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ABSTRACT

Andit tid watershed is part of Blue Nile basin located in the central highlands of Ethiopia. The lack of data and information at watershed level resulted in different conclusions from trend studies of river flow, sediment yield and crop productivity at a basin scale. There is an opportunity to improve water and land if it can be underpinned by a better scientific understanding of trends of flow, sediment yield and crop production at the basin level. This research is carried out using descriptive statistics, Mann–Kendall (MK) and Pettitt's test to determine the potential trends of river flow, sediment yield and crop productivity using Andit tid watershed case. The result showed that there was high variability of interannual river flow with CV >30%. The Pettitt test showed a significant abrupt change in monthly (March, July, August, September and October) and seasonal (summer and winter) river flow. The Pettitt test result of sediment yield and crop production showed no change. MK test showed a significant ($P < 0.05$) decreasing trend in March, August, September and October river flow. The other MK values showed no significant trends for all parameters. Researchers should consider representative watershed-based information and data for the analysis and interpretation of large basins.

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River flow; sediment yield; crop production; trends; Mann–Kendall test

1. Introduction

Nile ('Abbay' in its local name) is the longest river in the world and one of the most water-limited basins. Eighty-five percent of the total amount of water entering Lake Nasser at the Aswan dam originates from the Ethiopian Highlands (Sutcliffe & Parks, 1999). The Upper Blue Nile River basin which contributes over 60% of the Nile's water (Conway, 2000) is crucial for the socio-economic development and environmental stability of Ethiopia, Sudan and Egypt. These countries have experienced serious problems in their storage reservoirs and irrigation canals due to excessive sediment loads (Betrie et al., 2011). Seleshi et al. (2011) did research at the border of Sudan and reported that sediment concentrations were as high as 12.3 g L^{-1} . In this circumstance, studying the trend and variability of river flow and sediment yield is crucial to exactly put measures to lengthen the lifespan of reservoirs and canals.

The long-term trend analysis of runoff in the Blue Nile basin was studied by many scholars, for instance, Gebrehiwot et al. (2010), Kebede (2009), Legesse et al. (2003) and Tesemma et al. (2010). However, the conclusions of these studies have not shown a common consensus on the trends and variability of flow. Legesse et al. (2003) reported an increasing trend; Tesemma et al. (2010) reported no change and Kebede (2009) and Gebrehiwot et al. (2010) reported a decreasing trend of the annual flow of the Blue Nile basin. Furthermore,

studies that were conducted in the same year resulted in different trends and variability output.

Studies that estimate annual sediment load from the Upper Blue Nile basin also reported different sediment yield results. For instance, as reviewed by Gebremicael et al. (2013) the annual sediment yield of the Blue Nile basin ranged from 111×10^6 to 140×10^6 tons/year. To minimise this type of research output difference, basin-representative, experimental watersheds offer essential knowledge in recognising the hydrological and erosive processes including trends of crop production. The only long-term river flow, sediment and crop yield data monitoring has been carried out in the small Soil Conservation Research Project (SCR) watersheds which were established in 1981 and conserved with soil and water conservation structures in the upper reaches of large basins (Steenhuis et al., 2014). For example, discharge assessment at the watershed outlet is the standard analysis and forms the basis for the development of many fundamental theories of runoff (Blume et al., 2007; Erturk, 2010). Andit tid watershed is one of the SCR watersheds, which is representative of the upper Blue Nile basin. In this watershed, two rivers (Gudi Bado and Wani Gedel) confluence 150 m above the gauging station and create the river called 'Hulet Wenz'. In the gauging station of this river, daily river flow and event-based sediment samples data have been collected since July 1982.

In Ethiopian highlands including Andit tid watershed in the upper Blue Nile basin, soil erosion and sedimentation become the major threat to crop production by washing the top fertile soil. The hillside and mountainous nature, and shape of this watershed foster the formation of flooding and soil erosion. Numerous studies have been conducted in Andit tid over the years, including ones on suitability mapping for major crops (Yohannes & Soromessa, 2018); land capability classification (Yohannes & Soromessa, 2019); land use and land cover change impact on livelihoods and soil erosion (Abraham Tezera et al., 2016); soil erosion estimation and mapping (Desalegn et al., 2018); comparison of CFSR and conventional weather data (Roth & Lemann, 2015) and rainfall-runoff modelling (Engda, 2009). While the very crucial watershed characteristics of how are the monthly, seasonal and annual trends of the river flow and sediment yield were not addressed. Around 50 fixed plots in different positions of bunds were set up in the watershed to assess the effects of soil and water conservation on agricultural productivity, and for the past 24 years, we have been gathering data on crop yield and agronomic parameters from these plots. The effects of these soil and water conservation structures particularly Fanya juu and soil bunds on agricultural yield have not been thoroughly studied. The productivity trends of the major crops grown in the watershed were not also studied. Studying these issues is therefore anticipated to increase the watershed community's understanding of the importance of soil and water conservation for increasing crop productivity, preparing for seasonal changes in peak river flow, and using various mulching techniques or green cover in the early rainy seasons to reduce bulk erosion. As an objective, this study was focused to (i) analyse the long-term trend and variability of runoff, sediment yield and crop productivity of Andit tid watershed using statistical methods and (ii) characterise the watershed based on river flow, sediment yield and crop production using the data from 1994 to 2017.

In this paper, we addressed the monthly, seasonal and annual trends of runoff and sediment loss and the year-to-year changes in crop productivity in the watershed. Therefore, this study tells how the river flow, sediment yield and crop production have changed over time in the watershed; whether or not these parameters are increasing or decreasing. From the result of this study, researchers can go further about the factors causing any abrupt happened in all studied parameters. It can be used as a ground truth reference to evaluate the model simulation outputs of different studies that have been conducted in the Blue Nile basin. Policymakers can use the result of this research as the benchmark for making appropriate land management decisions, improving local land productivity and enhancing livelihood. The researchers can use it

for further studies and for deciding other watershed-based decisions rather they used simulated model output.

2. Methodology

2.1. Description of the watershed

Andit tid watershed is situated at 39°43' E longitudes and 9°48' N latitudes apart 180 km northeast of the capital city of Ethiopia, Addis Ababa (Figure 1). The altitude of the catchment ranges between 3040 (at the outlet) to 3550 (at the elevated area of the watershed) m.a.s.l. The mean annual rainfall is 1585.2 mm, and the minimum and maximum temperatures are 7°C and 17°C, respectively. The minimum and maximum soil surface temperatures are 8°C and 20°C, respectively. The agro-climatic zone of the watershed is Wet Dega/Wet high Dega. The dominant soil types of the watershed are Humic and ochric Andosols, Fluvisols, Regosols and Lithosols. It is characterised by severe soil degradation, especially in the lower part of the catchment. Soil fertility is limited through low pH and N- and P-deficiency. Smallholder mixed farming systems including grain production (barley) and Ox-plough farming oriented with free grazing practices is the major practice of the watershed community.

