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Research article

Does the recent afforestation program in Ethiopia influenced vegetation cover and hydrology? A case study in the upper awash basin, Ethiopia

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ABSTRACT

The Ethiopian government planned afforestation programs in the past decades whereas more attention was given to tree plantation since the 2010 year. However, the effectiveness of the afforestation programs and its impacts on vegetation cover and hydrology has not been well studied. This study aims to assess the recent campaigned afforestation program and its impact on vegetation cover and hydrology in the upper Awash basin, Ethiopia. Landsat 8 images of 2013–2020 years were used to calculate the NDVI for the upper Awash basin to assess trends in vegetation greenness for the basin. Moreover, observed streamflow and precipitation datasets of the basin were collected and used for assessing the impact of the afforestation on hydrology. The study result showed decreasing NDVI values despite the afforestation programs in the upper Awash basin. This shows either afforestation rate was less than the deforestation rate or the tree plantation campaign was not effective in the basin. In addition, the campaign based tree plantation focused on the number of tree planted not on how many trees are grown. On the other hand, mean annual precipitation and streamflow were generally increased from 2013 to 2020 in the upper Awash basin. Declining NDVI values but increasing mean annual precipitation in the Awash basin indicated that the declining vegetation was attributed to anthropogenic effects. The increasing streamflow during the same time could be due to the increasing mean annual precipitation. Moreover, the decreasing vegetation cover might have contributed for the increasing streamflow through increasing surface runoff and decreasing transpiration. However, further research is required to assess the precise impacts of afforestation on vegetation cover and hydrologic processes. Generally, the study result showed that the focus of afforestation should be on tree growing than on tree plantation alone.

1. Introduction

Vegetation plays an important role in determining material and energy fluxes between soil, atmosphere and water affecting biogeochemical composition of terrestrial ecosystem and the atmosphere (Lin et al., 2020). As such, vegetation influence terrestrial land surface and atmospheric processes and act as an interface between land surface and atmosphere (Yan et al., 2017). Studies investigated changes in vegetation cover and its impacts on climate and hydrologic processes using remote sensing technology (Pei et al., 2019; Kalisa et al., 2019; Yan et al., 2017; Nadal-Romero et al., 2016). For example, Kalisa et al. (2019) reported spatiotemporal vegetation cover dynamics over East Africa from 1982 to 2015. Moreover, forest cover change in the Mediterranean humid mountain area affected streamflow (Nadal-Romero et al., 2016). Yan et al. (2017) reported increasing trends in vegetation cover during 2000–2015 in Nanxiong basin of China.

Trends in vegetation cover is commonly assessed using Normalized Difference Vegetation Index (NDVI). The NDVI provides a critical historical perspective on vegetation status and it quantifies vegetation greenness and density by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation strongly absorbs) (Zhou et al., 2019). Time series analysis of NDVI is important for understanding the status and conditions of vegetation over time. Accordingly, several studies have investigated time series NDVI and its relation with climate variables (John et al., 2013; Zhou et al., 2019; Chu et al., 2019; Ding et al., 2020). However, the results of such analysis varies with time and seasons. Therefore, it is important to categorize the NDVI time series and climate analysis in terms of annual, seasonal or month basis (Pei et al., 2019). Since climate change inevitably affect vegetation growth, dynamics and functions (Pei et al., 2019), NDVI trend analysis and its relation with climate variables is important (Zhou et al., 2019).

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The remotely sensed derived NDVI can indicate growth status, phenology and vegetation density over large spatial extents and at a finer temporal resolution (Yan et al., 2017). Furthermore, NDVI has been used in various agricultural applications like for drought monitoring, crop yield prediction, calculating crop phenological information, estimating the aboveground biomass, and detecting land cover change (Mallick et al., 2021). It has been widely used to monitor vegetation dynamics and vegetation responses to human factors and climate changes (Gutman and Ignatov, 1998). For example, Dagnachew et al. (2020) reported increasing and decreasing mean annual NDVI and precipitation that varies spatially and temporally.

