Effect of Watershed Degradation on Hydrological Functions in the Sondu River Catchment

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Abstract

In recent years, forest degradation in the Mau Forest Complex has raised ecological and economic concerns. However, reliable information is largely lacking on the extent of forest degradation and its impact on hydrological services. This has hampered the identification of appropriate intervention strategies. We used geographic information systems and a rainfall-stream flow model to assess the extent of watershed degradation and its effect on hydrological functions in the Sondu River catchment over the past three decades. We found that 30 % of closed canopy forest constituting critical watersheds was converted to farmland between 1973 and 2008. We did not find a significant variation in the mean annual rainfall amounts, but there was a significant variation in monthly rainfall distribution. We found a significant increase in stream flow index. The increase in stream flow index was most likely caused by reduced interception and infiltration of rainfall due to decrease in forest cover. Changes in rainfall distribution and stream flow had adverse impacts on commercial tea production and hydro-electric power generation. Findings of the study provide a basis for developing a framework on payments for environmental services (PES) in order to support watershed rehabilitation.

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1. Introduction

Watershed degradation is a common phenomenon in countries where rural communities rely on the exploitation of forest resources for livelihood support (Wilkie *et al*., 2003). In such cases, sustainable management of forest resources and socio-economic development among these communities is contingent on striking a balance between economic use and ecosystem stability (IUCN, 1996; UN, 2007). This understanding is consistent with the United Nation's Convention on Biological Diversity that advocates for balanced management of resources for environmental and socio-economic stability (UNEP, 1996; Wilkie *et al*., 2003). In such situations, it is prudent to identify the conflicting values and appropriate tradeoffs to reconcile utilization and protection interests. In the absence of such guiding principles, utilization of forest resources tends to override conservation objectives thus causing adverse impacts on ecosystem stability (Kokwaro, 1988). The Mau Forest Complex is one of the forests where exploitation of forest resources has outstripped ecological stability, thereby compromising its capacity to sustain watershed functions, biodiversity conservation and livelihood support systems dependent on it (GOK, 2009; KFWG *et al*., 2008).

The Mau Forest Complex contributes approximately USD 1.3 billion annually to Kenya's GDP (KEFRI, 2010). However, decades of forest excisions, forest degradation and poor land management have reduced its closed canopy forest cover by about 25% (GOK, 2009). The situation has affected both upstream and downstream economic activities such as agriculture, fishing, electricity generation, livestock production, tourism and municipal water supply. Various stakeholders have called for measures to reverse forest degradation with a view to secure environment functions, economic activities and livelihoods of millions of people dependent on the forest complex (GOK 2009; LVBC & WWF, 2010). As demonstrated in similar situations elsewhere, restoring the functions of the Mau requires environmentally friendly land use in the upstream catchment areas (Wunder, 2005; Dung & Ngoc, 2006). However, upstream communities are presently reluctant to engage in environment-friendly land use practices because they don't perceive immediate benefits from such practices (Hope *et al*., 2005). In order to secure environment-friendly land use among these communities, corporate entities in the energy, agriculture and service sectors are willing to provide incentives under a Payment for Environmental Services (PES) arrangement, but are hampered by lack of a framework for upstream-downstream engagement.

Thus, the Kenya Forestry Research Institute (KEFRI) initiated a study in January 2010 to identify tradeoffs and synergies between upstream communities occupying watersheds in South West Mau and downstream corporate users of water resources in the Sondu River Basin as part of the process of developing a framework to guide upstream-downstream engagement. The study comprised three components, namely: evaluating the extent of forest degradation, determining the effect of forest degradation on hydrological functions and developing a PES framework for the Sondu River catchment. The first two components have been completed and are expected to provide background information for the implementation of the third component. In this paper we present the effect of watershed degradation on hydrological functions on the basis of results from the first two components of the study.

2. Materials and methods

Study area

The study was carried out in South West Mau Forest and adjoining areas within the Sondu River catchment. The catchment covers about 3,287 km^2. It comprises upper and lower catchments, which originate from South West Mau. The upper catchment covers Matunda, Ndoinet, Keringet and Olenguruone areas, whereas the lower catchment consists of streams and rivers that originate from the forest and drain into Sondu River. These rivers are Kitoi, Itare, Yurith and Kipsonoi (Figure 1).