2.2. River flow and sediment yield data collection

The river gauging stage was monitored continuously using a limnigraph accompanied by manual water-level measurements during storm events. The stage height (water level) which was monitored using limnigraph and the manual ruler was converted into discharge using the following equation (Bosshart, 1997):

$$Q(H < 67) = 0.03 * H^{2.749} \quad (1)$$

$$Q(67 < H \leq 250) = 10.846 * H^{1.35} \quad (2)$$

where Q is the runoff discharge in l/s and H is the true water level (height of the stage) in cm.

Every 10 min during runoff events, one-litre grab samples were taken to measure the amount of sediment immediately when the colour of the water turned brown. The sampling rate was reduced to 30 min and hourly intervals once the water level dropped and the colour returned to light brown. The overall stream flow and an estimate of the suspended material carried by the flow at that particular time interval were calculated using sediment samples and manual measurements of the river's water level. By oven-drying the one-litre samples and weighing the oven-dried soil, the quantity of sediment load within the sample was determined. The sum of the total water flow per time and the sediment concentration as obtained from the 1-L sample was then multiplied to get the total soil

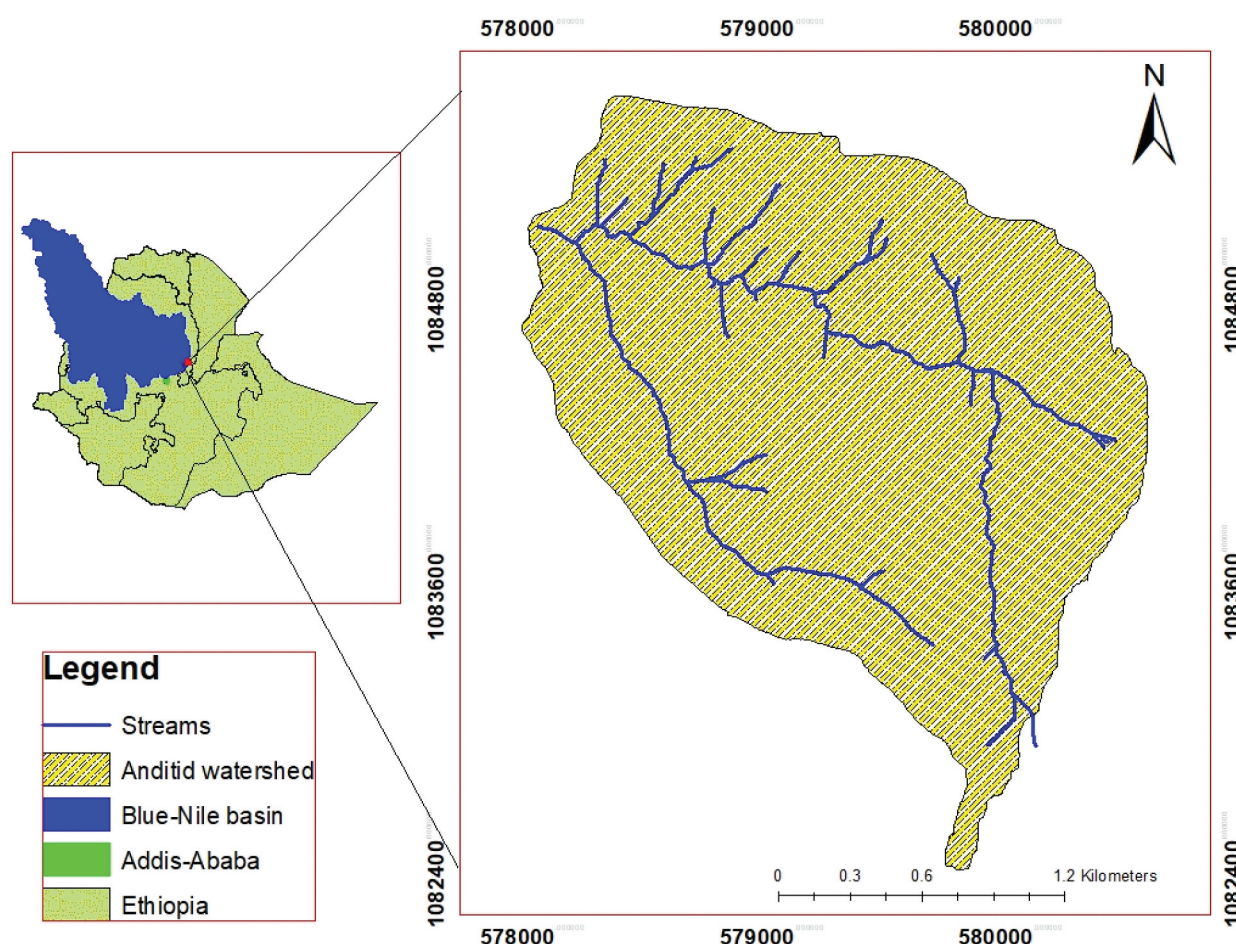


Figure 1. The location map of the study watershed.

loss for that measurement period. Suspended sediment concentration was also determined by dividing the weight of dry sediment by the volume of water (Miller et al., 2015; Womber et al., 2021).

For the seasonal analysis, the data have been divided into four seasons based on the local situation, which are winter (Bega) (December–February), Belg (March–May), summer (kiremt) (June–September) and spring (Tsedey) (October–November). The collected time-series data have some missing values. The missing value is interpolated during data processing. We used the Auto-Regressive Integrated Moving Average (ARIMA) function to fill in the missing data. ARIMA model is considered a powerful and extensively used statistical tool to analyse and predict time-series data. The main advantages of the model are that it can detect seasonal changes and consider serial correlation within the time series (Yurekli et al., 2007).

2.3. Crop yield data collection

Crop yield samples were taken from 35 fixed and 50 non-fixed plots located throughout the watershed during each cropping season. During samplings, information on crop management, inputs, soil depth, slope,

tillage, predecessor crops and crop types was included. Zone A (above the terrace or zone of deposition), Zone B (between terraces) and Zone C (below terraces or zone of transportation) were the locations from which samples were taken. The reason for different positions sampling was to identify the impact of soil conservation on crop production. The samples were taken from 4 m² of land for each plot position and we extrapolate to kg/ha. The crop types, crop management and time of cropping are decided by the land owners (farmers). In this data, all the crop types may not be sown in the fixed and non-fixed plots all over the study period (1994–2017). As a result, we only looked at the data from a single crop's growing years when analysing the trend in crop production. This information was primarily used to assess how crop production in the watershed would be affected by soil and water conservation and other new agronomic practices.

