25,589 ha, forestland 4,295 ha and wetland 687 ha. Shrubland reduced by 28,953 ha and grassland 1,751 ha. The spatial extents of the three sub-catchments and land cover classes for the years assessed are shown in Table II.

TABLE I- DAILY (M^3/S) AND ANNUAL (MCM) DISCHARGES AT FOUR GAUGE STATIONS OF MALEWA RIVER

Gauge	**Mean**		**Minimum**		**Maximum**		**SD**	
	Daily	Annual	Daily	Annual	Daily	Annual	Daily	Annual
2GB01	6.1	191.3	0.3	53.1	139.2	358.6	7.1	74.7
2GB05	3.4	106.4	0.3	28.6	115.4	235.7	5.6	47.0
2GB0708	2.3	70.9	0.00	7.6	144.4	186.1	6.1	45.6
2GC04	4.8	150.4	0.00	38.9	136.7	353.0	8.0	67.2

TABLE II - AREA OF SUB-CATCHMENTS BY LAND COVER CLASSES AND YEARS

Years	**Sub-catchments**	**Area of land cover classes (ha)**					
		C	**F**	**G**	**S**	**W**	**Se**
1973	I	54,298	22,901	4,001	18,628	140	
	II	12,541	14,578	1,735	5,302		
	III	21,996	743	3,389	16,165		
		88,835	**38,222**	**9,125**	**40,095**	**140**	
1986	I	55,516	21,663	5,852	16,651	287	
	II	14,853	13,085	3,906	2,282	30	
	III	24,081	823	13,566	3,803	19	
		183,285	**73,793**	**32,449**	**62,831**	**476**	
2000	I	55,626	18,579	1,326	24,182	237	
	II	16,964	14,319	1,390	1,457	11	
	III	30,016	851	1,909	9,459	43	
		102,606	**33,749**	**4,625**	**35,098**	**291**	
2013	I	58,500	24,938	7,183	8,515	812	3
	II	18,467	14,889		772	13	
	III	37,457	2,690	191	1,855	2	83
		114,424	**42,517**	**7,374**	**11,142**	**827**	**86**

Notes: C=Cropland; F=Forestland; G=Grassland; S=Shrubland; W=Wetland; Se=Settlement. Totals are shown in bold text.

Correlation between variables

The Pearson correlation (PPMC) of projected data on the variables: land cover classes, rainfall, NDVI and stream flows are shown in Table 3. The NDVI values had strong negative correlation with crop land (p=0.01), a strong positive correlation with grassland (p=0.01), a moderate positive correlation with forestland (r=0.509, p=0.000) and a moderate negative correlation with shrubland (p=0.01). As the areas under cropland and shrubland increases, NDVI values decrease and vice versa. However, as the area under forestland and grassland increases, the NDVI values also increases. Grassland had strong negative correlation with cropland (p=0.01).

As area under grassland increases, that of cropland decreases and vice versa. Wetlands had strong positive correlation with cropland and a moderate positive correlation with forestland. Area under wetland increases with increase in cropland and forestland. Shrubland had a moderate negative correlation with forestland. As the area under shrubland increase that of forestland and wetland decrease and vice versa. A very weak association between forestland and stream flows, shrubland and streamflow and wetlands and streamflow was noted. As the areas under forests, shrubland and wetlands increase the magnitude of stream flows also increase. Rainfall and stream flow had moderate positive correlation. As the amount of rainfall increased, the magnitude of stream flow also increased. NDVI had no correlation with streamflow.

TABLE III - PEARSON CORRELATION ON THE MEASURED VARIABLES

	F	R	N	St	C	G	S	W
F	1.000							
R	-.006 (.892)	1.000						
N	**.509**** (.000)	.042 (.351)	1.000					
St	**.098*** (.030)	**.531**** (.000)	.014 (.752)	1.000				
C	**.131**** (.004)	.014 (.752)	**-.740**** (.000)	.078 (.084)	1.000			
G	.013 (.770)	.059 (.189)	**.849**** (.000)	-.022 (.629)	**-.847**** (.000)	1.000		
S	**-.566**** (.000)	-.042 (.348)	**-.571**** (.000)	**-.104*** (.021)	-.010 (.818)	**-.487**** (.000)	1.000	
W	**.616**** (.000)	-.012 (.796)	**-.164**** (.000)	**.129**** (.004)	**.781**** (.000)	**-.416**** (.000)	**-.590**** (.000)	1.000

Notes: F=Forest; R=Rainfall; N=NDVI; St=Streamflow; C=Cropland; G=Grassland; S=Shrubland; W=Wetland
*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Influences of land cover changes on streamflow

The relationships between stream flows and land cover classes at Gauges 2GB01, 2GB05, 2GB0708 and 2GC04 are presented in Table IV