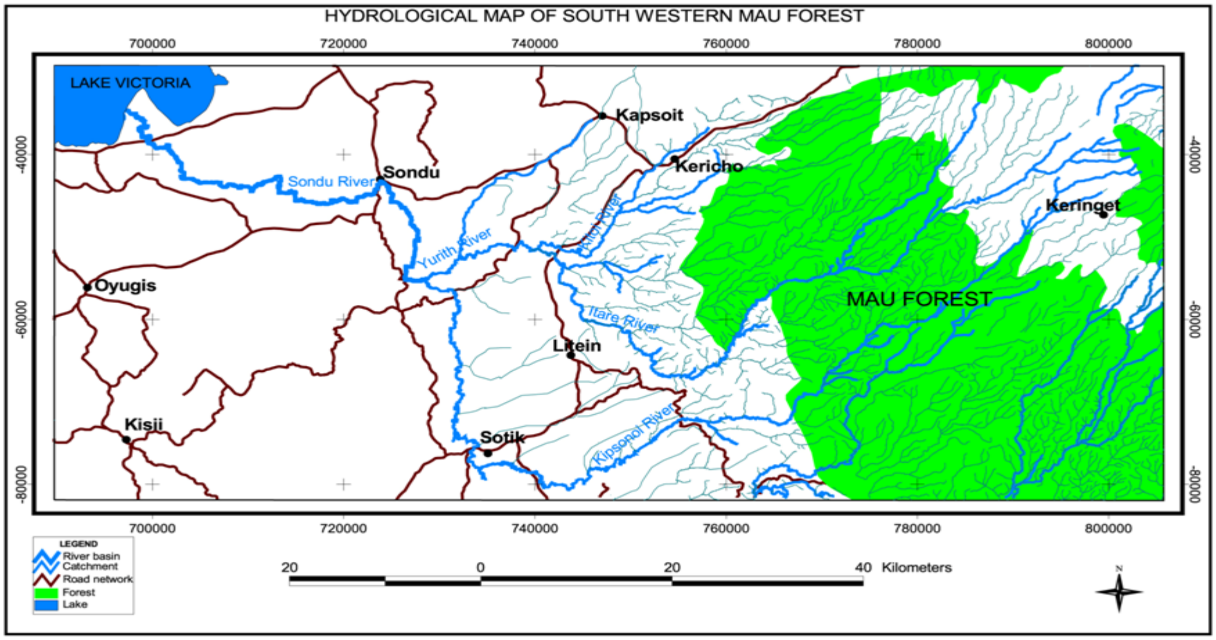

Figure 1: A hydrological map showing the upper and lower catchments of the Sondu River Basin

Evaluating extent of forest degradation

We used geographic information systems and remote sensing techniques to evaluate land use / cover changes in South West Mau between 1973 and 2008. Four sets of Landsat images (1973, 1986, 2000 and 2008) of 30 m spatial resolution were geo-referenced with the aid of topographic sheets (1: 50,000). We used standard image interpretation techniques (Wilkie & Finn, 1996; Leica Geosystems, 2003) to make an inventory of land cover features for each of the satellite images. The spatial coverage of different land cover features and vegetation cover were determined by quantifying the cumulative area under each respective spectral signature. Spatial analysis (Leica Geosystems, 2003) was carried out on the four sets of images to determine land use / forest cover changes.

Assessing changes in hydrological functions

A rainfall – stream flow model was used to assess the effect of forest cover change on hydrological functions. The model was used to determine the conversion ratio of rainfall to stream flow as a result of loss of tree cover. It employed the concept of effective rainfall to evaluate the amount of stream flow generated for every input of rainfall. The relationship was presented as a stream flow index, α, expressed as the ratio of stream flow to rainfall volume.

$$\alpha = R / P$$

Where;

α = stream flow index
R = stream flow volume (m^3), and
P = rainfall volume (m^3)

Data analysis
Variations in rainfall amounts and distribution, and stream flow index were analyzed in Genstat using the Poisson distribution as part of a generalized mixed linear model (Bolker et al., 2008; Levesque et al., 2011). Results were presented at 95 % confidence interval.