2.4. Homogeneity test of the data

The Pettitt test (Pettitt, 1979) was chosen to detect inhomogeneity in the time-series data. This test detects shifts in the average and calculates their significance (Liu et al., 2012) in a hypothesis test. In the

Pettitt test, the null hypothesis stated that the data are homogeneous, as against the alternative hypothesis tells that the data have abrupt change. The empirical significance level (p-value) was computed using XLSTAT 2020 v.3. In this study, this test was performed at a significance level of 5%.

2.5. Mann–Kendall (MK) test

Mann–Kendall trend test is an extremely important parameter for watershed modelling, and studying catchment characteristics which are very important to determine water resources planning strategies in the long term for any region (Kothawale & Rupa Kumar, 2005). The application of the Mann–Kendall non-parametric trend test is recommended by the World Meteorological Organization to detect statistically significant tendencies in environmental datasets (Irannezhad et al., 2016). The use of the Mann–Kendall trend test is widespread in the analysis of climatological and hydrological time series, because it is simple and robust, and can cope with missing values and values falling beneath the detection limit (Gavrilov et al., 2016). This non-parametric test is commonly used to detect monotonic tendencies in a series of environmental data, too (Pohlert, 2016). Mann–Kendall trend test is also used by many scholars to analyse crop production trends. For instance, Ahmad et al. (2017) and Polisetty and Paidipati, Fentaw and Dereje Hailu (2017) used Mann–Kendall and other non-parametric statistics to analyse the trends of Maize and Wheat production in Pakistan and India, respectively. The Mann–Kendall trend test is based upon Kendall (1975) and is closely related to Kendall's rank correlation coefficient. To determine the presence of a monotonic trend in a time series, the null hypothesis (H_0) of the Mann–Kendall test is that there is no monotonic trend in the series, while the alternative hypothesis (H_a) is that the data follow a monotonic trend over time. The MK test is a rank-based method for trend analysis of time-series data (Burn et al., 2004; Tesemma et al., 2010). The normalised test statistics Z for the MK test is computed using Equations (3)–(6) (Yu et al., 1993).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (3)$$

where

$$\text{sgn}(x_j - x_i) = \begin{cases} +1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \quad (4)$$

sgn is the signum function and x_i and x_j are the annual values in the years i and j , $i > j$, respectively,

The application of the trend test is done to a time series X_i that is ranked from $i = 1, 2 \dots n-1$ and X_j , which is ranked from $j = i + 1, 2 \dots n$. Each of the data points

X_i is taken as a reference point which is compared with the rest of the data point's X_j so that

If $S > 0$, then later observations in the time series tend to be larger than those that appear earlier in the time series and it is an indicator of an increasing trend, while the reverse is true if $S < 0$ and this indicates a decreasing trend.

Under the null hypothesis of no trend, the statistic S follows an approximately normal distribution with mean zero and variance (Kendall, 1975) statistic is given as

$$\text{var}(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^m t_1(t_1-1)(2t_1+5)}{18} \quad (5)$$

where n is the number of observations and t_i are the ties of the sample time series. And m is the number of tied groups.

When the sample size $n \geq 10$, as used in this study, the test statistic Z is calculated (Kendall, 1975).

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (6)$$

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

The presence of positive autocorrelation in the data increases the chance of detecting trends when actually none exists, and vice versa (Hamed & Rao, 1998). In the present study, autocorrelation has been taken into account using the Hamed and Rao method to avoid the above uncertainty. This version is based on the modified variance (Hamed & Rao, 1998; Taxak et al., 2014).

MK calculates Kendall's statistics (S), the sum of the difference between data points and a measure of associations between two samples (Kendall's tau) to indicate an increasing or decreasing trend. Positive values of those parameters indicate a general tendency towards an increasing trend while negative values show a decreasing trend. Finally, a two-tailed probability (p -value) was computed and compared with the user-defined significance level (5%) to identify the trend of variables.

2.6. Sen's slope estimation

Sen's Slope estimation test is also another non-parametric trend analysis method for climatic, hydrologic and sediment yield studies (Sen, 1968). It computes both the slope (i.e. the linear rate of change) and intercepts according to Sen's method. The magnitude of the trend is predicted by (Sen, 1968; Theil, 1950) slope estimator methods. A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend'.

Here, the slope T_i of all data pairs are computed as (Sen, 1968). In general, the slope T_i between any two values of a time series x can be estimated from

$$T_i = \frac{x_k - x_j}{j - k} \quad (7)$$

where x_j and x_k are considered as data values at time j and k ($j > k$) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is computed as

$$Q = \begin{cases} T_{\frac{N+1}{2}} & \text{if } N \text{ is odd} \\ \left[\frac{T_{\frac{N}{2}} + T_{\frac{N+1}{2}}}{2} \right] & \text{if } N \text{ is even} \end{cases} \quad (8)$$

A positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series

3. Results and discussion

3.1. Homogeneity test of the data

3.1.1. Pettitt's test of monthly, seasonal and yearly river flow and sediment yield

The Pettitt tests of river flow and sediment yield were applied to the monthly, seasonal and annual patterns. The empirical significance level of the Pettitt test (p -value) is shown in Figure 2. Statistically significant change points can be detected in March, July, August, September, October, summer, winter and even in mean annual river flow. The sediment yield data have no significant change points rather it has constant sequences for the months and seasons which have zero sediment yield records. Months and seasons have constant sequences with zero records in December, January, February and winter. In the time series of river flow amounts, the significant shift of the mean is downward over all the months and seasons.

3.1.2. Pettitt's test of crop production data

The Pettitt tests for homogeneity of crop yield data were applied to all sampling points (A, B and C). The empirical significance level of the Pettitt test (p -value)

is shown in Figure 3. Statistically significant change points cannot be detected in all positions of bunds. That means the crop production data were not inhomogeneous.

