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Impacts of land use and land cover change on surface runoff, discharge and low flows: Evidence from East Africa

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A R T I C L E I N F O

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A B S T R A C T

Region: East Africa.
Focus: A review of catchment studies (n = 37) conducted in East Africa evaluating the impacts of Land Use and Land Cover Changes (LULCC) on discharge, surface runoff, and low flows.
New hydrological insights: Forest cover loss is accompanied by increased stream discharges and surface runoff. No significant difference in stream discharge is observed between bamboo and pine plantation catchments, and between cultivated and tea plantation catchments. Trend analyses show that despite forest cover loss, 63% of the watersheds show non-significant changes in annual discharges while 31% show increasing trends. Half of the watersheds show non-significant trends in wet season flows and low flows while 35% reveal decreasing trends in low flows. Modeling studies estimate that forest cover loss increases annual discharges and surface runoff by 16 ± 5.5% and 45 ± 14%, respectively. Peak flows increased by a mean of 10 ± 2.8% while low flows decreased by a mean of 7 ± 5.3%. Increased forest cover decreases annual discharges and surface runoff by 13 ± 1.9% and 25 ± 5%, respectively. Weak correlations between forest cover and runoff ($r = 0.42$, $p < 0.05$), mean discharge ($r = 0.63$, $p < 0.05$) and peak discharge ($r = 0.67$, $p < 0.05$) indicate that forest cover alone is not an accurate predictor of hydrological fluxes in East African catchments. The variability in these results supports the need for long-term field monitoring to better understand catchment responses and to improve the calibration of currently used simulation models.

1. Introduction

The sustainable management of the earth's surface including Land Use and Land Cover Changes (LULCC) remains a critical environmental challenge that society must address (Mustard et al., 2004). Besides ecosystem vulnerability, LULCC are major determinants of global environmental change with potential severe impacts on human livelihoods (Olson et al., 2008). Such changes

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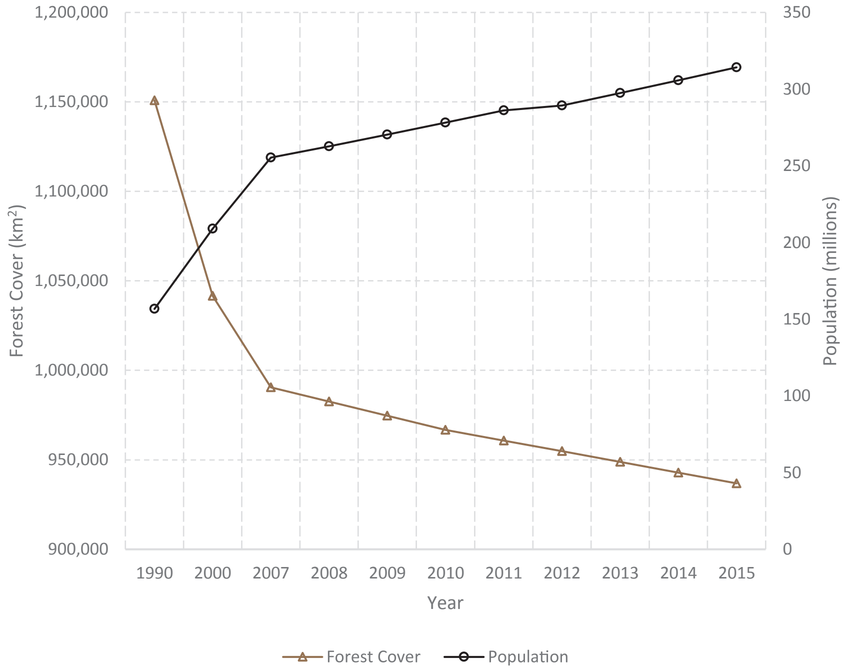

Fig. 1. Total forest cover decline and population increase in East Africa between 1990 and 2015.
(Data Source: The World Bank, 2017).

manifest in climatological, hydrological and biodiversity responses. Vitousek et al. (1997) estimated that between 39 and 50% of terrestrial ecosystems have undergone modification due to anthropogenic influence. The main drivers of LULCC are socio-economic development, population expansion, and pressures for land for agriculture (Lambin et al., 2003).

Like the rest of the world, East Africa is not an exception to these dynamics. East Africa depends largely on rain-fed agriculture, which makes rural livelihoods and food security highly vulnerable to shifts in water availability. Land is a critical resource for the livelihood of East Africans and there has been a steady decline in the size of land holdings per household. In order to meet this demand for land, LULCC in this region has resulted in loss of natural forests to human settlements, urban centers, farmlands, and grazing lands (Maitima et al., 2009). Between 1990 and 2015, East Africa forest cover decreased annually by about 1% while human population increased at an average annual rate of 2% (Fig. 1). The main forest types in East Africa that have undergone this decrease include tropical rain forests, tropical dry forests, tropical shrubs, tropical montane forest, and mangrove forests, while there have been concerted efforts to establish plantation forests. LULCC result in a trade-off between provisioning of food and fiber for human consumption, and minimization of negative impacts on other ecosystem services such as water quantity and quality (Mustard et al., 2004). Food production is dependent on water resources and therefore any likely impacts of LULCC on water resources have negative impacts on food production.

Although there has been abundant research on the impacts of LULCC on watershed hydrology, the evidence from the various studies is still contradictory. Malmer et al. (2009) argue that the general notion that "the basics of forest and water relations are well known", does not hold for watersheds with fragmented and dynamic land use patterns such as those observed in the tropical developing world. This means that the variation in catchment characteristics coupled with LULCC increases the uncertainty to find commonalities in observed hydrological signatures attributed to LULCC.

It is commonly argued that forests act both as 'pumps' through enhanced evapotranspiration (ET) rates and as 'sponges' through increased infiltration rates and soil moisture retention (Bruijnzeel, 2004; Arancibia, 2013). Forested watersheds therefore exhibit smaller streamflow rates than watersheds dominated by other managed land uses. Forest cover loss results in changes in albedo, reduction in aerodynamic roughness, reduction of leaf area, and reduction in rooting depth, consequently causing a reduction in ET which subsequently affects streamflow (Costa et al., 2003; Farley et al., 2005). The net effect of forest cover loss is increased water yield (Bosch and Hewlett, 1982). Additionally, a reduction in dry season flow is often cited as a consequence of deforestation (Bruijnzeel, 1988; Arancibia, 2013; Ogden et al., 2013; Liu et al., 2015).

However, despite these general conclusions, which are based on experiments at various spatial scales (e.g. plot, watershed and regional scales), empirical and physically-based (lumped and spatially distributed) modeling, and time series analyses, isolating the impacts of LULCC on water resources in a landscape is problematic because of uncertain interactions of factors driving these effects. Eshleman (2004) stated that these water yield increases associated with forest cover loss depend on a number of factors including the method of forest loss (Beschta, 1998), the extent of forest removal (Bosch and Hewlett, 1982), the rate of plant regeneration impacting ET (Federer and Lash, 1978; Swank et al., 1988), climatic conditions (Chow, 1964; Bosch and Hewlett, 1982; Whitehead and Robinson, 1993), and hydrogeology and catchment physical properties (Likens et al., 1978). The lack of controls in experimental