Moreover, vegetation cover influence hydrologic processes of a basin. For example, Sorriso-Valvo et al. (1995) reported the impacts of afforestation on hydrologic processes and soil erosion on hillslope side of small Calabrian catchment. The hydrologic response to large-scale afforestation and vegetation greening is spatially variable on key hydrologic variables (Li et al., 2018). A study conducted in India reported that afforestation is not the only factors that affect hydrologic processes, other basin characteristics such as soil, geology, and topography are also important (Venkatesh et al., 2014). Afforestation positively affects NDVI and they are linearly related (Lin et al., 2020).

To reduce deforestation, Ethiopian government have been launched afforestation programs in different times. For example, the government of Ethiopia launched a Climate Resilience Green Economy (CRGE) strategy in 2011. The strategies include protecting and managing the existing forest, and afforesting and reforesting the degraded land (Zeleke and Vidal, 2020). Accordingly, the government of Ethiopia has set a goal of afforesting and reforesting about 3 million hectares of land by 2030 (FDRE, 2011). In addition, Ethiopia launched National Green Development program in 2019, which aims to combat climate change and environmental degradation (Woldegiorgis, 2020). Under this program, Ethiopia planned to plant more than 4 billion trees on 1.5 million hectares across the country (https://pmo.gov.et/greenlegacy/). Despite afforestation and tree planting initiatives declared in different times by Ethiopian government, its effectiveness and the impacts of the plantation on vegetation cover is not well known in Ethiopia in general and in the upper Awash basin in particular. Moreover, there is no study conducted that show weather these afforestation program launched in different time are effective or not. Therefore, this study is intended to assess vegetation cover using remote sensing based NDVI trend analysis and its impacts on streamflow of the upper awash basin, Ethiopia from 2013-2020.

2. Study area

Awash basin is one of the most utilized and important basins from the total of 12 basins in Ethiopia. The basin is the main population centers of the country and the lifeline for more than 18.6 million people located in the central Rift Valley in Ethiopia. The basin is situated between 7°53′N and 12°N latitude and 37°57′E and 43°25′E longitude with the drainage area of 116, 449 km^2. The river emerges from the central highlands 150 km west of Addis Ababa and flows via the central Rift Valley to Lake Abbe on the border with Djibouti (Edossa et al., 2010; Karimi et al., 2015).