3. Results and discussion

Forest degradation and land use change
There were significant changes in the area under forest cover, farmland and commercial tea production between 1973 and 2008. The closed canopy forest cover decreased from 163,737 ha to 114,027 ha between 1973 and 2008, which is a 30 % reduction (Table 1). The area under farmland increased from 49,339 ha to 99,823 ha, which is an increment of 102 %. The area under commercial tea estates increased from 34,536 ha to 38,996 ha.

Table 1: Land use / cover changes in South West Mau between 1973 and 2008

Land cover	**Area (ha)**			
	1973	**1986**	**2000**	**2008**
Forest	163,737	152,937 **(-6%)**	146,640 **(-10%)**	114,027 **(-30%)**
Disturbed forest	12,971	14,905 **(15%)**	17,685 **(36%)**	1,760 **(-86%)**
Farmland (upstream)	49,339	50,817 **(3%)**	52,747 **(7%)**	99,823 **(102%)**
Tea estates	34,536	34,706 **(0.5%)**	35,765 **(3.5%)**	38,996 **(13%)**

Mean annual rainfall
There was no significant variation in mean annual rainfall amounts between 1973 and 2008 ($F_{(1,22)}$ = 0.34; p = 0.567). A comparison across the four decades indicated that there were minor variations in rainfall amounts (Table 2), but these were not statistically significant.

Table 2: Mean annual rainfall amounts in South West Mau for between 1974 and 2008

Month	Mean annual rainfall amounts (1973 – 2008)			
	1970s	**1980s**	**1990s**	**2000s**
Jan	96	90.2	109.1	137.5
Feb	105.4	88.7	111	64.3
March	184.3	187.7	161.4	168.6
April	222.1	278.5	217.5	244.6
May	324.4	262.5	229.8	241.2
June	215	164.8	159.8	160.9
July	201.4	192.8	160.3	147.4
Aug	235.9	219.6	166.8	173.6
Sept	204.5	196.3	139.8	174.5
Oct	160.9	138.1	199.3	164.1
Nov	131.9	156.2	159.6	169
Dec	77	75.5	87.2	144.7
Mean (decade)	**179.9**	**170.9**	**158.5**	**165.9**

Monthly rainfall distribution

There was a significant variation in monthly rainfall distribution for the four decades. Months that were known to have lower rainfall experienced a very significant increase in mean monthly rainfall between 1973 and 2008 (Figure 2).

