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Assessing the Impacts of Land Use/Land Cover Changes on Water Resources of the Nile River Basin, Ethiopia

Mohammed Gedefaw [1,2,*], Yan Denghua [3,*] and Abel Girma [1]

1 Department of Natural Resources Management, University of Gondar, Gondar P.O. Box 196, Ethiopia
2 College of Environmental Science and Engineering, Donghua University, Shanghai 201620, China
3 State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resource and Hydropower Research, Beijing 100038, China
* Correspondence: mohammedgedefaw@gmail.com (M.G.); yandh@iwhr.com (Y.D.)

Abstract: Land use/land cover change and climate change have diverse impacts on the water resources of river basins. This study investigated the trends of climate change and land use/land cover change in the Nile River Basin. The climate trends were analyzed using the Mann–Kendall test, Sen's slope estimator test and an innovative trend analysis method. Land use/land cover (LULC) change was examined using Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper (ETM+) with a resolution of 30 m during 2012–2022. The findings revealed that forestland and shrub land area decreased by 5.18 and 2.39%, respectively. On the other hand, area of grassland, cropland, settlements and water bodies increased by 1.56, 6.18, 0.05 and 0.11%, respectively. A significant increasing trend in precipitation was observed at the Gondar (Z = 1.69) and Motta (Z = 0.93) stations. However, the trend was decreasing at the Adet (Z = −0.32), Dangla (Z = −0.37) and Bahir Dar stations. The trend in temperature increased at all stations. The significant changes in land use/land cover may be caused by human-induced activities in the basin.

Keywords: climate trend; land use land cover; Nile River Basin; water resources

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1. Introduction

Land use change and climate variability are two important factors that affect water resources and freshwater ecosystems [1]. Currently, land use/land cover (LULC) change is one of the major global environmental challenges to humanity. Land use/land cover change (LULCC) can be driven by multiple forces: demographic trends, climate variability, national policies, and macroeconomic activities which in turn have a significant impact on hydrologic systems both at basin and regional scales [2,3]. It significantly affects hydrological response [4,5], ecosystem services [6] and climate processes. LULCC has become a global concern [7] because of its diverse impacts on water resources [8–10]. The expansion of agricultural land use causes significant changes in runoff and sediment load [11,12]. Land use change can also lead to a significant change in groundwater recharge and base flow [13], flood frequency [14], peak runoff [15] and total suspended sediment concentration and can change the hydrological system of the region [16,17]. It has been one of the main contributors to climate change [18]. On the other hand, climate change has also affected the land use system through changes in agricultural productivity and forest ecosystem [19] and leads to alteration of hydrological conditions of the watersheds [20–22].

Climate change, deforestation, forested wetland shrinkage and desertification have also resulted in the spatiotemporal deterioration of vegetated ecosystems [23]. Many studies in Africa have revealed a decline in availability of water and agricultural productivity within catchments as a result of changes in land use and land cover [24,25]. To understand the impacts of land use/land cover change on water resources, it is essential to know the historical effects in land use/land cover on the hydrological system [26]. Human activities alter the hydrological systems of river basins mainly due to the expansion of cultivated lands and LULCC [2,23,27]. Such changes were not well understood by society. For instance, conversion of forestland to cultivated land between 1985 and 2011 in the Angereb watershed has increased the mean wet flow by 39% and reduced the dry mean flow by 46% [2]. The spatial temporal variability of climate change, land use/land cover change and management practice in the watershed are extremely challenging for sustainable water resource management in the river catchment. Surface runoff is lower and groundwater flow becomes higher in forestlands due to the infiltration of rainfall into deep aquifers. However, surface runoff becomes higher in bare lands and groundwater flow is lower [28,29]. Different studies have so far shown that LULC changes had adverse effects on the water resources of river basins. For example, LULC changes induced by human activities and rainfall variability have adversely affected the condition of water resources in the Great Ruaha Sub-catchment of the Rufiji Basin [24], and decreased base flows due to land modifications in the Upper Great Ruaha river basin [30]. Qiu et al. (2011) [31] simulated the effects of the Conversion of Cropland to Forest and Grassland Program on the catchment water budget in the Jinhe River using the SWAT model. The results showed that LULC changes had adverse impacts on the water resources of the Jinhe river basin. The increase in agricultural land activities is associated with transformation of the land use and an increase in water abstraction for irrigation purposes as a result of an increase in surface runoff following rainfall events. Land use change decreased the blue water and green water flow of the Weihe River Basin [32]. The spatial distribution showed an uneven change. The LULC changes in the Blue Nile River Basin, which occurred during the period of 1985 to 2015, increased the annual flow (2.2%), wet seasonal flow (4.6%), surface runoff (9.3%) and water yield (2.4%). Conversely, the observed changes had reduced dry season flow (2.8%), lateral flow (5.7%), groundwater flow (7.8%) and ET (0.3%) [33]. Human activities and climate changes were the main driving factor for the reduction in discharge [34] and mean annual stream flow in the middle reaches of the Yellow River basin [35].