3.2. River flow (m^3) trend analysis result

The results of the descriptive statistics; MK trend test and Sen's slope are presented in (Table 1). The result showed the maximum and minimum river flows from the watershed were recorded in 1996 ($5242418.1 m^3$) and 2015 ($444779.5 m^3$) respectively with a mean of $1958943.1 m^3$ and a standard deviation of $1287910.5 m^3$. The coefficient of variation (CV %) indicated high variability of monthly, seasonal and annual river flow ($CV > 30$) (Table 1). The tendencies were also analysed using an auto-correlated Mann-Kendall trend test, as modified according to Hamed and Rao (1998) to take into account the possibility of autocorrelation in the meteorological data. If an auto-correlated trend test was used, a significant monotonic tendency could be detected in the annual dataset. The monthly MK and Sen's slope trend test result implied there is a significantly decreasing trend in March, August, September and October at ($P < 0.05$) level of significance (Figure 4).

The rainfall distribution pattern of Andit tid watershed is bimodal and concentrated from March to May (Belg season) and June to September (summer season). Based on the distribution pattern of rainfall, these months are the main rainy months of the watershed. So, the significant decrement in river flow in these months and the insignificant decrement of the other months have a relation with either development of the water holding capacity of the soil or decreasing trend of the rainfall in the watershed. Even though these all months showed abrupt changes, by using Hamed and Rao autocorrelation testing we detected the sharpness of the data. The seasonal and annual MK and Sen's slope trend results showed no significant change in river flow for the last 24 years (1994–2017), while it was insignificantly decreasing. Similar to our

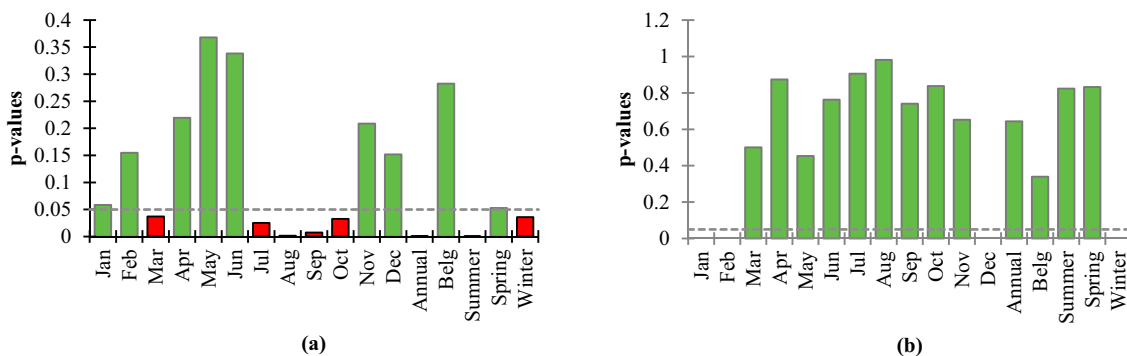


Figure 2. The Pettitt's test result of monthly, seasonal and annual (a) river flow and (b) sediment yield.

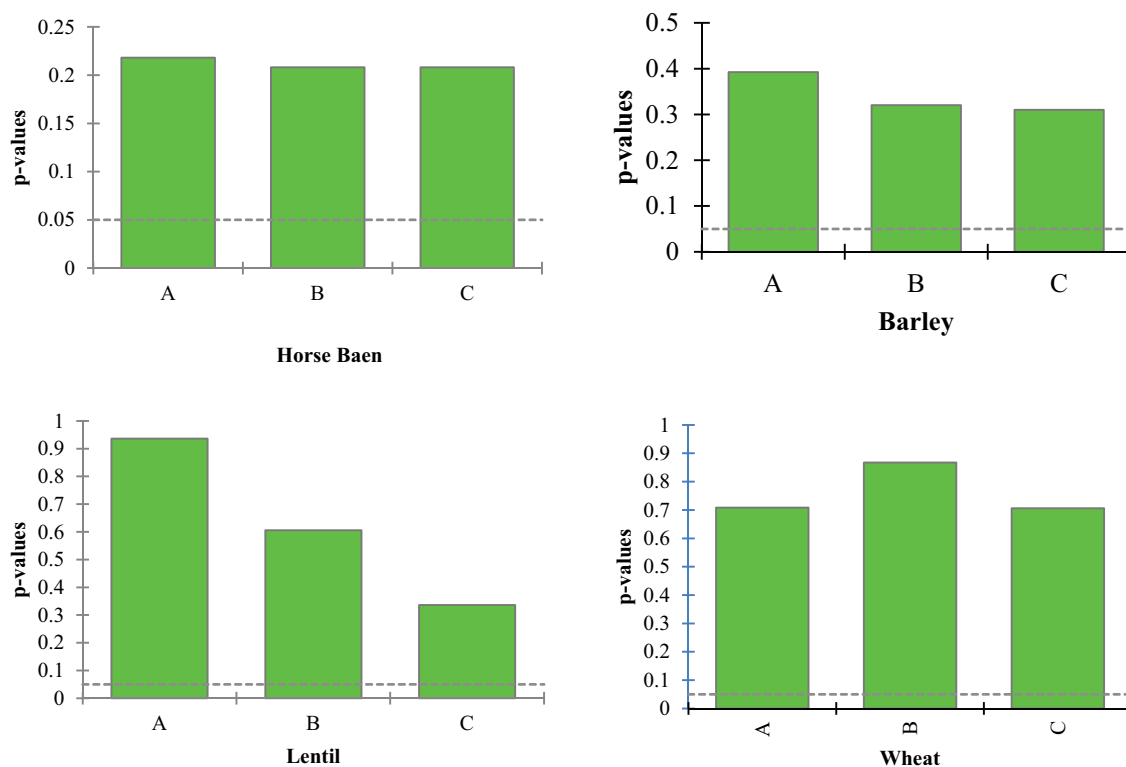


Figure 3. The Pettitt's test result of the crop production data in different position terraces (A, B and C).

Table 1. Monthly, seasonal and annual trend and variability result of river flow (m^3).

