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An assessment of the vegetation cover change impact on rainfall and land surface temperature using remote sensing in a subtropical climate, Ethiopia

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Highlights

- Effects of vegetation change on rainfall and land surface temperature is detected.
- Landsat images were used to analyze vegetation cover change.
- Most parts of the forest land have lost in the past 32 years.
- Mean annual rainfall decreased with declining vegetation cover.
- Land surface temperature increased as vegetation cover declined.

Abstract

Quantifying the impact of vegetation cover change (VCC) on climatic variables is a gap that the fields of conservation and rehabilitation must address. This study aims to assess VCC and its impacts on rainfall and land surface temperature (LST) in a highly deforested and populated area of Ethiopia. We used (i) Landsat images to analyze VCC using Normalized Difference Vegetation Index (NDVI) and threshold method and (ii) Climate Hazard Group InfraRed Precipitation (CHIRPS) and Moderate Resolution Imaging Spectroradiometer (MODIS) to evaluate rainfall and LST in the area using Mann-Kendall trend (MKT) test. Results show that 4.7% (210,177 ha) and 2.6% (116,387 ha) of the area was covered by vegetation in 1985 and in 2017 respectively, which implied that 2.1% (93,790 ha) of vegetation cover loss over the last 32 years. Although the mean annual rainfall increased from 1981 to 2017 and mean dry season LST increased from 2000 to 2017, the MKT test shows no significant trend with p-values of 0.09 and 0.35 rainfall and LST, respectively. Mean annual rainfall decreased with declining vegetation cover and mean LST increased as vegetation cover declined in central, northern and southeastern parts of the study area.

The outputs from this study would provide information to maintain the agro-climatic condition, assure sustainability in resource utilization and proper land use planning and decision making for the concerned stack holders.

Introduction

Land use/land cover changes (LULCC) has become a major issue for natural resource management and environmental change monitoring (Ahmed, 2016). LULCC has impacts on terrestrial ecosystems including forestry, biodiversity and agriculture that have been recognized as high-priority issues in global, national, and regional development initiatives. Thus, land productivity such as forest cover could be declined because of LULCC under continuous cultivation, overgrazing and soil erosion (Melese, 2016). These activities also contribute to climate change (Hailemariam et al., 2016). LULCC analysis focuses on understanding the processes, patterns and dynamics behind transitions in land use and their driving forces (Nduati et al., 2013). LULCCs are temporally and spatially dynamic (Ayele, 2011). Deforestation has already significantly impacted the climate in Ethiopia (Fekadu, 2015) and presents a major threat to atmospheric conditions, loss of biodiversity, desertification, and displacement of people (Fekadu, 2015; Belay and Getaneh, 2016; Dinkayoh, 2016). Clear-cutting of forests has resulted in heavy soil erosion and land degradation and, consequently, declines in annual crop yields, especially in the Ethiopian highlands (Mekonnen et al., 2016). Therefore, studying the rate of VCC and its impacts on the environment using remote sensing is a key issue for effective decision making in the conservation of natural resources.

Remote sensing technology is important for observing and quantifying the natural resources and dynamic phenomena on the Earth's surface (Zhang et al., 2010). In recent years, remote sensing data has effectively assessed long-term changes in vegetation cover (Batool et al., 2015). It is also widely used in studies of environmental and climate sciences (Zhang et al., 2010). Satellite imagery presents a cost-effective opportunity to capture and to analyze land cover (LC) data over large geographic regions.

Mapping, quantifying and monitoring LC is essential for understanding the current state of the landscape. Normalized Difference Vegetation Index (NDVI) is one of satellite imagery product which indicates the greenness of vegetation cover (Akinsanola and Babalola, 2016) as related to the scale of vegetation cover: either dense or sparse (Lamchin et al., 2004). NDVI indicates the existence of vegetation cover, which plays a great role in mitigating local climate change and climate variability, in addition to fractional vegetation cover (Rasul and Ibrahim, 2017). Studies have shown that NDVI is an indicator of vegetation growth, coverage, monitoring and the spatiotemporal characteristics of LULC (Lamchin et al., 2004; Ahmed, 2016; Zewdie, 2016). Thus, assessing spatiotemporal deviations in vegetation cover is a key indicator for understanding natural changes in the environment (Lamchin et al., 2004).

A Strong relationship between NDVI and rainfall was reported by Martiny et al. (2006). Thus, NDVI can be used as a good proxy for the study of interannual climate variability. Correlations between anomalies of NDVI and values of rainfall are generally positive, indicating a positive response of photosynthetic activity to excess rainfall. Rainfall is the most important climatic factor that closely correlates with NDVI (Richard and Poccard, 2010). A simple linear relationship between NDVI and rainfall with positive correlation has been found in many studies (Li et al., 2004; Richard and Poccard, 2010; Lamchin et al., 2004). It was identified that the rainfall pattern is decreased due to vegetation cover declined (Batool et al., 2015).

There is a strong negative correlation between LST and NDVI values (Rehman et al., 2015; Chaithanya et al., 2017; Suresh and Mani, 2017). Vegetation with dense cover has the lowest mean LST and highest mean NDVI; while non-vegetated areas have the highest LST and lowest mean NDVI (Sun et al., 2011), which implies that lower LST is usually measured in areas with higher NDVI values. The temperature is greater in areas, which have low vegetation cover (Sruthi and Aslam, 2015). These indicated that vegetation cover can reduce LST (Sruthi and Aslam, 2015) and Land Surface Temperature (LST) is sensitive to vegetation cover (Chaithanya et al., 2017). LST is highly influenced by the LULC, and as such is sensitive to vegetation and soil moisture; specifically, the amount of vegetation cover is the main factor on the relationship between vegetation cover and LST (Rasul and Ibrahim, 2017).