Since land use change has a significant and profound effect on water quality and quantity, there is an urgent need to understand the interaction between land use change, hydrology and water resources management [36,37]. This calls for the need to understand the extent to which alterations of the land use and land cover have impacted on water availability in river sub-catchments.

The increasing demand for water abstractions by industries, households and irrigation projects within the river basin has aggravated these problems. Thus, investigating the correlation between land use/land cover change and hydrological systems plays a critical role for the management of water resources in the river basin. These enable policy makers, local government bodies and decision makers to formulate and implement effective and appropriate response strategies to reduce the adverse impacts of land use/land cover change on water resources. Hence, the aim of this study is to investigate the observed impacts of LULCC on water resources in the Nile River Basin, Ethiopia. Furthermore, the study investigated the trends in climate from 1980 to 2016.

2. Materials and Methods

2.1. Description of the Study Area

The Nile River Basin is the Nile's largest tributary; the largest in terms of discharge volume, and the second largest in terms of area in Ethiopia. Geographically, the Nile River Basin is found in the northwestern part of Ethiopia which lies between 70°40′ N and 120°51′ N latitude, and 340°25′ E and 390°49′ E longitude. It covers an area of 199,592.17 km^2 [36]. The basin drains much of the central, north–central and northwestern Ethiopian Highlands. The basin is subdivided into 16 sub-basins based on major rivers in the basin and its tributaries [38]. The topography of the Nile River Basin is extremely complex, with elevations ranging from 435 m in the lowlands near the Sudan border to 4229 m in the basin's upper section. The upper plateau near Lake Tana and the lower elevations close to the Sudan border both have flat areas. Furthermore, the highland areas in the eastern, northern, southeastern, and northeastern sub-basins are distinguished by high altitude, steep slope, hilly, gully, rugged terrain, troughs and mountainous landforms. As far as LULC is concerned, agriculture, shrub land, and forest are the major LULC categories, followed by water bodies, grassland, settlements, bare land and wetland [39]. Agriculture is the dominant LULC class in the eastern, northern, northeastern, and southeastern sub-basins. The forest LULC class is predominant in the western, southern, northwestern, and southern central sub-basins. The climate of the basin varies from cool to hot due to topographic variations, with large variations within a limited elevation range [40]. The sub-basins are characterized by moderate to high annual mean temperature (25–30.3 °C) and high annual rainfall (1083.4–2051.4 mm). The mean annual rainfall of this river basin decreased from southwest (>2000 mm) to northeast (≥789.34 mm) with a mean annual temperature of 18.5 °C [41]. Lake Tana is the major water source of this river basin (Figure 1).

