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Climate and Land-cover Change in Dryland-Catchments, and their Effect on Spate-hydrology of Farming Community in Semi-arid Lowlands of Raya-Valley, Northern Ethiopia

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Short Abstract

Spate-irrigation, a system foreseen as a potential means of improving agricultural production in rainfall deficit lowlands, is profoundly threatened by climate and land-cover change upstream. Yet, the actual implications of these changes on spate-hydrology has not been well studied. The objective of this study was thus to analyse the hydrological-response of dryland catchments to changing climate and land-cover in the Raya-valley. Long-term climate data were collected from National Meteorological Agency, and land-cover information extracted from Landsat satellite images. Soil Conservation Systems Curve-Number method was then employed to formulate the likely impacts of climate and land-cover dynamics on spate-hydrology. Average temperature, and evapotranspiration of the study area raised at a Coefficient of 0.13°C yr^{-1}, and 16.43mm yr^{-1} respectively. Rainfall on the other hand dropped at a coefficient of 5.1mm yr^{-1}. Land-cover change and Normalized Difference Vegetation Index analysis also showed improvement in vegetation-cover, enhancing water-retention capacity of the soil upstream. Declining rainfall, coupled with rising temperature and evapotranspiration on the top of increasing water-retention capacity of the soil aggravated moisture stress, thereby threatening spate-hydrology at a coefficient of $0.23x10^6 m^3$ yr^{-1}. Appropriate policies and strategies would therefore be desirable to address contesting interests on scarce water resources in the face of climate-change.

Keywords: Climate change; Land-cover change; Spate-hydrology; Farming community; Raya valley

1. Introduction

Ethiopia, a country whose economy highly dependent on rain feed agriculture, is threatened by high degree of variability and unreliability of rainfall pattern, and very much deteriorated by recurrent droughts (Hiben et al., 2013; Mitiku and Merga, 2002). Spate-irrigation is therefore foreseen as a potential means of improving agricultural production in rainfall deficit lowlands of Raya-valley. Despite its growing importance, combined effects of changing climate and land-cover in the upstream are affecting spate-hydrology to support crop production in the lowlands. Yet, the actual implications of these changes on hydrological response of the catchment has not been well studied. The objective of this study was thus to analyse the hydrological response of dryland catchments to changing land-cover and climate in the Raya-valley, the case of Guguf catchment. Long term climate data were collected from National Meteorological Agency, and Land-cover information were extracted from Landsat satellite images. Soil Conservation Systems Curve-Number method was then employed to formulate the likely impacts of climate and land-cover dynamics upstream on spate hydrology of the lowland farming community. Declining rainfall, coupled with rising temperature and evapotranspiration, allied with increasing water-retention capacity of the soil mainly as a result of improving landcover in the highlands aggravated moisture stress downstream, thereby making available moisture insufficient for crop production in the lowlands. This in turn also threatens availability of surplus water to generate spate hydrology i.e. the volume of water readily available for spate irrigation.

2. Methods

2.1. Climate data analysis

Long term historical daily climate data i.e., from 1980 to 2015, such as T_{min}, T_{max} and rainfall of the study area was collected from National Meteorological Agency (NMA), and evapotranspiration derived using Hargraves method (Allen et al., 1998). Data gaps were filled using AgMERRA satellite observation data downloaded from www.agmerra.com (Rosenzweig et al., 2013). Regression analysis was then carried out to look at long term trend of climate variables.

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2.2. Land-cover and NDVI change analysis

Landcover and NDVI dynamics trends were evaluated through remote sensing analysis of Landsat satellite images for the study area, i.e., path 168, raw 051. Satellite images of a dry month for the years 1984, 1994, 2002, and 015 were acquired from USGS website https://earthexplorer.usgs.gov/, and classification carried out based on supervised image processing, maximum likelihood method (FAO, 2005). Change detection was then carried out using overlay analysis in a GIS environment. Moreover, Normalized Difference Vegetation Index (NDVI) analysis was also carried out using the following formula:

$$ndvi = \frac{nir-red}{nir+red}, \qquad \text{equation 1}$$

Where NDVI is Normalized Difference Vegetation Index, NIR is Near Infrared band, and Red is Red band of electro-magnetic spectrum.