TABLE IV- STREAM FLOW AND LAND COVER CLASSES

Gauge	Model	*b*	*SE b*	β	*t*	*Sig.*
2GB01	(Constant)	2.276	5.353		.425	.671
	Area under forestland	4.189E-005	.000	.015	.246	.806
	Area under grassland	2.153E-005	.000	.034	.630	.529
	Area under wetland	**.006**	**.003**	**.134**	**1.978**	**.049**
2GB05	(Constant)	5.347	.875		6.110	.000
	Area under grassland	-1.836E-005	.000	-.039	-.855	.393
	Area under shrubland	**.000**	**.000**	**-.115**	**-2.249**	**.025**
	Area under wetland	-.016	.011	-.072	-1.449	.148
2GB0708	(Constant)	1.378	.776		1.776	.076
	Area under grassland	-.001	.001	-.338	-1.378	.169
	Area under shrubland	.000	.000	.067	.620	.536
	Area under wetland	.126	.077	.334	1.638	.102
2GC04	(Constant)	5.347	.875		6.110	.000
	Area under grassland	-1.836E-005	.000	-.039	-.855	.393
	Area under shrubland	**.000**	**.000**	**-.115**	**-2.249**	**.025**
	Area under wetland	-.016	.011	-.072	-1.449	.148

At Gauge 2GB01, area under wetland significantly ($p \leq 0.05$) predicted stream flows. Area under wetland explained a significant ($p \leq 0.05$) proportion of variance in streamflow values. At Gauge 2GB05 area under shrubland was a significant ($p \leq 0.05$) predictor of stream flows, although the model was insignificant. Area under shrubland at Gauge 2GC04 was a significant predictor of streamflow ($p \leq 0.05$). The null hypothesis of no significant impacts of the land cover changes on streamflows of the Malewa Rivers was not supported.

Significant predictors of stream flows were: areas under wetlands (2GB01) and shrubland (2GB05 and 2GC04). When combined, grassland and rainfall (2GB01); shrubland and rainfall (2GB05); grassland and rainfall (2GC04) were significant predictors of stream flow. Rainfall alone was a significant predictor of streamflow recorded in all the four gauges. There was no evidence to suggest that forest restoration had significant impact on stream flows.

Influence of land cover changes and rainfall on streamflow

The relationship between land cover classes, rainfall and stream flows for the four gauges are shown in Table V.

At Gauge 2GB01, area under grassland and amount of rainfall significantly ($p \leq 0.05$) predicted stream flows. Both area under grassland and shrubland, and rainfall combined explained a significant ($p \leq 0.05$) proportion of variance in stream flow. At Gauge 2GB05, area under shrubland and amount of rainfall combined predicted ($p \leq 0.05$) stream flows.At 2GB0708, area under shrubland and the amount of rainfall significantly ($p \leq 0.05$) predicted streamflow, with a significant overall model. At 2GC04, area the NDVI values and amount of rainfall combined were significant ($p \leq 0.05$) predictors of streamflow.

TABLE V- STREAM FLOW, LAND COVER CLASSES AND RAINFALL

Gauge	Model	b	SE b	β	t	Sig.
2GB01	(Constant)	1.287	6.288		.205	.838
	Area under forestland	.000	.000	.039	.797	.426
	Area under grassland	**-6.958E-005**	**.000**	**-.108**	**-2.325**	**.020**
	Area under shrubland	**.000**	**.000**	**-.112**	**-1.976**	**.049**
	Amount of rainfall	**.063**	**.004**	**.533**	**14.048**	**.000**
2GB05	(Constant)	**3.123**	**.842**		**3.709**	**.000**
	Area under grassland	-2.794E-005	.000	-.060	-1.409	.159
	Area under shrubland	**.000**	**.000**	**-.103**	**-2.200**	**.028**
	Area under wetland	-.016	.010	-.072	-1.559	.120
	Amount of rainfall	**.027**	**.003**	**.387**	**9.297**	**.000**
2GB0708	(Constant)	1.057	.599		1.763	.078
	Area under shrubland	**-.001**	**.000**	**-.071**	**-2.009**	**.045**
	NDVI values	4.354	3.094	.157	1.407	.160
	Area under wetland	-.016	.027	-.043	-.599	.550
	Amount of rainfall	**.025**	**.003**	**.356**	**8.434**	**.000**
2GC04	(Constant)	-.289	.788		-.367	.714
	Area under forestland	.000	.000	.279	1.716	.087
	NDVI values	**-3.962**	**1.946**	**-.097**	**-2.036**	**.042**
	Area under wetland	-.011	.007	-.250	-1.530	.127
	Amount of rainfall	**.060**	**.004**	**.520**	**13.424**	**.000**

Influences of rainfall on stream flow

In all the four gauge stations, rainfall when considered alone significantly predicted stream flows (Table VI).

with conversion to croplands, although forests association with increased wetlands is largely unexplained, safe for the notion that water would be discharged slowly to the wetland.