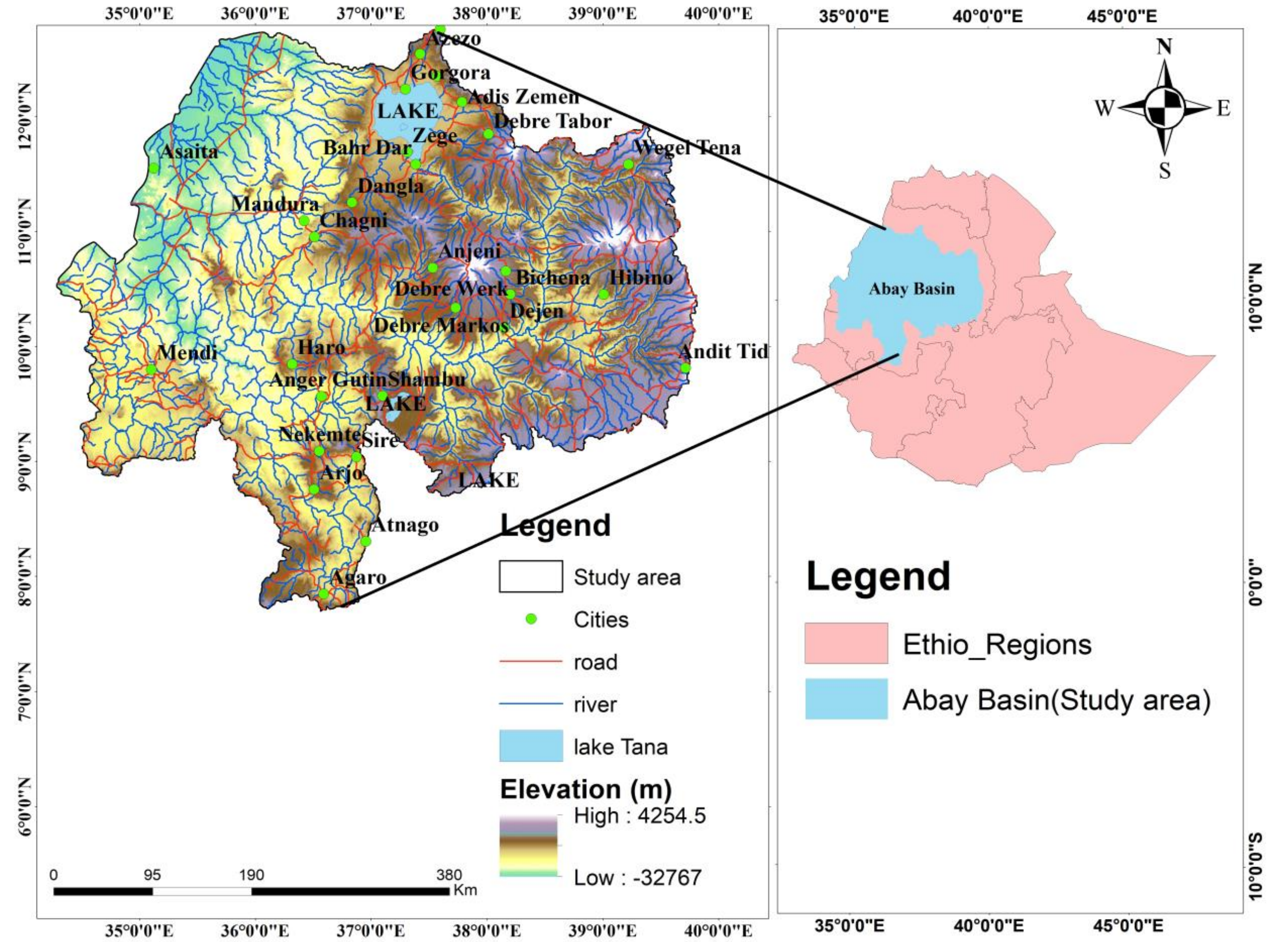


Figure 1. Location map of Abay/Nile River Basin.

2.2. Data Sources

2.2.1. Land Cover Data Sources

The land cover satellite data of the study area were collected from the Ministry of Energy and Water Resources of Ethiopia. The topographic map, soil map, ecological landscape potential map, forest map, and vegetation map were chosen for accuracy testing and validation. Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper (ETM+) with a resolution of 30 m from 2012 to 2022 were used for land cover classification. The satellite data for land covers in the study area were obtained from the Global Land covers dataset (GlobeLand30) product. Land cover change was investigated between the years 2012 and 2022. The expanded classification system was adopted to capture the local characteristics of the study area (Table 1).

Table 1. Land cove types in Nile/Abay River Basin.

Land Cover Types	Code	Description
Forest land	Fl	Land covered with trees, with vegetation cover over 30%, including deciduous and coniferous forests, and sparse woodland with cover 10–30%, etc.
Grass land	Gl	Land covered by natural grass with cover over 10%, etc.
Shrub land	Sl	Land covered by small shrubs, plants less than 30 cm height.
Settlement	S	Land modified by human activities, including all kinds of habitation, residential, commercial, industrial, transportation facilities and interior urban green zones, etc.
Water body	Wb	Water bodies in the land area, including rivers, lakes, reservoirs, fish ponds, lands covered by temporary snow, glaciers and icecaps, etc.
Crop land	Cl	Land used for agriculture, horticulture and gardens, including paddy fields, irrigated and dry farmland, vegetation and fruit gardens, etc.

2.2.2. Meteorological Data

Daily precipitation and temperature data from stations during the period of 1980–2016 were obtained from the National Meteorological Services Agency of Ethiopia (NMSA) and National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center. https://www.ncdc.noaa.gov/cdo-web/ accessed on 20 September 2023.

2.3. Methods

2.3.1. Analysis of Land Use/Land Cover Change

The overlaying operation was used to perform spatial analysis, which revealed how land use and land cover changed over time and established a connection between the two. A land cover transformation map was obtained and utilized for transformation matrix analysis by intersecting the two land cover/land use maps (2012 and 2022). The magnitudes of land cover shifts were calculated as [42].

$$A = TA(t_2) - TA(t_1), \tag{1}$$

$$CE = [CA/TA(t_1)] * 100, \tag{2}$$

where: TA = Total Area, CA = Changed Area, CE = Change Extent, and t_1 and t_2 are the beginning and ending time at which the land cover studies were conducted, respectively.

The Kappa coefficient and error matrix are standard measures of the reliability and accuracy of the maps produced. The Kappa statistics were determined in this study using methods described in detail in previous studies [43,44]. The Kappa coefficient was calculated using [45].

$$K = P(A) - P(E)/1 - P(E) \tag{3}$$

$$P(A) = \frac{(A + D)}{N}, \tag{4}$$

$$(E) = \left(\frac{A1}{N}\right) * \left(\frac{B1}{N}\right) + \left(\frac{A2}{N}\right) * \left(\frac{B2}{N}\right), \tag{5}$$

where: K is the Kappa coefficient, $P(A)$ is the number of times the k raters agree, and $P(E)$ is the number of times the k raters are expected to agree only by chance [46]. A and D are unchanged categories, $A1$ and $B1$ are the subject's categories, and N is the change in results.