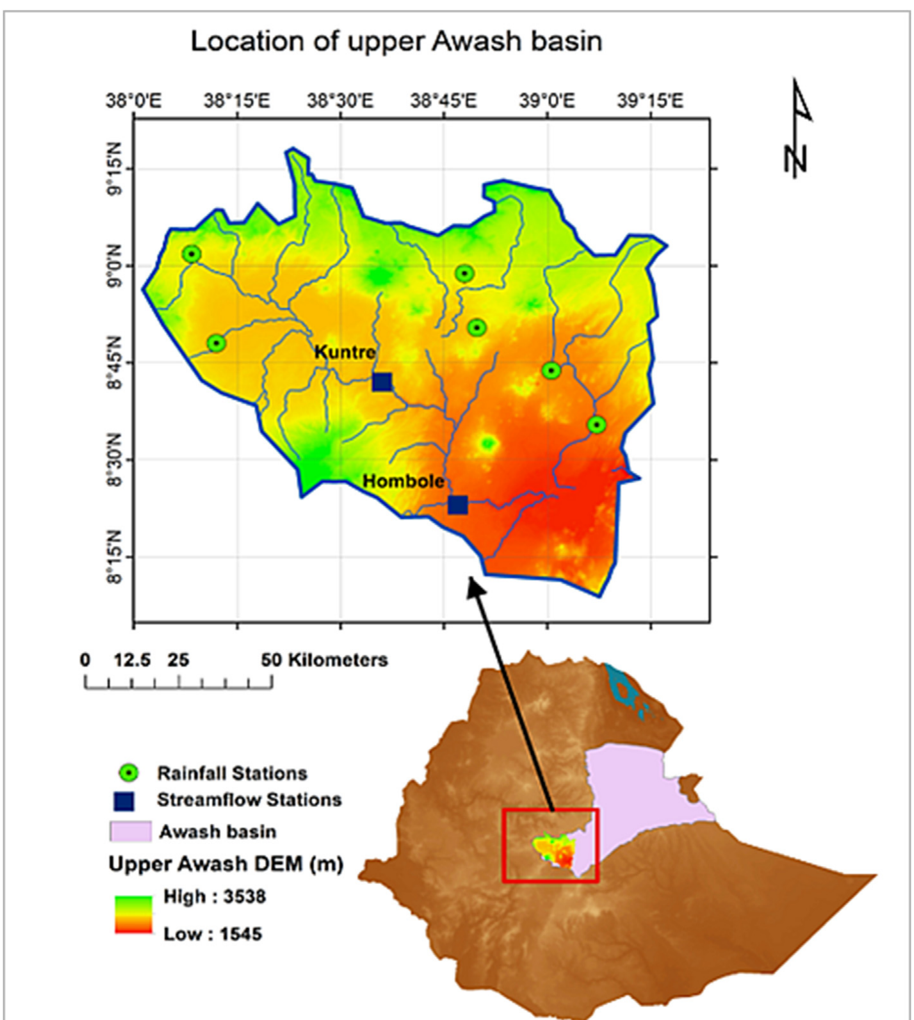

Figure 1. Location of upper Awash basin and the hydrometeorological stations.

Awash basin is divided into upper, middle and lower river basin based on its climatological, socio-economic, agricultural and water resources characterization (Taddese et al., 2004; Adeba et al., 2015). This study focuses on the upper part of the basin that is situated at the upstream side of the basin in which the river emerges and headwater of the Awash basin. The upper Awash basin is the main part of the highlands of the basin that is suitable for plantation with enough amount of precipitation for rain feed agriculture and suitable for the plantation of seedlings for afforestation. The upper Awash basin at the headwater of Awash River basin are situated between 8°16′ and 9° 18′ latitudes and 37° 57′ and 39°17′ longitude (Figure 1). The total drainage area of the upper Awash basin is estimated to be 11,720 km^2 at the outlet of Koka reservoir. Elevations range between 3,538 to 1,545m above sea level and the major urban centers of the country, such as Addis Ababa, Adama, and Bishoftu are located within the upper Awash basin (Shawul et al., 2019).

The climatic condition of Ethiopia including the upper Awash basin is mainly controlled by the seasonal migration of the Intertropical Convergence Zone (ITCZ) and other related atmospheric circulations resulted from its complex topography (Taye et al., 2018). Accordingly, the climatic condition of the upper Awash basin is characterized as moist with mean annual temperature of 27.18 °C (Reta et al., 2019). The mean annual precipitation of the upper Awash basin is about 832 mm where the area receives 80% of the precipitation during the main rainy season (June to September) (Gebremichael et al., 2022). The major land use land cover types of the study area include agricultural land, forest, bush and shrub land, and built up where agriculture is the dominant (Daba and You, 2022).

3. Data, methods and techniques

To evaluate the influence of the recent afforestation program on the hydrology, the corresponding precipitation and streamflow datasets of the basin are required. However, obtaining the recent and updated hydrometeorological datasets is challenging task especially in developing countries like Ethiopia. From the total precipitation stations in the upper Awash basin, only six of them have the recent measured data and with better quality and records. As such, precipitation from 2013 to 2020 for the Addis Ababa (Bole), Bishoftu, Mojo, Akaki, Teji and Ginchi were collected from Ethiopian Meteorological Agency (EMA) and used for this study (website). Using these six stations, the average area precipitation using nearest method was computed in Matlab environment. From the hydrometeorological datasets, the streamflow data collected from Ministry of Water Irrigation and Energy of Ethiopia are not updated yet until 2020 for the whole basin. The streamflow stations of Kuntre and Hombole have better recordings from 2013 to 2018 (not updated to 2020) compared to the rest streamflow stations in the basin and was used to evaluate the influence of the recent afforestation on the hydrology (Figure 1).

Landsat 8 of the year 2013–2020 were downloaded from United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). The imageries were downloaded from path 168, 169 and raw 54. The spatial resolution of all the imageries are 30 m and downloaded during dry season where cloud cover is less than 10%. We computed the NDVI trends using Landsat 8 from 2013 to 2020 to evaluate the influence of the recent afforestation program on the vegetation cover in the upper Awash basin. The earlier period of 2010, 2011 and 2012 have not included in this study to compute the NDVI values due to the Landsat 8 image product has strip, and the aim of this study is to assess the impact of recent afforestation program. The strip might cause biased value of NDVI that does not represent the real value of the basin. Therefore, the NDVI values from the year 2013 onwards was considered to evaluate the influence of the recent afforestation on the vegetation cover in the basin. In addition, to avoid the effect of crops that are temporally green during the growing periods in the basin mostly from May to November, the satellite images of the dry season after the harvesting period were used for the NDVI analysis.

