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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Analysis of the combined and single effects of LULC and climate change on the streamflow of the Upper Blue Nile River Basin (UBNRB): Using statistical trend tests, remote sensing landcover maps and the SWAT model" *by* Dagnenet F. Mekonnen et al.

Dagnenet F. Mekonnen et al.

dagnfenta@yahoo.com

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Anonymous Referee #1 Overall the subject is interesting and relevant in the context of land and water management, human activities and climate change. However, I have some major concerns with regard to the

1. Style: language and technical issues like too many grammatically incorrect sentences or numbers provided in the text differ from numbers in tables etc.,

Reply from authors: accepted and major corrections will be made in the revised manuscript as suggested. In addition, the manuscript will be proofread by English native speaker to improve the quality of the manuscript.

2. Methodology: Surface runoff and infiltration, two very important processes in the context of this study, are simulated by the SWAT model using the curve number approach, which is not critically discussed in the manuscript,

Reply from authors: accepted and corrected. SWAT provides two options to simulate streamflow for the watershed using either the soil conservation service (SCS) curve number (CN) method (USDA, 1972) or Green & Ampt infiltration method (GAIM) (Green and Ampt, 1911). The CN method was chosen in this study because of its ability to use daily input data (Arnold et al., 1998; Neitsch et al., 2011; Setegn et al., 2008) as compared to GAIM, which requires sub-daily precipitation as a model input that can be difficult to obtain in data-scare region like UBNRB. Although, the CN method is the most common method adopted to predict streamflow, it doesn't consider rainfall intensity and duration, only total rainfall volume (King et al., 1999). CN method estimates the amount of runoff based on the retention parameters (S), which is a function of CN, and initial abstractions (surface storage, interception, and infiltration). Runoff occur when daily rainfall is greater than initial abstraction (equivalent to 0.2 S). However, (Ponce and Hawkins, 1996; Steenhuis et al., 1995), suggest that 0.2 retention parameter may not be representative elsewhere in the world, so that it should be interpreted as regional parameter (Jacobs and Srinivasan, 2005). Hence, justifying initial abstraction ratio to retention parameter (S) on the basis of measurements in the UBNRB will further improve the runoff simulation using SWAT model. In contrast, GAIM considers rainfall intensity/duration and is advantageous when flood routing and peak discharges are needed. However, when modeling hydrological system of large area such as UBNRB, temporal aggregation will smooth out the streamflow peaks, and the use of GAIM is becoming ineffective (King et al., 1999).

As suggested, we will added more necessary explanation and discussion on the surface runoff and infiltration processes as simulated by CN method in the revised manuscript.

3. Conclusions: According to the study, average annual rainfall has not significantly increased in the simulation period but streamflow increased significantly and the authors conclude that this is mainly due to changes in LULC.

Reply from authors: accepted and we will correct in the revised manuscript.

Although, the results of MK test for the annual and long rainy season rainfall and streamflow show increasing trend for the last 40 years in the UBNRB, the magnitude of Sen's slope for streamflow is much larger than the Sen's slope of rainfall (Figure 3). Moreover, for the short rainy season streamflow shows statistically significant positive increasing while the rainfall shows no change. The mismatch of trend magnitude between rainfall and streamflow could be attributed to the combined effect of LULC and climate change, associated with decreasing actual evapotranspiration (Ea) and increasing rainfall intensity and extreme events.

General comments 1.1 Style (language): It is disappointing that the language in most of the sections is quite poor. Many sentences are way too long and in addition most of them are grammatically incorrect, which makes reading unnecessarily tedious. One example of a confusing sentence is: page 12 lines 6-8: "This result tallies well with earlier studies in the basin at station level such as that of (Gebremicael et al., 2013) who analysed for nine stations of UBNRB on an annual basis and the result of eight stations were similar, except for the Debire markos station." ???

Reply from authors: We will improve the quality of the manuscript following your well taken and constructive comments. The manuscript will also proofread by native english speaker. The mentioned confusing sentence will be corrected as shown in the revised manuscript.

"The trend analysis result of the annual rainfall time series has a good agreement with

(Gebremicael et al., 2013), who carried out trend analysis for 9 stations of UBNRB and reported no significant change of annual rainfall during the period 1973-2005 for 8 stations except Assosa rainfall station".

1.2 Style (technical issues) Numbers provided in section 5.3 lines 5-6 differ from numbers in Table 6. Relative change values have been calculated wrongly. In Section 5.4 the authors say that mean annual streamflow increase by 15.6%. However, calculating the relative change from the numbers provided in Table 8, the relative change is 18.15% (see comment in manuscript PDF file). Inconsistent use of terms: P-value ! p-value; flow ! streamflow Figure 1: The map should be improved. It is, for instance, not easy to identify the 15 rainfall stations, because they are sometime hidden by the flow stations. You may simply use different sizes of map symbols to avoid this. ....

Reply from authors: accepted and will be corrected in the revised manuscript. Numbers and calculations provided in sections 5.3 and 5.4 were correct. Corrections have been made for Table 6 and Table 8 as they were mistakenly presented the simulation result of the SWAT model before fine tuning. The map is also improved. The corrections for Table 6, 8 and Figure1 are shown below.

The texts can be improved as follows while revising the manuscript.