2.3.2. Mann–Kendall (MK) Test Method

Trend analysis is used to identify whether the observed values of a time series data are increasing, decreasing, or show no trend. The non-parametric Mann–Kendall (MK) test has been applied in most studies to detect trends in hydro–meteorological time series since it does not require normally distributed data. This paper used the innovative trend analysis method (ITAM) to detect the trends in rainfall and temperature time series data. To evaluate the reliability of ITAM, the results were compared with the MK and Sen's slope estimator tests. The trends in rainfall time series data were assessed at 10%, 5% and 1% level of significance using the MK, ITAM and Sen's slope estimator methods. Significance was considered at the 10% threshold. The Mann–Kendall test is a non-parametric statistical test employed to detect monotonic trends in series of environmental, climate, and hydrological data. The MK test has been used to detect the presence of monotonic (increasing or decreasing) trends in the study area and whether the trend is statistically significant or not. Since there are chances that outliers are present in the dataset, the non-parametric MK test is useful because its statistic is based on the plus or minus signs, rather than on the values of the random variables, and therefore, the trends determined are less affected by the outliers [47]. Each data value is compared with all subsequent data values. If the data value from a later time period is greater than a data value from earlier time period, the statistic S is increased by 1. However, if the data value from a later time is less than a data value from earlier time period, the statistic S is decreased by 1. The net sum result would give the value of S.

The test statistics "S" is calculated by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \tag{6}$$

$$sgn\left(x_j - x_i\right) = \begin{cases} +1 \text{ if } \left(x_j - x_i\right) > 0 \\ 0 \text{ if } \left(x_j - x_i\right) = 0 \\ -1 \text{ if } \left(x_j - x_i\right) < 0 \end{cases} \tag{7}$$

where x_j and x_i represent the data points at periods j and i, respectively. While the amount of data series is larger than or equivalent to ten $(n \geq 10)$, the MK test is then categorized by a standard distribution with the mean $E(S) = 0$ and variance $Var(S)$, given as [48]:

$$E(S) = 0 \tag{8}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)}{18} \tag{9}$$

The test's Z statistic is obtained using approximation, as follows:

$$Z = \begin{cases} \frac{s-1}{\delta} \text{ if } S > 0 \\ 0, \text{ if } S = 0 \\ \frac{s+1}{\delta} \text{ if } S < 0 \end{cases} \tag{10}$$

where Z follows a normal distribution, a positive Z and a negative Z depict an upward and downwards trend for the period, respectively.

2.3.3. Sen's Slope Estimator Test

The magnitude of the trend is predicted by slope estimator methods. In general, the slope Qi between any two values of a time series x can be estimated using the following equations.

The slope Q_i between two data points is given by the equation [48]:

$$Q_i = \frac{x_j - x_k}{j - k},\ for\ i = 1, 2, \ldots N \quad (11)$$

where x_j and x_k are data points at time j and $(j > k)$, respectively.

2.3.4. Innovative Trend Analysis Method (ITAM)

The Innovative Trend Analysis Method has been used in many studies to analyze hydro–meteorological time series data, and its reliability has been compared with the results of the MK method. In ITAM, the hydro–meteorological time series data are divided into two halves and arranged in ascending order independently. Then, the two halves are placed on a coordinate system, with (X_i: i = 1, 2, 3, … n/2) on the X-axis and (X_j: j = n/2 + 1, n/2 + 2, … n) on the Y-axis. If the time series data on a scattered plot are collected on the 1:1 (45°) straight line, it means there is no trend. It shows an increasing or decreasing trend if the time series data points accumulate above or below the 1:1 straight line, respectively. The magnitude of the trends in time series data can be estimated by calculating the average difference between the values of X_i and X_j. The change in trend is determined by the first half of the time series data points. Therefore, the trend indicator is estimated by dividing the average difference from the straight line to the average of the first half of the time series data points. The ITAM trend indicator is multiplied by 10 to represent the same scale as the MK method and Sen's slope estimator test at a 10% level of significance.

The trend indicator is calculated as [48]:

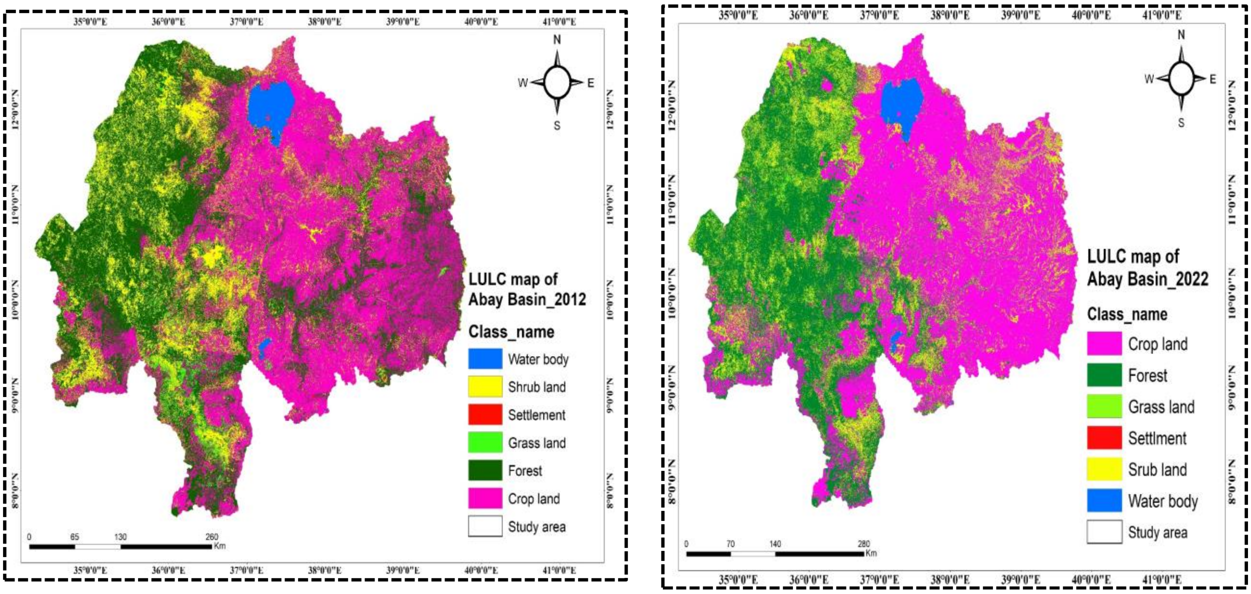
$$\phi = \frac{1}{n} \sum_{i=1}^{n} \frac{10\left(x_j - x_i\right)}{\mu} \quad (12)$$

where, ϕ = trend indicator, n = number of observations in the subseries, x_i = data series in the first half subseries class, x_j = data series in the second half subseries and μ = mean of data series in the first half subseries.

3. Results and Discussion

3.1. Analysis of Land Cover Change in the Nile River Basin

The 2012 and 2022 land use/land cover map of the Nile River Basin was generated from Landsat TM and ETM+ imagery classification (Figure 2). The spatial distribution of major LULC classes for 2012 and 2022 are presented in Table 2. The results show that shrubland and forestland were significantly reduced by 2.39% and 5.49% (Table 2), respectively. In a visual examination of land use maps, it was evident that from 2012 to 2022, the area under forest and shrub coverage diminished significantly in the study region. Agriculture was the predominant land use type in the Nile River Basin, which covered 41.42% in 2012 and 47.60% in 2022 (Table 2). A significant expansion of cultivated land of about 6.18% between 2012 and 2022 was observed, whereas the forest coverage diminished between 2012 and 2022, which accounted for about 5.49%. This finding is supported by the results of [49]. The reduction in water bodies and forestland area may be associated with human activities surrounding the river basin [50].



(**a**) (**b**)

Figure 2. LULC in (**a**) 2012 and (**b**) 2022.

Table 2. Land use/land cover change detection in the Nile/Abay river basin during 2012 and 2022.

No.	Land Cover Types	Initial Area 2012	Final Area 2022	Changing Status
		Percent (%)	Percent (%)	Percent (%)
1	Forest land (Fl)	37.05	31.56	−5.49
2	Grass Land (Gl)	2.18	3.74	1.56
3	Shrub land (Sl)	17.53	15.14	−2.39
4	Settlement (S)	0.07	0.12	0.05
5	Water Body (Wb)	1.74	1.85	0.11
6	Crop land (Cl)	41.42	47.60	6.18

3.2. Analysis of the Impacts of Land Cover Change on Water Resources

Due to anthropogenic activities and climate change, the water resources of the Nile River Basin were significantly affected [51]. Furthermore, the dynamic changes in land use/land cover in the Nile River Basin impacted the water resources. The change detection results of the different LULC types from 2012 to 2022 are presented in Figure 3. The high demand for cultivated land for crop production in the Nile River Basin devastated the water resource potentials of the river basin. Land use/land cover changes have a great influence on the rainfall runoff process. The cultivation of forests and the demand for more agricultural land forced by urban development into settlements and infrastructure forms a sealed surface, which adversely changes the partitioning of precipitation towards increasing surface runoff and reduced ground water recharge [52–56]. The increase in surface runoff due to built-up areas which have a high proportion of impervious surfaces decreases water percolation and groundwater contribution to stream flow. This is supported by the results obtained by [57], who studied the impacts of land use and land cover changes on flow regimes of the Usangu wetland and the Great Ruaha River. His findings stated that the change in the land use and land cover within the catchment caused an increase in runoff, a decrease in base flow, an increase in sediment deposition on the bank of the river and a decrease in the width of the river channel.