The time series Landsat 8 imageries were geometrically and radiometerically corrected, and mosaicked. NDVI of each image from 2013 to 2020 were calculated based on the standard formula (Eq.1). The NDVI is the most widely used index for monitoring the spatiotemporal dynamics of green vegetation and Ecoclimatic studies (Chu et al., 2019). The value ranges from -1 to 1 where value less than 0 indicates bare land and/or waterbody while values greater than 1 shows vegetation. The NDVI value approaching 1 indicates healthy and dense vegetation and NDVI value approaching -1 indicates bare land and/or waterbody while values approaching 0 shows scarce and/or unhealthy vegetation (Chu et al., 2019).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where NIR is represents spectral reflectance in the near infrared (800–1000 nm) and RED represents spectral reflectance in the red (620–750 nm) portions of the electromagnetic spectrum, respectively.

Accordingly, the NDVI were calculated for each year and mapped, from which spatial mean NDVI value were computed and used to assess the trend of vegetation cover changes for the study area. The mean NDVI value of the upper Awash basin was computed using the image obtained from Landsat 8 for each year of the study period from 2013 to 2020. The areal precipitation mean value was computed for each year from 2013 to 2020, and for streamflow stations from 2013 to 2018 (due to the lack of updated streamflow data). The mean values of NDVI, precipitation and streamflow were computed using Eq. (2).

$$Mean = \frac{\sum_1^N V}{N} \tag{2}$$

V = the value of NDVI, precipitation or streamflow for each day.

N = the number of years for NDVI and precipitation but number of days for stream flow.

Moreover, time series hydrometeorological datasets such as precipitation and streamflow were analyzed to see the trends of the variables during the study periods (i.e., 2013 to 2020). Accordingly, the trends of precipitation and stream were analyzed graphically. Finally, the results of time series NDVI, precipitation and streamflow trends were interpreted. However, due to the limited data available we could not evaluate in a quantitative way the observed empirical correlations.

4. Results and discussions

4.1. NDVI

Figure 2 shows NDVI maps of the upper Awash basin from 2013 to 2020. NDVI value ranges from -1 to 1. NDVI values less than 0 shows bare land and/or waterbody while values greater than 0 indicates vegetation cover. Accordingly, the result show that NDVI varies both spatially and temporally, particularly during the 2014 and 2016 more areas was with NDVI values greater than 0 particularly in the southeastern parts of the study area compared to the other years. Figure 3 shows mean NDVI trend from 2013 to 2020. Maximum mean NDVI value was observed during the 2013 while minimum mean NDVI value was observed during 2017. The result generally shows decreasing NDVI trend from 2013 to 2020. This manifests that vegetation cover was decreased during these periods in the upper Awash basin. The declining vegetation cover despite the afforestation programs that have been implemented in Ethiopia including in the upper Awash basin. This could be due to the fact that deforestation rate was higher than afforestation and/or lack of enough management and follow for the planted seedlings. The afforestation programs in Ethiopia have been done through campaign in which some may be involved against their interest. As such, the seedlings may not properly planted and in addition, the people who planted the seedlings do not monitor and care the planted trees. It is not common to see the organization or individuals to care about what they planted. This is a very great challenge