2.3. Hydrological response to Climate and Land-cover dynamics

Direct runoff volume, .i.e., spate hydrology to support lives of farming community in the lowlands, was estimated using Soil Conservation Systems – Curve Number method, equation 2, 3, 4, and 5, (Schneider and McCuen, 2005). The model quantifies the effect of changes in rainfall and land cover on hydrological response of catchments in the absence of sufficient hydrological data (Descheemaeker et al., 2008; Gebresamuel et al., 2010; and Teka et al., 2014), by employing preorganized daily rainfall, landcover, soil, and elevation data sets.

$$Q = \frac{(P-IaS)^2}{(P+(1-Ia)S)}, \quad when\ P > I_aS, \qquad \text{equation 2}$$

$$Q = 0, \quad when\ P < I_aS, \qquad \text{equation 3}$$

$$Ia = \lambda S, \qquad \text{equation 4}$$

Where Q is estimated runoff (mm), P is the measured daily rainfall (mm), Ia is the initial abstraction (mm), λ initial abstraction ratio and S is the maximum water retention parameter (mm) determined from weighted CN value.

Initial abstraction ratio of λ = 0.05 was adopted based on Descheemaeker et al. (2008), and Teka et al. (2014) recommendation, as an optimum initial abstraction ratio for the highlands of northern Ethiopia, based on least squares fitting for most experimental plots. Storage (S), is related to the dimensionless runoff curve number (CN), equation 5, and CN was estimated based on the storm-event method (Schneider and McCuen, 2005), which is a data-derived value that varies according to rainfall.

$$S = \frac{25400}{CN} - 254, \qquad \text{equation 5}$$

Where S is the maximum water retention parameter (mm), and CN is weighted curve number.

3. Results and discussion

3.1. Climate dynamics in Guguf Catchment

Observed climate data, i.e. 1980 to 2015, mainly temperature, rainfall, and evapotranspiration showed evident changes (Figure 1). Temperature of the study area significantly raised at a coefficient of 0.2 °C yr^{-1} for T_{max}, and 0.03 °C yr^{-1} for T_{min}. In line with this study, IPCC (2014) stated that, each of the last three decades has been successively warmer than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere (IPCC, 2014). Moreover, evapotranspiration raised at Coefficient of 16.43 mm yr^{-1}, rainfall on the other hand dropped at a coefficient of -5.1 mm yr^{-1}. Declining rainfall, coupled with rising temperature and evapotranspiration aggravated moisture stress, thereby making available moisture insufficient for crop production (Gebrehiwot et al., 2015). See Figure 1. This in turn also threatens availability of surplus water to generate runoff (Pechlivanidis et al., 2011).

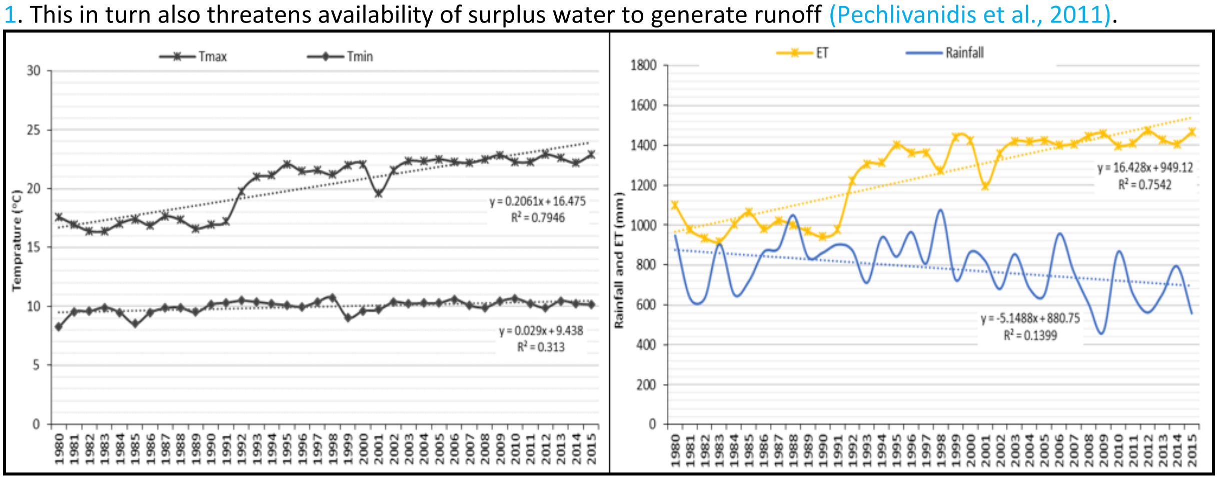

Figure 1: T_{min}, T_{max}, ET, and Rainfall trends of the study area, i.e. 1980 - 2015

3.2. Land cover and NDVI dynamics in Guguf Catchment

Significant modification and conversion of land cover has happened over the catchment during the last three decades. As proved by NDVI and landcover analysis, Vegetation cover showed higher improvement at a coefficient of 23.1 ha yr^{-1}, followed by cultivation (10.38ha yr^{-1}), and settlement (2.36ha yr^{-1}). Bare land on the other hand kept dropping at a coefficient of -34.84ha yr^{-1}. (Table 1).