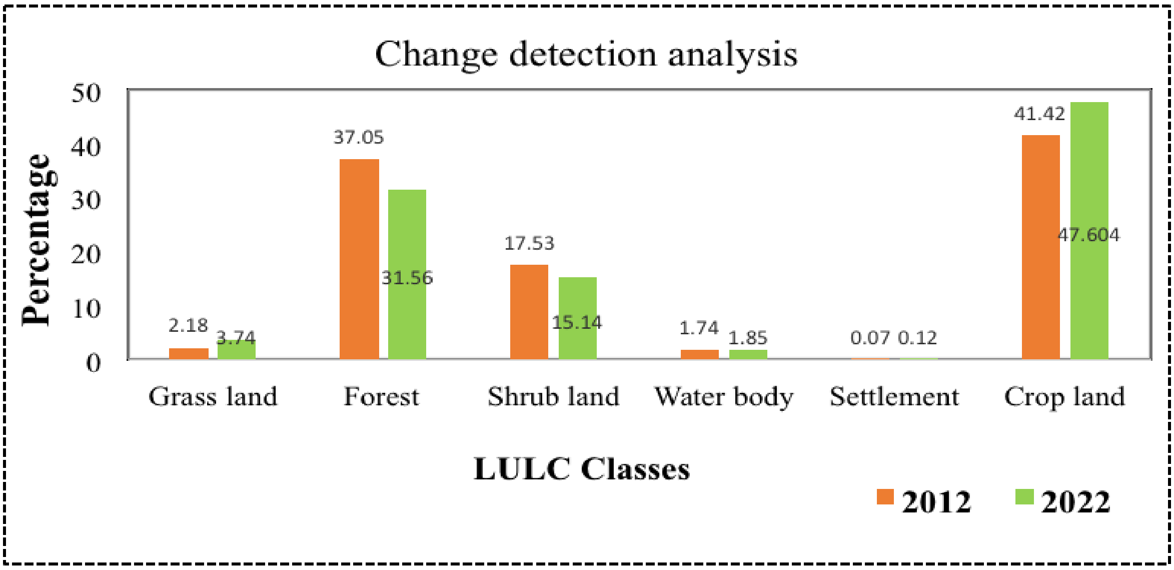


Figure 3. Change in LULC types between 2012 and 2022.

3.3. Analysis of Climate Trends

3.3.1. Analysis of Trends of Precipitation

The findings showed that the annual precipitation shows a significant increasing trend in Gondar (Z = 1.69), a sharp decreasing trend in Adet (Z = −0.32), a slightly decreasing trend in Dangla (Z = −0.37), a significant increasing trend in Bahir Dar and a significant increasing trend in Motta (Z = 0.93) (Figure 4). Significance levels at $\alpha = 0.01$, $\alpha = 0.05$, $\alpha = 0.1$ were taken to detect the trends at all stations. The ITAM test showed an increasing trend in Gondar and Motta and a decreasing trends in Adet, Bahir Dar and Dangla. The increase and decrease in innovative trend analysis (ITAM) test values represent strong and weak magnitudes, respectively. The variability in trends of precipitation across stations might be due to human activities and climate change impacts [58–60]. The trend in precipitation seen for each station could imply that the changes are more pronounced for certain locations and less so for others. The trend results are depicted in Table 3.

Table 3. Trends for stations in the Nile River Basin.

S/No	Name of Stations	Z (MK)	ϕ	β	Change (%)
1	Gondar	1.69 **	0.54	1.84 **	0.93
2	Adet	−0.32	−0.79	3.50	2.20
3	Bahir Dar	−0.07 *	−23.51	1.80 *	1.36
4	Dangla	−0.36	−0.39	1.26	1.27
5	Motta	0.93 ***	1.48	0.63 ***	0.79

* Trends at 0.1 significance level; ** trends at 0.05 significance level and *** trends at 0.01 significance level.

3.3.2. Analysis of Trends in Temperature

The results revealed that a statistically increasing trend was observed at Bahir Dar (Z = 2.63), Gonder (Z = 6.96) and Motta (Z = 4.58) stations. Even though there were variations in trends of temperature in Adet and Dangila stations, the trends were not statistically significant. From 1980 to 2016, the temperature increased by 0.5 °C, which shows a change in the climate system in the Nile River Basin. In general, the trend in temperature was increasing in all stations.