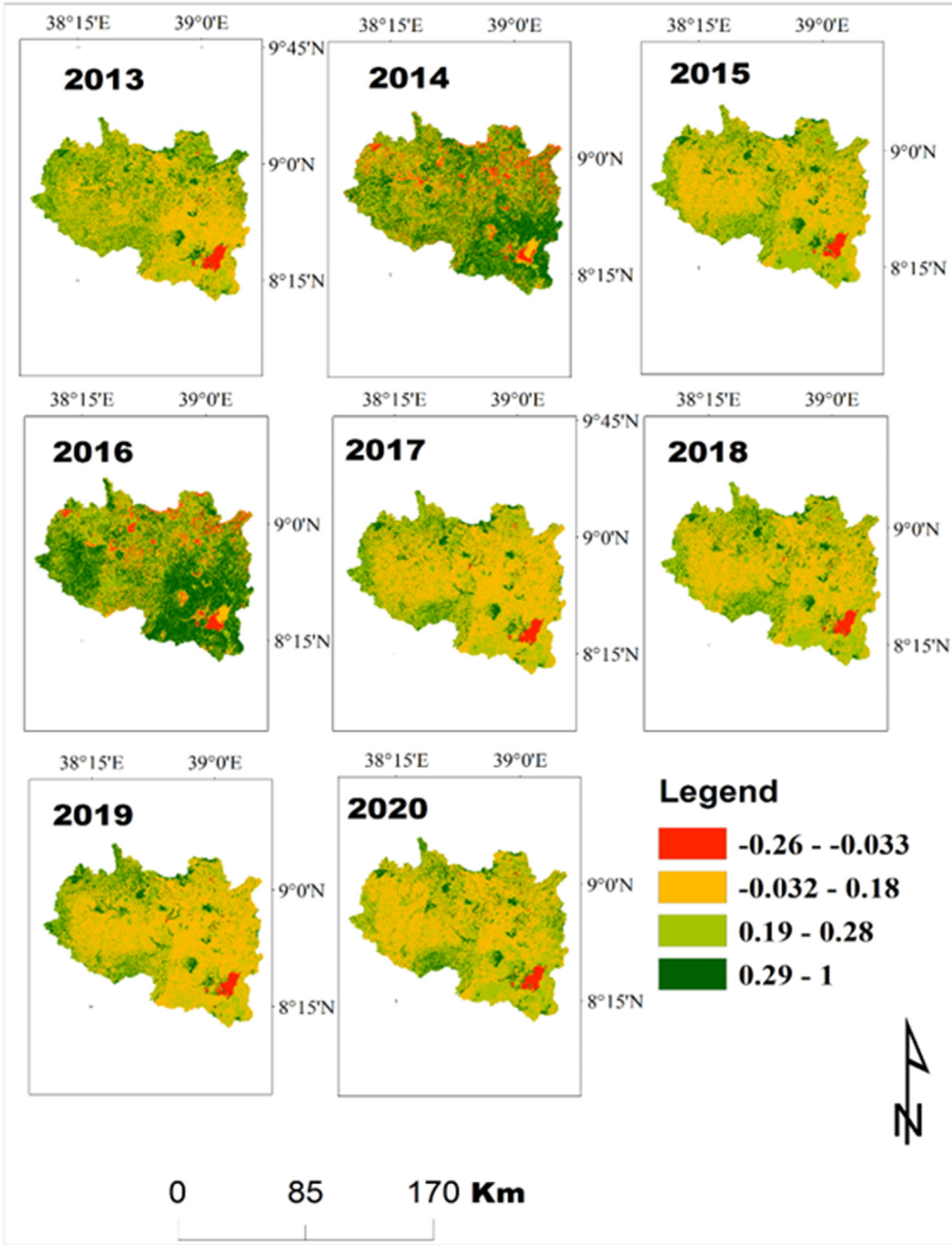

Figure 2. Spatiotemporal NDVI from 2013 to 2020.

for the effectiveness of the campaign-based afforestation. Limitations of campaign-based tree plantation and participatory forest management includes unclear ownership and use rights, low levels of community participation, poor productivity and weak institutions (Kassa et al., 2017).

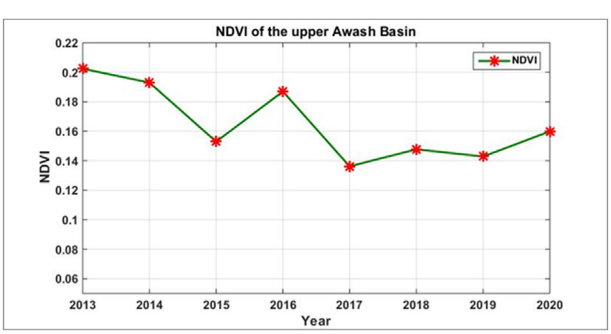

Figure 3. The NDVI value of the upper Awash basin.