This study investigates the impacts of VCC on the variability of climate parameters (rainfall and LST) in the North Gondar Zone using remote sensing and statistical analysis. Deforestation in the study area has been prevalent for different land use purposes. However, no study has comprehensively addressed the rate of deforestation and its impact on the climate. Thus, estimates of the changes in vegetation cover and its impact on climate variability on large spatial and temporal scales are necessary to sustainably manage vegetation resources and monitor the climate. This study seeks to assess the spatial and temporal changes in vegetation cover for the period 1985 to 2017 and examine its impacts on climate variabilities (rainfall and LST).

This study would provide information which is important to maintain the agro-climatic condition, assure sustainability in resource utilization and proper land use planning and decision making for policy makers, agricultural experts, foresters, non-governmental organizations (i.e., forest management stakeholders), planners and land administrators. Besides, the present study will provide firsthand information for the other researchers who have an interest to conduct further study related to landscape change and landscape disturbance from remote sensing data.

Section snippets

Description of the study area

North Gondar Zone is one of the largest zones in the Amhara National Regional State, Ethiopia. It has 23 administrative districts and covers a total area of 4,476,421 ha. The study area is geographically located between 11°37′31″ to 13°54′9″ N and 35°16′36″ to 38°44′54″ E and found north to Lake Tana (Fig. 1). The projection of the total population of North Gondar Zone is 3,654,920 (CSA, 2013). People in rural areas of the North Gondar Zone engage in mixed farming, both growing crops and …

NDVI and LC change

For the years 1985 (Fig. 2a) and 2017 (Fig. 2d), the NDVI of the study area ranges from +1.00 to -0.51 and+0.53 to -0.22, respectively (Table 2). In 2000 (Figs. 2b) and 2010 (Fig. 2c), the NDVI values ranged from -0.56 to 0.67 and -0.53 to 0.63, respectively. Overall, the maximum value of the vegetation index decreased from 1.00 in 1985 to 0.53 in 2017. As Table 2 shows, the mean value also decreased from 0.14 in 1985 to 0.07 in 2017. Hence, the highest mean value of NDVI revealed the greatest …

Discussion

Over the past 32 years, North Gondar Zone has lost 2.1% of its total vegetation. Increased population growth and agricultural activity are two primary reasons for the reduction in vegetation cover. Similar results were found in Melese (2016), reported that a greater rate of deforestation than afforestation is the driving factor in the depletion of vegetation in Ethiopia. Population increases clearly increase the demand for additional agricultural and settlement land in a given area. These needs …

Conclusion

This study uses NDVI values as a proxy for observing vegetation cover in the central, northern and southeastern parts of North Gondar Zone, Ethiopia. Threshold results indicate that 4.7% of the study area was covered by vegetation in 1985, which had been reduced to 2.6% by 2017. Hence, the study area has lost 2.1% of its vegetation cover in the last 32 years. Despite the fact that it was insignificant, the area shows an increasing trend of minimum, maximum and mean annual rainfall from 1981 to …

Ethical statement

I testify on behalf of all co-authors that our article submitted to journal of Remote Sensing Applications: Society and Environment: entitled "An assessment of the Vegetation Cover Change Impact on Rainfall and Land Surface Temperature using Remote Sensing in a subtropical climate, Ethiopia" by Worku Nega, Biniam Tesfaw Hailu and Aramde Fetene:

(1) The manuscript has not been published in whole or in part elsewhere; …

(2) The manuscript is not currently being considered for publication in another journal; …

(3) …

…

Declaration of competing interest

The authors declare no conflict of interest. ...

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…In recent times, geospatial technology such as Remote Sensing (RS), Geographical Information Systems (GIS) and Global Positioning System (GPS) are advancing expeditiously to generate rapid, continuous, and accurate results with high precision (Dayal et al., 2021; Lai et al., 2019; Mishra 2015). The potential use of this technology has already been explored in several problems in hydrology (Bhanja and Mukherjee 2019; Dayal et al., 2021; Fenta et al., 2017; ; Himanshu et al., 2017a; 2017b; 2018; Jamshidi et al., 2019; Kikon et al., 2016; Kumar et al. 2019a, 2021; Lai et al., 2019; Machado et al., 2020; Mahmood and Hossain 2017; Merrikhpour et al., 2021; Mondal et al., 2018; Nega et al., 2019; Nithya et al., 2019; Paul and Pal 2020; Swain et al., 2017; Thakur et al., 2021), and therefore, it can be extended in managing the UDS. While some previous studies (Pathak et al., 2020; Rai et al., 2017) used only interpolated daily rainfall data having the spatial resolution of 0.25° provided by the India Meteorological Department (IMD), this paper used Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (IMERG).…

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…This result is very possibly due to the decrease in the air humidity promoted by vegetation through transpiration. Plant cover has a positive effect on local precipitation, and the volume is decreased due to vegetation cover reduction (Nega et al., 2019). Excessive removal of vegetation (>55% of the original surface) can significantly reduce the regional level of precipitation (Panday et al., 2015).…

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