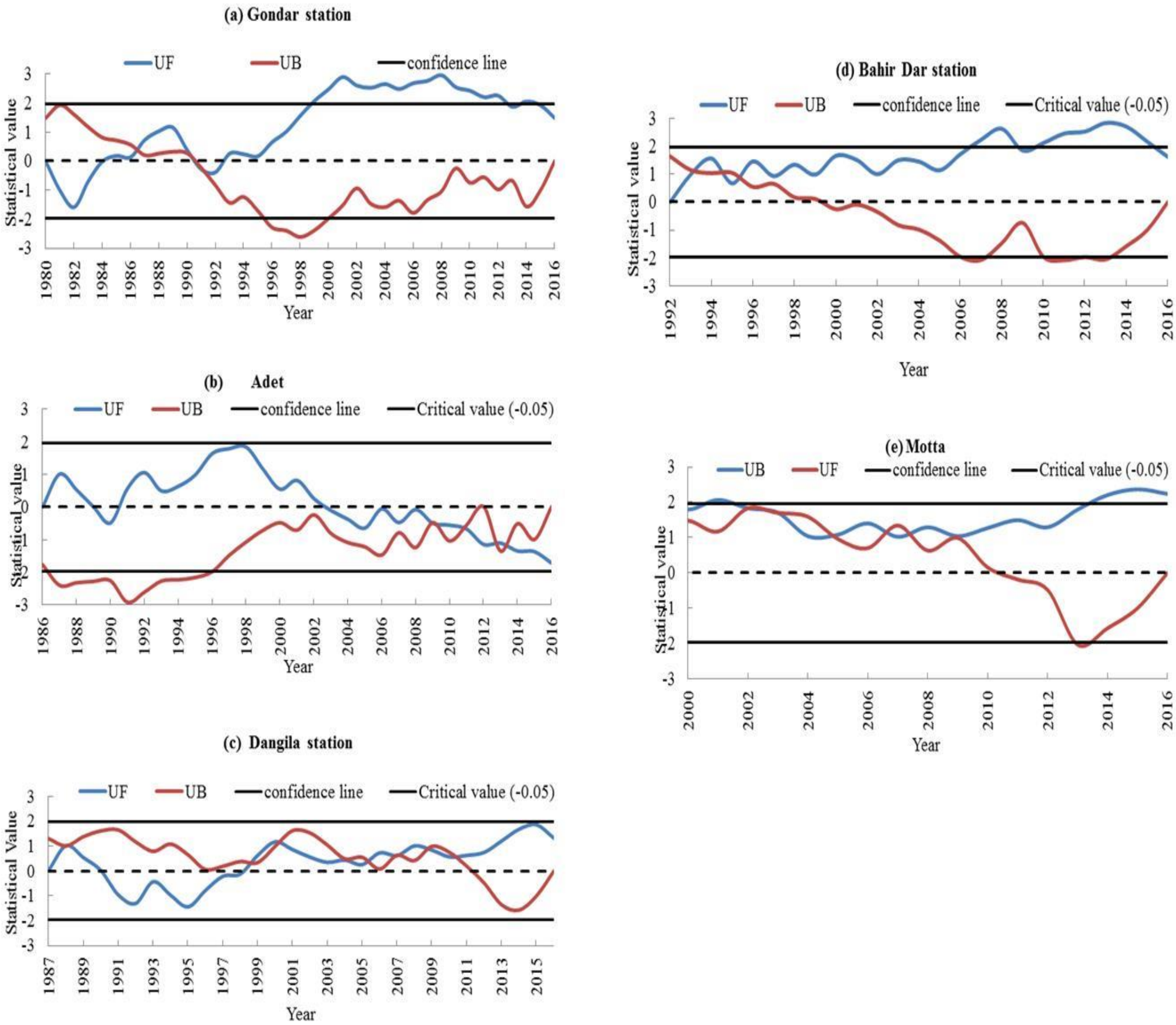


Figure 4. Trends of precipitation in the Nile River Basin.

4. Discussion

A land use/land cover change detection analysis was conducted to assess the spatial and temporal changes in land use/land cover (LULC) in Nile River Basin. The findings of this study show that, as a results of anthropogenic activities and climate change, the water resources of the Nile River Basin was significantly affected [61]. For example, the water bodies were significantly reduced by 1.72% from 2003 to 2013. Of the total water body coverage of the Nile River Basin, 5.49, 1.56, 2.39, 0.05 and 6.18% was converted into forestland, grassland, shrub land, settlement and croplands, respectively. These changes might be due to human activities and climate change in this region [62]. The intense human activities have increased artificial surfaces and cultivated land [63]. Therefore, climate change and human activity may produce a strong effect on vegetation and land cover in this region. The impact of the climatic variability on agricultural production is further aggravated by widespread soil degradation that has led to a reduction in the capacity of soils to hold moisture.