Variable	Min	Max	Mean	Std. deviation	CV (%)	Auto correlated MK value	Sen's slope
Jan	176.7	386153.6	19463.6	78364.0	402.6	-0.182	-61.1
Feb	159.6	223193.3	12066.5	45320.1	375.6	-0.196	-43.0
Mar	176.7	530881.6	41086.9	114416.0	278.5	-0.317 *	-134.7
Apr	650.7	519234.0	52437.7	111165.9	212.0	-0.152	-532.5
May	440.0	718838.5	76863.6	156037.2	203.0	-0.072	-351.6
Jun	405.0	235257.0	30448.6	51939.2	170.6	-0.007	-2.9
Jul	768.8	1097059.9	486088.3	277947.7	57.2	-0.290	-16361.3
Aug	146895.1	1484077.1	711755.7	329228.4	46.3	-0.398**	-30692.0
Sep	56181.9	1223821.6	287340.3	307614.6	107.1	-0.39**	-10781.3
Oct	1005.4	958392.5	154254.0	256500.3	166.3	-0.304*	-2692.8
Nov	171.0	359716.5	54510.8	97395.5	178.7	-0.207	-477.5
Dec	176.7	481175.8	32627.0	100025.8	306.6	-0.186	-89.2
Belg	2821.5	1768954.1	170388.2	364775.3	214.1	-0.174	-2609.2
Summer	337438.1	3555128.0	1515633.0	789769.4	52.1	-0.384	-56588.0
Spring	1418.5	1260204.0	208764.9	309568.7	148.3	-0.203	-4518.4
Winter	513.0	618263.2	64157.1	161234.1	251.3	-0.254	-265.2
Annual Q (m^3)	444779.5	5242418.1	1958943.1	1287910.5	65.7	-0.326	-67192.0

Min, minimum river flow in m^3 ; Max, maximum river flow in m^3 ; std., standard deviation of river flow in m^3 ; CV, coefficient of variation in percent; MK, Mann-Kendall.

result, Tesemma (2009) reported that there was no trend in the mean annual and flood season runoff in the Upper Blue Nile basin. The trend analysis study performed using indicators of hydrologic alteration (IHA) at the Tekeze river basin showed a significant decreasing trend in maximum flow duration and rise rate (Fentaw and Dereje Hailu, 2017). The study conducted at Awash River showed a significantly decreasing trend of discharge from 1980 to 2016 (Gedefaw et al., 2018). The result of our research is in contrast with the studies conducted in the Blue Nile basin which reported a significantly increasing trend of runoff during the wet season, the short rainy season and the annual period (Gebremicael et al., 2013). The other

studies reported that the simulated annual runoff increased by 10% over the 40 years as a result of the increase in degraded soils (Steenhuis et al., 2014).

3.3. Sediment yield (ton) trend analysis result

The results of some descriptive statistics, MK trend test and Sen's slope are presented in Table 2. The result showed the maximum and minimum sediment yield from the watershed were recorded in 1994 (3064.7 tons) and 2007 (392.1 tons) respectively with a mean of 1693.8 tons and a standard deviation of 744.4 tons. The coefficient of variation (CV %) indicated the high variability of the monthly,

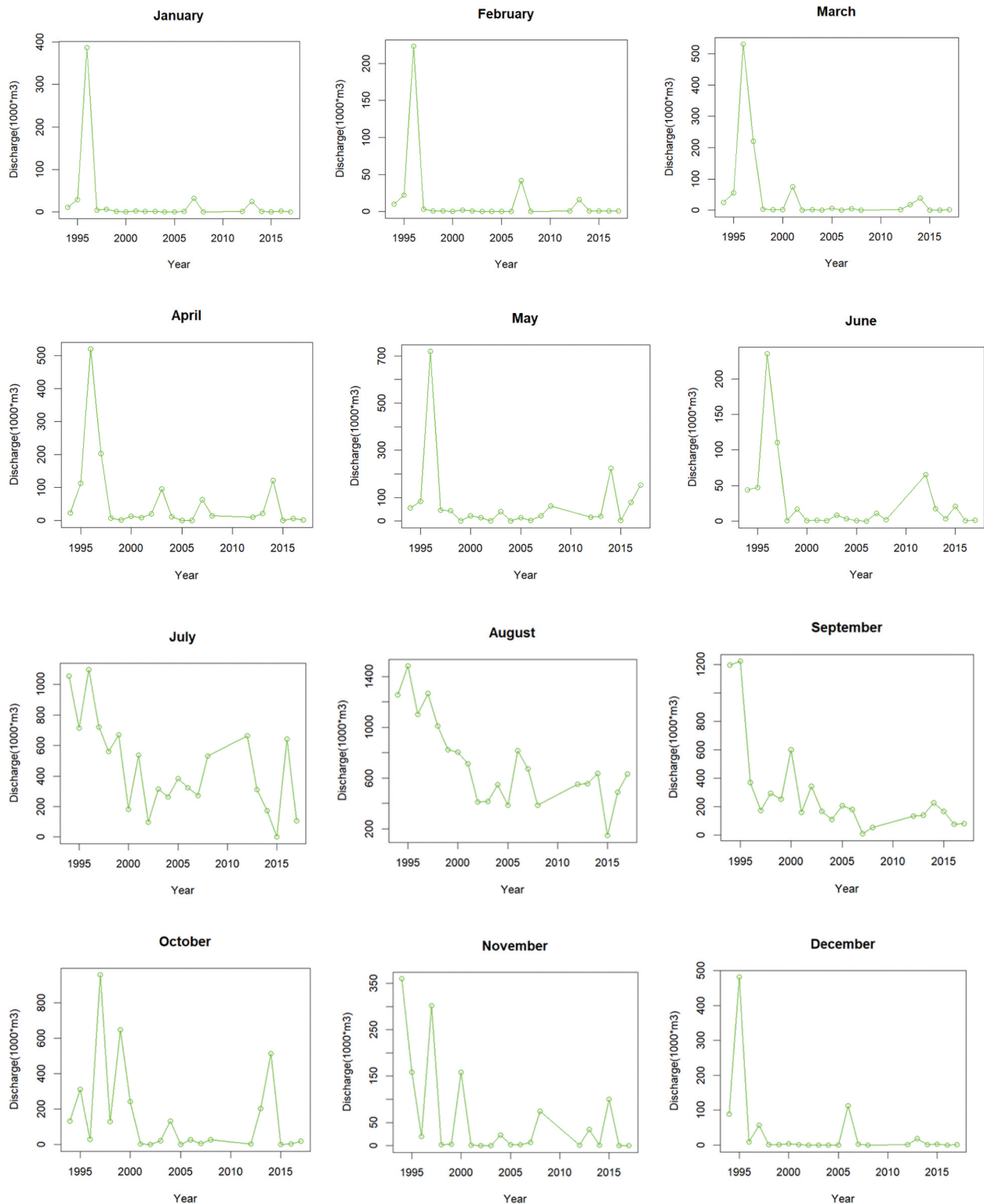


Figure 4. The long-term trends of monthly river flow (m^3/s) (March, August, September and October showed a significantly decreasing trend).

seasonal and annual sediment yield ($\text{CV} > 30\%$). The tendencies were also analysed using an autocorrelated Mann-Kendall trend test, as modified according to Hamed and Rao (1998) to take into account the possibility of autocorrelation in the meteorological data. The monthly, seasonal and annual MK and Sen's slope trend test results showed that there was no significant increasing or decreasing

trend of sediment yield at ($P < 0.05$) level of significance for the last 24 years (1994–2017), while it was insignificantly decreasing (Figure 5).