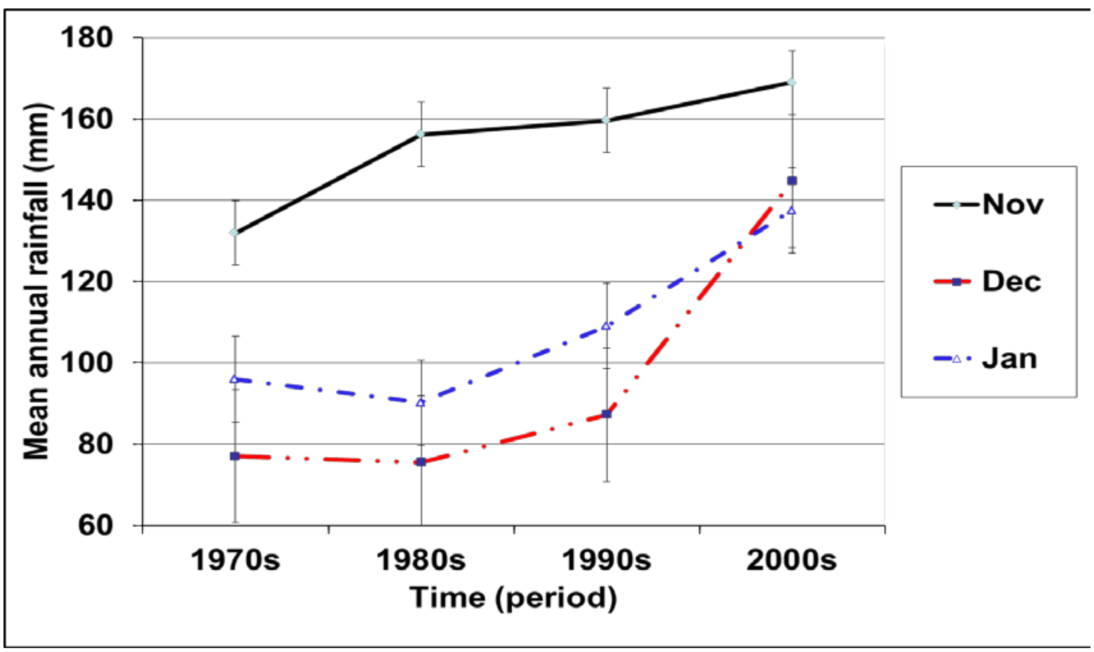

Figure 2: Months with increase in mean monthly rainfall in South West Mau between 1973 and 2008

Months that previously had higher rainfall experienced a significant reduction in mean monthly rainfall between 1973 and 2008 (Figure 3).

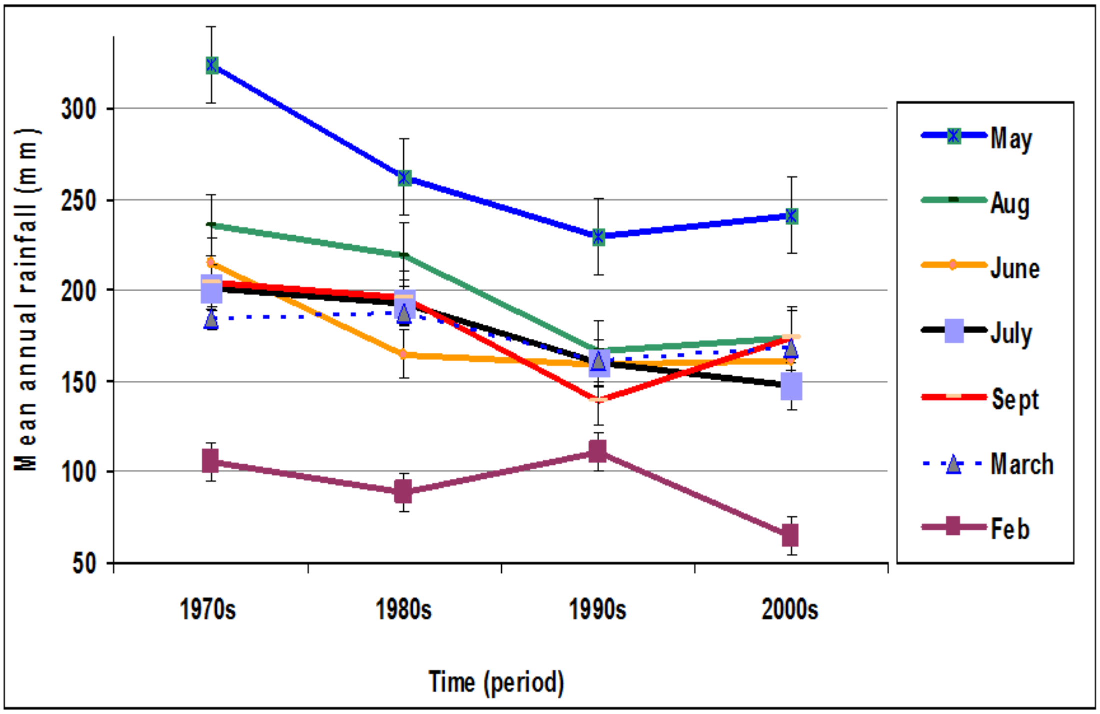

Figure 3: Months with decrease in mean monthly rainfall in South West Mau between 1973 and 2008

Forest degradation and stream flow index

There was a correlation between decrease in forest cover and stream flow volume. Stream flow index increased significantly between 2000-2003 and 2006-2008 ($F_{(1,81)} = 139.91$; $p < 0.001$) (Figure 4). This period accounted for about 67 % of the overall decrease in forest cover. However, stream flow was only higher immediately after a rainfall event, but it reduced to a bare minimum a few days later. This was likely caused by less interception and infiltration of rainfall due to reduced vegetation cover.