Community centered tree planting is effective for the effective afforestation program while campaign-based tree planting, without the interest of the people, is not an effective intervention because tree plantation without addressing the social derives that caused deforestation will not mitigate deforestation (Fleischman et al., 2020). A well planned and multi-year commitment is required for successful afforestation program and mitigate climate changes. According to Veldman et al. (2019), tree planting has been promoted as climate change mitigation strategies. However, large-scale tree planting programs resulted most of the time with high failure rates resulting in little carbon sequestration and wastage of resources (Duguma et al., 2020; Fleischman et al., 2020). Tree seedlings cannot grow anywhere rather they need proper soil to grow on, watering during the dry season, and protecting against human and livestock damages (Duguma et al., 2020). Studies showed that higher survival rate of seedlings are observed in a fenced and sheltered area compared to the non-fenced and unsheltered areas (Wassie et al., 2009; Reubens et al., 2009).

According to Duguma et al. (2020), the challenges that limited the success of afforestation program in Ethiopia include (i) the ultimate objective of the campaign is tree planting when the aim should be tree growing. In the same manner, the number of trees planted in a given area are the performance indicators but does not show the number of trees grown, or the area of land covered with trees, (ii) planting the right trees at the right place and for the right purpose is less emphasized, (iii) after planting management is very limited, and (iv) lack of tree tenure to formally transfer the management of planted trees to local communities. As such, for effective afforestation program and to minimize ecosystem degradation, these challenges should be tackled and mindsets of the community should be changed; and tree plantation and growing should not be campaign based rather it should be based on the interest of the people.

4.2. Precipitation

The daily mean areal precipitation (mm/day) from the six gauging stations in the upper Awash basin manifests decreasing trend from 2013 to 2015 similar with the NDVI result, however, from 2016 to 2020 the precipitation magnitude shows significant increasing trend in contrary with NDVI as shown in Figure 4. The result of the precipitation trends reveals that there was drought in 2015 and there is minimum precipitation value from the whole study period. However, the result of the NDVI shows that minimum value was observed during 2017. From Figures 3 and 4, it is possible to say that the NDVI and precipitation trends for the upper Awash basin were not the same during 2013–2018. In general, the precipitation shows increasing trends between 2015 to 2020, which is contrary with the NDVI trend during the same periods. It is anticipated that the increasing precipitation trend helps the seedling to grow well and as a result, vegetation cover would be increased in the basin. However, the NDVI value decreased contrary to the increasing magnitude and trend of precipitation in the basin. Study showed that vegetation greenness strongly correlated with precipitation (Berry and Mackey, 2018; Lamchin et al., 2020). Therefore, the decreasing NDVI in contrary to increasing precipitation and afforestation program shows that deforestation rate is higher than afforestation and/or the planted trees were not successfully grown.

4.3. Streamflow

Figures 5 and 6 show mean streamflow for the Hombole and Kuntre gauging stations, respectively. The result shows that streamflow decreased from 2013 to 2015 but increased from 2015 to 2018 for the Hombole station. On the other hand, streamflow decreased from 2013 to 2014 while increased from 2014 to 2018 for the Kuntre gauging station. The result generally showed that streamflow has similar trends with that of the precipitation trends for the upper Awash basin. However, the trend

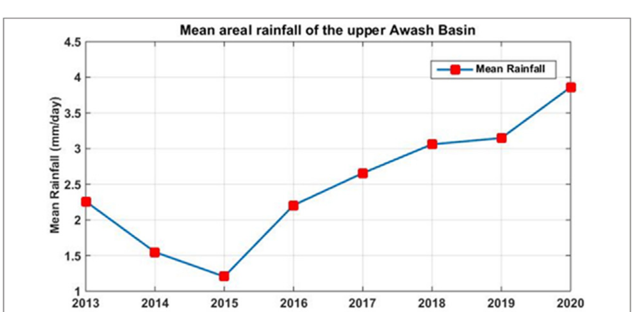

Figure 4. The mean areal precipitation (mm/day) from six precipitation-gauging stations in the upper Awash basin.

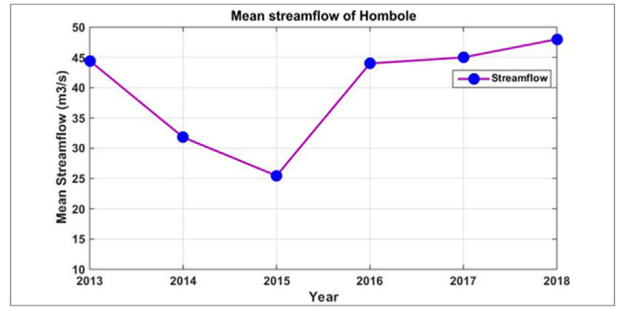

Figure 5. Mean streamflow of Hombole station (2013–2018).