Even though it was insignificant; the annual MK and Sen's slope indicated decreasing trend in sediment yield. The decreasing trend in the sediment yield is due to the application of different soil and water conservation measures in the watershed. Fanya juu and

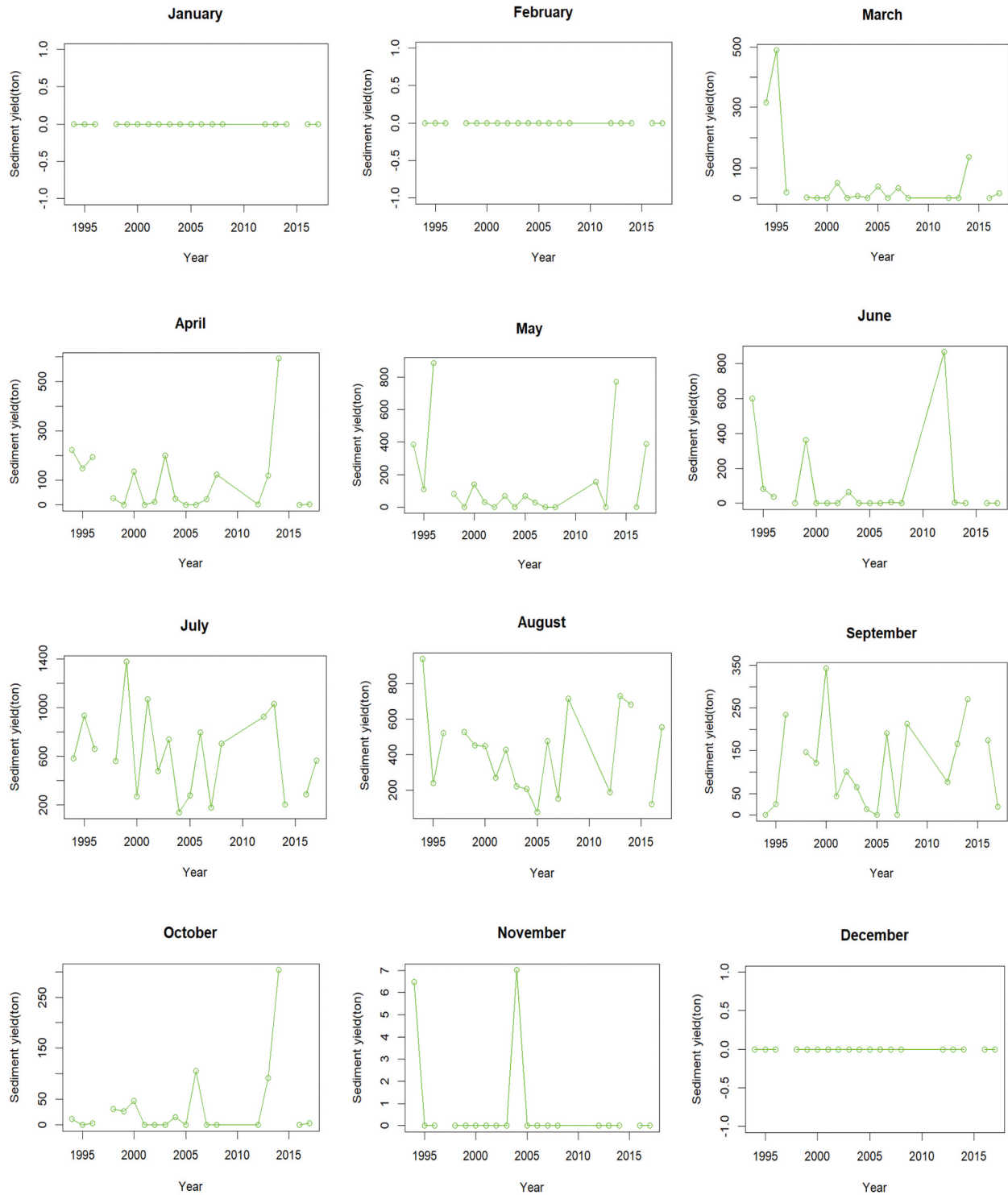


Figure 5. The long-term trends of monthly sediment yield (ton) of Andit tid watershed

bench terraces were applied in the watershed as an intervention to protect the soil from erosion. Currently, due to a lack of maintenance, the constructed soil and water conservation measures are dimensioned and consequently, it will affect river flow and crop productivity if they are not maintained properly. Similar to our finding, the trend analysis study conducted in the eastern part of the middle Yellow River basin showed the

most significant decrease, with sediment yield decreasing up to 90% in the 2000s compared with the 1950s (Zhongbao et al., 2015). Studies in Blue Nile basin reported by Steenhuis et al. (2014) revealed that the sediment loads have been highly increasing, but this needs further validation as data availability is limited. The other studies conducted in the Blue Nile basin outlet also revealed statistically increasing sediment

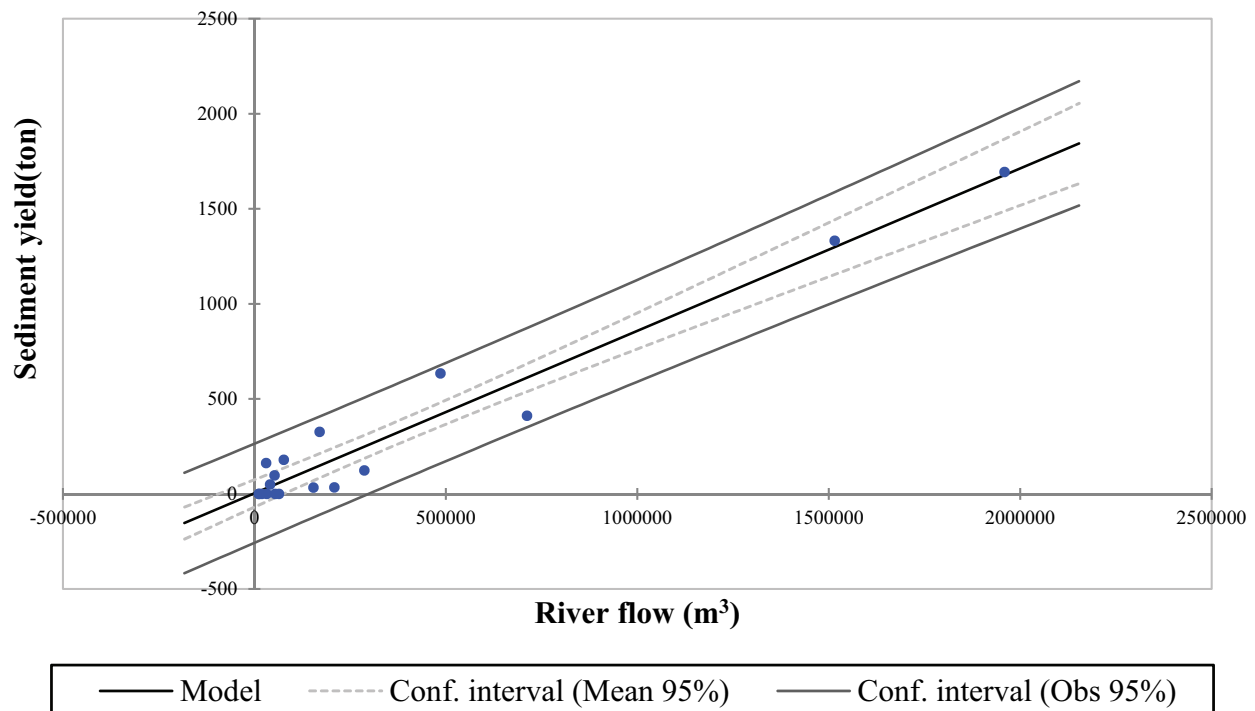
Table 2. Monthly, seasonal and annual trends of sediment yield (ton).