The impacts of land use and land cover change investigated by different researchers suggested that by increasing rainy season flow and decreasing dry period flow, the near future climate scenario would exacerbate extreme flow. Conversion of cultivated land on steep slopes into woodland, however, may reduce these intense flows. Under overlapping projections of potential land use/land cover and climate change, stream flow responses will be intensified at the outlet of the Tana watershed. The study region is characterized by maximum rainfall from June to August and little rainfall from March to May. There is inter-annual variability of rainfall between the stations. Some researchers tried to investigate the impacts of LULC changes on water resources. For example, Dibaba et al., (2020) [64] assessed the separate and combined impacts of climate and LULC change in the Finchaa catchment, and suggested that the changes in LULC led to an increase in surface runoff and water yield and a decrease in groundwater, while the predicted climate change indicates a decrease in the yield of surface runoff, groundwater and water yield. The combined study of the effects of LULC and climate change is a scenario considered equivalent to that of climate change. On the other hand, Berihun et al., (2019) [65] reported that, from 1982 to 2017, the observed LULC changes resulted in runoff increases ranging from 4% in Kecha to 28.7% in Kasiry, though climate variability had no significant impact on estimated runoff in terms of annual rainfall, while both LULC transition and climate variability had a significant effect on estimated evapotranspiration. Furthermore, other studies investigating the effects of historical climate and LULC change on the hydrology of the Nile River Basin showed that the impact of climate change (16.86%) on catchment stream flow was greater than that of land use/land cover change (7.25%), while the combined change effect accounted for a 22.13% increase in flow. In general, this result shows that high flow is more responsive to climate change, while land use/land cover change has shown a more substantial impact on low flow. Legesse et al., (2003) [65] indicated that a 10% decrease in rainfall resulted in a 30% decrease in the simulated hydrological response of the catchment, whereas a 1.5 °C rise in air temperature would result in a reduction of about 15% in the simulated discharge, while converting the current dominantly cultivated land in the studied river basin to woodland would reduce the discharge at the outlet by about 8% in south–central Ethiopia. When we see how the connection between human activities and climate change affects water resources, both have adverse impacts. The reduction in discharge causes challenges for global river ecosystems as a result of human activities and climate change (frequent extreme weather problems) [66,67]. Direct human activities also have an effect on variations in runoff [68]. They reduced the discharge of the Yellow River basin by 73.4% and 82.5% in 1980–2000 and 2001–2014, respectively [69]. The hydrological cycle of watersheds in both spatial and temporal changes is a complex process that is widely influenced by climate change and human activities. The IPCC (2013) [15] report indicated that climate change has led to changes in global precipitation patterns since the 20th century, which has changed the global hydrological process and directly affected the spatial and temporal distribution of global water sources; thus, it can cause changes in discharge [70]. Human activities, such as changes in land use/cover, dam construction and urbanization, have an obvious impact on all aspects of the water cycle [46], which can greatly change the spatiotemporal distribution of water resources. For example, Yuan et al., (2016) [68], reported that as a result of climate change, about 60.07–67.27% of the changes were observed during the change period I (1981–2002) and change period II (2003–2010), accounting for about 58.89–78.33% of changes due to human activities controlling stream flow changes. Furthermore, research should be carried out to determine the cumulative impact of land use/land cover and climate change on the Nile River Basin stream flow. This and other factors draw the researcher's attention to work on this subject. The hydrological study on the land use and land cover changes within the Nile River catchment showed that the flow characteristics have changed, with an increase in surface flow and reduction in base flow.

As far as the trends in climate are concerned, a significant increasing trend was observed at Gondar (Z = 1.69) and Motta (Z = 0.93) stations. However, a sharp decreasing trend was observed at Adet (Z = −0.32) and Dangla (Z = −0.37) stations. The trends in temperature were increasing at all stations. This result was in line with the global average temperature, which has increased by 0.85 °C from 1880 to 2012, and this may even accelerate in the near future [71]. The within-year and between-years variability in rainfall over the Nile Basin is high, making over-reliance on rainfed supply systems risky [48]. The high potential evaporation values in the Nile region ranging from some 3000 mm/year in northern Sudan to 1400 mm/year in the Ethiopian Highlands, and around 1100 mm/year in the hills in Rwanda and Burundi, make the basin particularly vulnerable to drought events. Drought risks are further amplified by the high variability of the rainfall between seasons and years. This is manifested by uncertainty in the onset of rains, occasional cessation of rainfall during the growing season, and consecutive years of below average rainfall. It has marked adverse impacts on the productivity of rainfed agriculture, and represents a serious constraint to rural development. However, the average temperature has fluctuated significantly in the past decade [48]. This will lead to significant environmental impacts. Gondar, Adet, and Bahir Dar stations exhibited a coefficient of variation of CV > 0.1, except for Dangla and Motta stations. This result is generally consistent with other studies, which reported increased precipitation and non-uniform precipitation changes. The Mann–Kendall test, Innovative Trend Analysis Method and Sen's slope estimator test showed the decreasing and increasing trend of rainfall across the stations. However, there was no statistically significant trend at the 95% level at any station. This result is also supported by [47], which showed that the seasonal trend in most parts of the country was decreased by 30% to 40%. This variation may influence regional climate systems as well as the hydrological cycle.

5. Conclusions

In this study, the impacts of land use/land cover change on water resources in the Nile River Basin were investigated. The trends in climate change were detected using the MK, Sen's slope estimator test and ITAM. The results showed that forestland and shrublands were significantly reduced by 6.18% and 2.39%, respectively. As far as the trends in precipitation are concerned, a significant increasing trend was observed at Gondar ($Z = 1.69$) and Motta ($Z = 0.93$) stations. However, a sharp decreasing trend was observed at Adet ($Z = -0.32$) and Dangla ($Z = -0.37$) stations. The trends in temperature were increasing at all stations. The change in trends in precipitation at each station could imply the impacts of climate change on water resources. Thus, these could indicate that climate change can affect the water resources of the river basin. Therefore, it can be concluded that there is evidence of some changes in the trend of rainfall, which has impacted the water resources of the Nile River Basin during the study period. Although further study is needed, climate change and LULC changes could impact the availability of water resources in river basins.

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