Table 1. Land cover dynamics (area %) of the Catchment

Year	Bare	Settlement	Cultivation	Forest	Shrubs
1984	23.68	0.66	51.12	2.62	21.91
1994	16.99	0.87	52.17	3.01	26.97
2002	8.09	1.51	55.38	4.08	30.93
2015	2.12	2.05	57.16	9.19	29.49

As is also true for other researches (Abebe, 2014; and Gebresamuel et al., 2010), significant area of catchments was increasingly cultivated. On the other hand, there was evident expansion of woodlands in recent years (Bewket and Sterk, 2005) following afforestation and reforestation efforts. This is therefore a bold indicator that, campaigns made to restore hilly landscapes of Guguf catchment were fruitful. However, restoration of these steep hill sides enhanced storage capacity of the soil, and thereby limiting direct surface runoff (Abebe, 2014; Bewket and Sterk, 2005; Descheemaeker et al., 2008; Gebresamuel et al., 2010; and Nyssen et al., 2010).

3.3. Implications of Climate and landcover change on Spate-hydrology of semi-arid lowlands

The study profoundly referred that, volume of direct runoff, i.e. spate-hydrology to support lives of spate-based farming community in the lowlands, was threatening over the last three decades (Figure 2), mainly as a result of changes in climate and land cover (Figure 1, and Table 1). Estimates in annual volume of spate-hydrology declined at a coefficient $0.23x10^6 m^3 yr^{-1}$. See Figure 2.

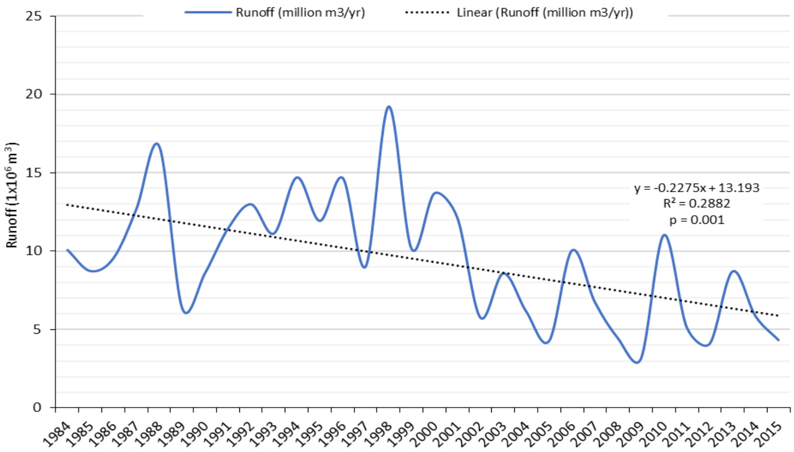

Figure 2: Direct runoff volume estimates ($1x10^6$ m^3 yr^{-1})

Changes in land cover basically determined threshold rainfall, i.e. number of rainfall events capable of generating runoff. Before runoff occurs, a threshold rainfall is always required due to interception and depression storage, as well as initially high infiltration losses depending on land cover type (Descheemaeker et al., 2008; Gebresamuel et al., 2010; and Teka et al., 2014). Rainfall events capable of generating river flow before 2000 were beyond average with some exceptions, whereas all years after 2001 remained below average. Therefore, raising water retention capacity of the soil mainly as a result of improving landcover in the highlands, on top of reduced rainfall and raising evapotranspiration exacerbated water stress, and thus limiting surface runoff to support spate-based farms in the lowlands.

4. Conclusions

Climate variables granted that there was considerable difference in rainfall, temperature and evapotranspiration distribution of the catchment over the last three decades since 1980. Despite increasing temperature and evapotranspiration, annual rainfall reduced significantly. Declining annual rainfall and number of rainy days beyond threshold rainfall, coupled with arising temperature and evapotranspiration aggravated moisture stress. Landcover and NDVI analysis also noted improvements in vegetation cover, and therefore contributing to increasing water retention capacity of the soil in the highlands. Intensifying moisture stress due to declining rainfall, and raising temperature and evapotranspiration; combined with improvement in water retention capacity of the soil in the highlands mainly as a result of improving landcover has therefore threatened hydrological response of highland catchments., i.e., spate-hydrology readily available in the lowlands, which is the volume of water to support spate-based farms in the lowlands. Thus, based on this study, dynamics in climate and landcover in the highland catchments has significantly affected spate-hydrology to support spate-based farms in the lowlands of Raya valley. Appropriate policies and strategies are therefore required to mediate contesting interests between the highland and lowland community on scare water resource in the fate of climate change.

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