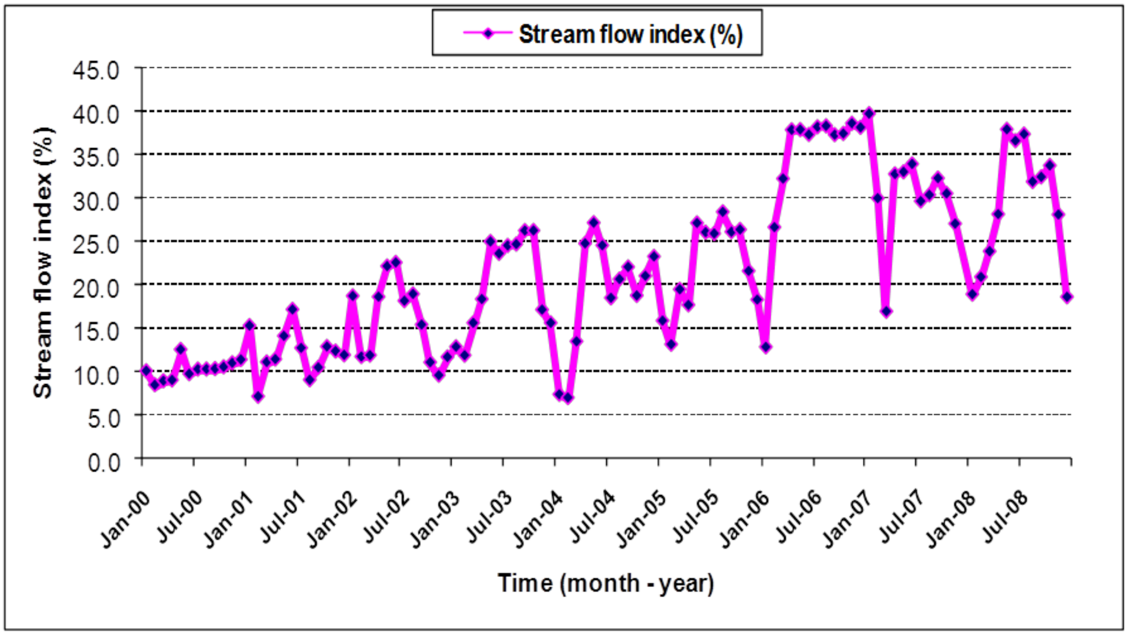

Figure 4: Variations in stream flow index in South West Mau between 2000 and 2008

Ecological and economic implications

Changes in rainfall distribution and stream flow index had an adverse impact on commercial tea production and hydroelectric power generation. A shift in rainfall distribution made it hard for tea estates to accurately predict rainfall trends as part of the planning process for crop production. There were also frequent crop attacks by frost, which became a common feature of months where rainfall amounts declined. Changes in stream flow index disrupted hydro-electric power generation along the Sondu River Basin. The power plant was only adequately supplied with water during times of high rainfall, which lasted only a few days. This was attributed to loss of tree cover and reduction in the capacity of the catchment to hold rain water for a long time and release it gradually as stream flow. Instead stream flow became perfectly synchronized with rainfall pattern because a great proportion of stream flow constituted runoff.

There were fears that reduced tree cover upstream was causing increased runoff as part of stream flow, and that this was ending up in Lake Victoria. Although this was outside the scope of our study, there were concerns that sediment carried with stream flow had the potential to harm aquatic life.

Challenges encountered

The study encountered two major challenges, namely: data gaps on stream flow as a result of breakdown of water gauging stations (between 1973 and 2008); and inconsistencies between data obtained from manual gauging stations and data obtained from automated stations.

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