	Minimum	Maximum	Mean	Std. deviation	CV (%)	MK test	Sen's slope
Jan	0.0	0.0	0.0	0.0		CS	CS
Feb	0.0	0.0	0.0	0.0		CS	CS
Mar	0.0	489.3	49.4	116.1	234.7	-0.224	0
Apr	0.0	593.7	97.8	136.4	139.5	-0.140	-1.445
May	0.0	886.0	179.9	246.1	136.8	-0.034	0.000
Jun	0.0	868.5	162.1	281.3	173.5	-0.126	0.000
Jul	137.9	1378.9	634.6	329.0	51.9	-0.036	-2.933
Aug	74.9	938.6	411.9	217.5	52.8	-0.138	-6.627
Sep	0.0	342.8	123.8	94.6	76.4	0.077	1.558
Oct	0.0	303.9	33.7	69.9	207.5	0.008	0.000
Nov	0.0	7.0	0.6	1.9	339.1	-0.224	0.000
Dec	0.0	0.0	0.0	0.0		CS	CS
Belg	0.0	1500.8	327.1	401.5	122.8	-0.004	-0.171
Summer	337.0	2315.5	1332.4	578.6	43.4	-0.080	-9.805
Spring	0.0	303.9	34.2	69.7	203.7	0.008	0.000
Winter	0.0	0.0	0.0	0.0		CS	CS
Annual SY(ton)	392.1	3064.7	1693.8	744.4	43.9	-0.036	-5.441

SY, sediment yield; CS, sequences are constant or '0' ton records.

Table 3. The long-term monthly suspended sediment concentration (SSC) of Andit tid watershed.

Month	Mean	Median	Minimum	Maximum	Standard deviation
January	0	0	0	0	0
February	0	0	0	0	0
March	3.32	0.04	0.00	17.93	5.05
April	2.74	1.32	0.00	10.43	3.47
May	2.77	1.76	0.00	10.23	3.28
June	3.25	0.00	0.00	22.03	6.05
July	1.76	1.32	0.45	5.19	1.42
August	0.59	0.52	0.03	1.85	0.46
September	0.70	0.48	0.00	3.79	0.91
October	0.30	0.04	0.00	3.72	0.81
November	0.02	0.00	0.00	0.31	0.07
December	0	0	0	0	0
Annual			1.29		

Regression of Sediment yield (ton) by River flow (m^3) ($R^2=0.947$)**Figure 6.** The regression graph of river flow (m^3) and sediment yield (ton) of Andit tid watershed.

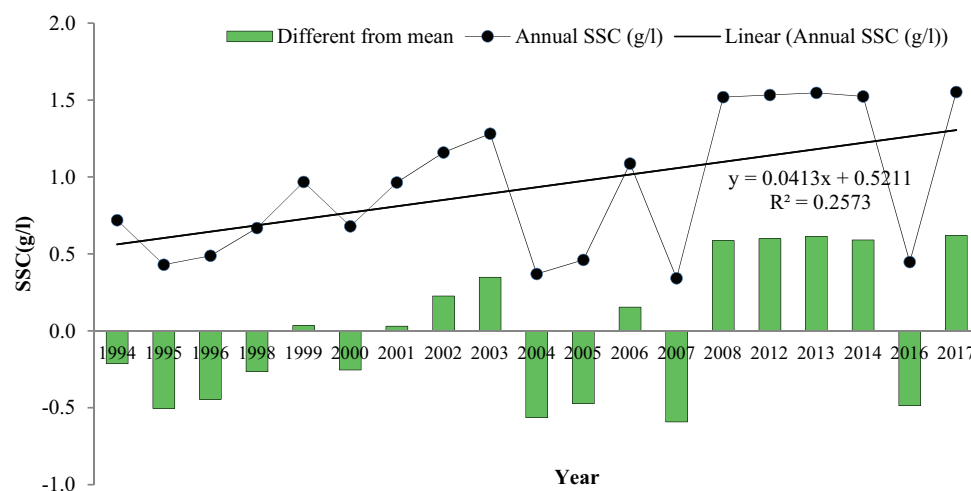


Figure 7. The long-term annual Suspended Sediment Concentration (SSC) of Andit tid watershed.

Table 4. Trends of crop production in different positions of bunds).

Sample position	Sampled year	Min (kg/ha)	Max (kg/ha)	Mean (kg/ha)	Std. deviation	CV (%)	MK value	Sen's slope
Barley production								
A	17 years	455.7	1750.0	940.2	369.5	39.3	0.015	1.718
B	17 years	418.2	1443.8	827.7	324.0	39.1	0.206	14.921
C	17 years	360.9	1375.0	741.8	271.7	36.6	0.250	13.542
Wheat production								
A	14 years	328.1	1325.0	775.7	328.3	42.3	-	-
B	14 years	237.5	1241.1	644.6	322.6	50.0	-0.077	-10.056
C	14 years	131.3	1450.0	588.1	341.3	58.0	0.022	6.5
Lentil production								
A	16 years	250	1593.8	691.2	347.8	50.3	-0.183	-9.263
B	16 years	250	1462.5	608.9	292.4	48.0	-0.067	-5.221
C	16 years	300	1175.0	563.0	236.7	42.0	-0.1	-5.477
Horse bean production								
A	8 years	300	2250	927.3	607.1	65.5	0.327	35.655
B	8 years	300	1750	839.6	470.3	56.0	0.429	47.13
C	8 years	200	1875	734.5	534.5	72.8	0.429	41.563

A, above bund; B, between bunds; C, below bunds; Min, Minimum; Max, Maximum.

load from 91×10^6 tons/year in 1980–1992 to 147×10^6 tons/year in 1993–2009 (Gebremicael et al., 2013).