TABLE VI- INFLUENCE OF RAINFALL ON STREAMFLOW (REMOVE GRIDS)

Gauge	Model	b	SE b	β	t	Sig.
2GB01	(Constant)	**1.200**	**.422**		**2.840**	**.005**
	Amount of rainfall	**.062**	**.005**	**.531**	**13.885**	**.000**
2GB05	(Constant)	**1.200**	**.277**		**4.326**	**.000**
	Amount of rainfall	**.027**	**.003**	**.386**	**9.272**	**.000**
2GB0708	(Constant)	.261	.274		.954	.341
	Amount of rainfall	**.025**	**.003**	**.358**	**8.481**	**.000**
2GC04	(Constant)	.121	.419		.289	.773
	Amount of rainfall	**.059**	**.004**	**.514**	**13.279**	**.000**

DISCUSSION

This work demonstrates that land cover changes affect the quantity of streamflow of the Malewa river. Vegetation health was negatively affected by growth in cropland and demise of shrubland. This however improved when there was growth in areas under grassland and forestland. Changes in grassland affected the intensities of vegetation, and this was influenced by expanding cultivation. It appears that exploitation of wetlands was linked to increase in cropland, implying that much of the land under wetlands was subject to conversion to other uses rather than remaining as water masses. Clearance of shrubland was associated with losses of forests and wetlands, and on the contrary, more forests and wetlands were linked to extensive shrubland. Forestland, shrubland and wetlands were all positively associated with streamflow, meaning, aside from rainfall, these three are the determinants of streamflow. However, wetland and shrubland have significant, though weak relations to streamflow. In the absence of rainfall, shrubland and grassland significantly influenced streamflow. Rainfall had substantial influence on streamflow in all gauges. Surprisingly, NDVI as an indicator of vegetation health did not show influence on streamflow in the lower parts of the catchment. Flows to 2GC04, however, showed evidence of relationship with streamflows, suggesting that the drainage area is still fairly vegetated. These results demonstrate the importance of vegetative cover and not necessarily trees in a landscape. The fact that grassland and shrubland (and to some extent forests) have the ability to increase soil cover means that more water is likely to infiltrate and be retained in the soil sub-surface. Artificial wetlands seem to have been created

While these findings seem to confirm those of other similar studies, it is evident that there are still mixed conclusions. Increased stream discharge and surface runoff has been associated with forest cover loss. An increasing trend in annual discharge of the Nyangores river in the upper Mau region has been attributed to land cover change (97.5%) and climate change (2.5%) (Mwangi *et al*., 2016). However, a review of 37 catchments in East Africa show that despite the loss in forest cover about, 63% of the watersheds had no significant changes in annual discharges while 31 % were showing increasing trends. About half of the watersheds did not show trends in wet seasons and low flows. On the contrary, 35 % had decreasing trends in low flows. It was also established that forest cover and runoff, mean discharge and peak discharge were weakly correlated. The authors conclude that forest cover alone did not present an accurate predictor of streamflow in the catchments (Guzha *et al*., 2018). This finding is in line with that from this study. In a similar study in the wider Lake Naivasha basin, it was noted that due to upstream landscape changes driven mainly by population increase, there was an increase in total runoff despite no changes in rainfall. As such, monthly total runoff volumes increased significantly ($p<0.01$) by up to 32 % (Odongo *et al*., 2014).

As reported in the WeruWeruKiladeda sub-catchment of the Pangani Basin in Tanzania, following a decrease in forest and agricultural land due to increased urbanization, shrubland and bare land (1990 to 2009), river flow showed a low dry season and peak wet season flows (Chiwa, 2012). Due to deforestation, land fragmentation, cultivation of wetlands and rapid increase in human settlements, streamflow and ground water reduced in the eastern Mau (Kundu *et al*., 2004). Baseflow was found to decrease due to combined effect of human and natural factors in the River Enjoro catchment (Chemelil, 1995). In the Ewaso Ngiro South River, upper catchment forest cover and number of rainy days declined while there was a general increase in mean annual rainfall (Kiura, 2009). It has been explained that an increase of shrubland allows less infiltration of water due to crusting of the soil which causes both higher peak flows and an increase in total volume of discharge. Cultivated land allows less infiltration than forest, and is often more prone to runoff and overland flow (Gumindonga, 2010).

CONCLUSIONS

It is evident that wetlands, shrublands and grasslands play important roles in sustaining streamflow. Wetlands have the ability to slowly release water downstream. Grassland and shrubland increase soil cover therefore water is likely to infiltrate and be retained in the soil sub-surface.

This study recommends the following interventions. Firstly, considering that rainfall is key to streamflow yield, it is important to manage ecosystems beyond the immediate catchment. Secondly, we recommend intensifying activities including planting of grasses, cover crops and woodlots. This will slow down stream flows and increase water infiltration. Thirdly, we recommend participatory scenario planning to manage different stakeholder expectations on land use. Expansion of cropland and mitigation of losses on shrubland and forests is suggested to intensify sustainable agricultural production through a scheme of optimal land use applying sustainable land use practices such as agroforestry and woodlots that have economic returns to the farmers. Finally, further studies are needed to ascertain the quantum contributions of land cover change and climate variables on stream flows at specific restoration sites; and to determine seasonal influence of land cover changes on streamflows.

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