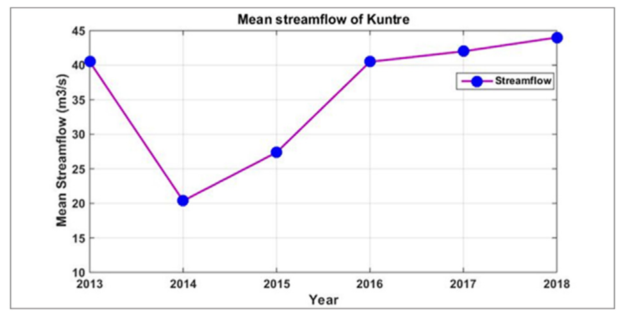

Figure 6. Mean streamflow of Kuntre station (2013–2018).

is different from that of NDVI trends as in the case of precipitation for the upper Awash basin.

The increasing streamflow in the upper Awash basin from 2015 to 2018 is due to the increasing precipitation during this time. In addition, the declining vegetation cover in the basin contributed for the increasing streamflow through increasing surface runoff during wet season. Deforestation increased mean annual streamflow, peak streamflow and surface runoff (Guazha et al., 2018). According to Gholami (2013), deforestation have a potential to increase surface runoff during rainy season resulting in increased wet season streamflow. However, deforestation decreased infiltration and groundwater recharge resulting in reduced baseflow, which further negatively affect streamflow during dry season. For example, Shawul et al. (2019) reported increasing surface runoff but decreasing groundwater recharge in the upper Awash basin due to deforestation. Likewise, the conversion of natural vegetation to agricultural land decreases dry season flow and increases wet season flow (Mango et al., 2011).

The limitations of this study are that we limited the study periods from 2013 to 2020 because of the availability of hydro-climatologic data. Moreover, the scope of this study is limited to assess the impacts of the recent afforestation program implemented in Ethiopia. In addition, the study did not consider the relationship between NDVI and precipitation and river runoff because we only consider only six rain gauge stations as the basin is data scarce. Therefore, we think that doing correlation with such limited precipitation data may not represent the reality.

5. Conclusions

Afforestation programs or tree plantation have been implemented in Ethiopian during the past several decades. Afforestation and tree plantation could minimize land degradation if properly implemented and monitored. However, the tree plantation alone does not guarantee increasing vegetation cover, continuous monitoring and managing the planted trees are equally important for the effectiveness of afforestation programs. The study result shows that vegetation greenness declined in the upper Awash basin during 2013–2020 despite afforestation programs implemented by Ethiopian government in the country. This indicated that tree plantation implemented in the upper Awash basin was not effective or deforestation rate was higher than afforestation in the basin. The ineffectiveness of the afforestation program in the upper Awash could be mainly due to the fact that: (i) it was campaign based where all peoples who participated in the plantation may not be based on their interest, (ii) the focus of the campaign was how many trees are planted but not on how many trees grown and areas are covered by trees, and (iii) continuous management of the planted trees are missing.

On the other hand, mean annual precipitation and streamflow for the same year are generally increasing for the upper Awash basin unlike that the NDVI trends. This show that the decreasing vegetation greenness or cover in the upper Awash basin was not due to lack of precipitation rather it could be due to anthropogenic effects. The declining vegetation cover observed in the basin during the 2013 to 2020 could contributed to the increasing mean annul streamflow by increasing surface runoff and reduced transpiration loss due to the presence of trees. The results of this study shows that for the effectiveness of afforestation program, tree growing and managing the planted trees should be given more focus than focusing on the number of trees planted. Moreover, further study is required to understand the impacts of plantation on climate and hydrologic processes. Particularly, detail study is required to fully understand the effect of afforestation program on streamflow, and the relationship between NDVI and precipitation and streamflow. Since limited station data are used for this study, these correlations are not done in this study.

Declarations

Author contribution statement

Alexander Takele, Haileyesus Belay Lakew & Gizachew Kabite: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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