3.4. Relation between sediment yield and river flow

Great care must be applied when studying the relationship between river flow and sediment yield in watersheds where biological and physical factors are subjected to change during the rainy season. In this study, we have seen the correlation and regression of river flow and sediment yield by taking the long-term monthly, seasonal and annual average data of both parameters. The correlation matrix implied that the river flow and sediment yield have significantly correlated ($R = 97.3\%$) at ($P < 0.01$). The regression analysis clearly shows that the river flow and sediment yield have a linear relation with the equation (Sediment yield (ton) = $3.41 + (8.55 \times 10^{-4}) \times \text{River flow (m}^3\text{)}$). The graph showing the regression between river flow and sediment yield is in Figure 6:

3.4.1. Suspended sediment concentration (SSC)

The annual average long-term suspended sediment concentration (SSC) for the study watershed was 1.29 g/L, ranging from 0.34 g/L in 2007 to 1.55 g/L in 2013 and 2017 as shown in Figure 6. As seen in Figure 7, there are no noticeable increasing or decreasing patterns in the watershed's annual SSC; however, it has been slightly rising since 2008.

According to the monthly SSC analysis, the months with the highest SSC are March, April, May, June and July (3.32, 2.74, 2.77, 3.25 and 1.76 g/L, respectively), while December, January and February have SSC levels of 0 g/L (Table 3). As previously noted, the river flow reaches its peak in August compared to the other months, although August's suspended sediment concentration was only 0.7 g/L. The watershed's loose soil, which is easily washed away at the beginning of the rainy season, causes the concentrations of sediment to peak before the rainy season starts. The months with the highest sediment concentration are those in which there is no cover over the ground, rendering the soil to

easily eroded. Additionally, beginning in the middle of March, all cultivated fields are ploughed and ready for crop growth; subsequently, modest rainfall can carry a lot of soil and can contribute to a high concentration of suspended sediment. All agricultural land and other land uses get covered with green vegetation after mid-summer, and the soil also develops a high cohesive force; this results in a decreased concentration of suspended sediment in August and September compared to early summer. The occurrence of SSC peak before flow peak is attributed to the soil properties that are loose erodible sediment at the beginning of the rainy season because of ploughing (Zimale et al., 2018). Sediment concentrations in rivers at the beginning of the monsoon season are high and then decrease gradually (Tilahun et al., 2011, 2013).

3.5. Crop production (kg/ha) trends

In this trend analysis, we analysed the crop production trends of major growing crops of the watershed with soil and water conservation structures applied in the watershed. The major growing crops of the watershed are Barley, Wheat, Horse Bean and Lentils. So we analysed the trends by relating the production to soil and water conservation. Table 4 shows some descriptive statistics and Mk test value and Sen's slope for the crop yield in the watershed. The descriptive statistics indicated that all the plots immediately above the bunds (zone A) delivered higher crop yields, while the plots below bunds (zone C) gave lower crop yields. This implies the positive impacts of soil and water conservation practices applied in the watershed. Even though the conservation structures are partially diminished due to lack of maintenance, they are still contributing to crop productivity. The lowering of crop yield in the plot below the bunds (zone C) is expected to be the result of nutrient depletion as a result of the loss of topsoil with erosion and lack of water storage capacity of the soil. In the other report by Hurni (2000) of Andit tid watershed from 1982 to 1994, all the crops delivered the highest yield immediately above bunds and the lowest yield immediately below bunds. The crop production performance of the watershed for the last 24 years (1994–2017) was generally low. The watershed is characterised by relatively high population and livestock densities, a high degree of land degradation, low crop yield and production as well as drastically reduced fallow periods (Hurni, 2000). The coefficient of variation (CV) indicated that there was inter-annual variability of crop yield in all crop types and all positions of bunds (CV > 30%). The MK value and Sen's slope value showed statistically insignificant trends for all crop types and positions of bunds. Even though it was insignificant; Lentil production in the watershed showed decreasing trend. This might be the result of

disease and pests affecting Lentil in the watershed. The increasing (even though it was insignificant) trend of other crop types might be the result of new crop varieties and agronomic practices demonstrated in the watershed by the Debre Brihan Agricultural Research Centre and Bureau of Agriculture. The average barley, wheat and horse bean grain yield of the watershed from 1987 to 1994 were 112.8, 57.14 and 139.3 kg/ha, respectively (Hurni, 2000). When compared to crop production before 1994, the mean crop yield of the watershed is highly increased.

4. Conclusion and recommendation

In this paper, we analysed the variability and trend of river flow, sediment yield and crop productivity of Andit tid watershed from 1994 up to 2017. To analyse the variability and trend; we used descriptive statistics and non-parametric statistical tests. To detect the abrupt changes in the data, autocorrelation has been taken into account using the Hamed and Rao method. With this analysis, the coefficient of variation of inter-monthly, inter-seasonal and inter-annual river flow and sediment yield indicated high variability (CV > 30) of both parameters. Similar to river flow and sediment yield; crop production also showed high inter-annual variability. The annual and seasonal trend analysis result revealed that there were no statistically significant ($P < 0.05$) changes in the trend of river flow and sediment yield. Monthly trend analysis showed statistically significant decreasing trends for river flow at March, August, September and October river flow.

The correlation and regression analysis of river flow and sediment yield indicated that they have a statistically strong linear relation ($R = 97.3\%$). This study determined through the SSC analysis that the early summer runoff transported more sediment than the mid and late-summer runoff. This is a result of the early-summer bareness of the ground and the soil's tendency to quickly erode, whereas in the mid- and late-summer, the green cover and the formation of cohesive soil force help to minimise the sediment carried by runoff.

This study confirmed the positive effects of soil and water conservation measures on crop productivity. All crops from plots above soil bunds delivered the highest yield and the lowest yield was harvested from plots below bunds. The overall crop productivity trend in the watershed showed an increasing trend except for Lentil. Lastly, for large-scale river flow, sediment yield and crop production analysis, we suggest for the researchers to focus on the representative watershed (s) with required data monitoring. Researchers can find out more about the causes triggering any changes in all analysed parameters.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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