Corrections for section 5.3 lines 5-6: "For the calibration period, the values of R2 , NSE and RVE (%) from the four model is ranged from 0.79 to 0.91, 0.74 to 0.91 and -3.4 % to 4 %, and for the validation period it ranged from 0.84 to 0.94, 0.82 to 0.92 and -7.5 % to 7.4 % respectively".

Corrections for section 5.4: "Mean annual streamflow increased by 16.9 % between the period 1970s and the 2000s. However, the rate of change of mean annual streamflow is different in different decades. For example, it increased by 3.4 % and 9.9 % during the period 1980s and1990s respectively from the baseline period 1970s. The ration of mean annual streamflow to mean annual precipitation (Qt/P) increased from 19.4 % to 22.1 %, and actual evaporation to precipitation (Ea/P) decreased from 61.1 % to

60.5 % from the 1970s to 2000s. Moreover, the ration of surface run-off to streamflow (Qs/Qt) has significantly increased from 40.7 % to 50.1 % and 55.4 % in the 1980s and 1990s respectively and decreased to 43.7 % in the 2000s. In contrast, the base flow to streamflow ration (Qb/Qt) has significantly decreased from 17.1 % to 10.3 % and 3.2 % respectively during the period 1980s and 1990s but has increased to 20 % in the period 2000s". Please see Table 6 and Table 8 in the supplement

On pae 1, l3, "UBNRB" It is not recommended to use abbreviations in the title. Reply from authors: accepted and will be corrected in the revised manuscript. On page 1 l15, "UBNRB" Abbreviation not introduced Reply from authors: accepted and it can be corrected in the revised manuscript On page 1 l19, Delete decreased and replace "changed" would be more accurate, because it increases in the last period

Reply from authors: accepted and will be corrected in the revised manuscript

On page 1 l20, Delete increased and replace "changed" would be more accurate, because it decreases in the last period

Reply from authors: accepted and will be corrected in the revised manuscript . On page 1, l22 "SWAT" Don't use an abbreviation if you haven't introduced it so far. The model name is actually not relevant in the Abstract.

Reply from authors: accepted and will be corrected in the revised manuscript . On page 1, l29-30 and page 2, l1 This sentence is way too long! The water resources are not limited everywhere in the Nile basin! The last part about data scarcity does not really fit here.

Reply from authors: accepted and will be corrected in the revised manuscript

On page2,l2-3, delete the sentence " with projected increases on water demands and water uses" today and water demands are projected to increase in future.

Reply from authors: accepted and will be corrected in the revised manuscript

On page 2, l3, delete "brought", "brought" is the wrong term from my point of view. Maybe better "induced"

Reply from authors: accepted and will be corrected in the revised manuscript

On page2, l3-5, "exacerbate the water scarcity of the Nile basin as they are the key factors that can modify the hydrology and water availability of the basin. Furthermore, unbalanced water utilization of the downstream countries 94% (Egypt and Sudan) remained the crucial sociopolitical issue for many years" This is only clear if the reader knows the political context. To what do the 94% refer to exactly? This needs reformulation.

Reply from authors: accepted and all texts with general facts and have political context will be deleted in the revised manuscript. For instance, texts on page 1 L29- page 2, l7 will be removed from the revised manuscript and will be replaced as follows.

"The Ethiopian government has carried out a series of studies aiming to significantly increase large reservoir for water storage in the Upper Blue Nile River Basin (UBNRB) both for irrigation and hydropower development, in order to support national development and to reduce poverty (BCEOM, 1998). Accordingly, the Government of Ethiopia has planned and realized large scale irrigation and hydropower projects such as Grand Ethiopian Renaissance Dam (GERD), the largest dam in Africa when it is completed. However, the hydrology of the UBNRB is characterized and influenced by high variations in climate and altitude/topography, landuse landcover (LULC) change exhibiting highly seasonal flows (Philip J. et al., 2016). Moreover, its development and management should be agreed and reached consensus between shared countries, as it contributes more than 60 % of the water resources of the Nile river (McCartney et al., 2012). Hence, better and optimized water resource development strategies is needed, to tackle all these complexities. This can be achieved only by understanding the combined and single impacts of LULC and climate variability as they are the key driving forces that can modify the hydrology and water availability of the watershed (Oki and

Kanae, 2006; Woldesenbet et al., 2017b; Yin et al., 2017). LULC can modify the rainfall path into run-off by altering critical water balance components, such as surface run-off, groundwater recharge, infiltration, interception and evaporation (Marhaento et al., 2017; Woldesenbet et al., 2017b). The UBNRB already experiences significant spatial and temporal climate variability (McCartney et al. 2012), less than 500 mm yr−1 of precipitation falls near the Sudan border to more than 2,000 mm yr−1 in some places in the southern basin (Awulachew et al., 2009). Potential evapotranspiration (ET) also varies considerably and is highly correlated with altitude, it exceeds 2,200 mm yr-1 near the Sudan border from approximately 1,300 to 1,700 mm yr-1 in the Ethiopian highlands(McCartney et al., 2012). As a result of the precipitation and ET cycles, stream flow is highly characterized by extreme seasonal and inter-annual variability".

On page 2, l9, Not only has Ethiopia carried out studies, but is also currently realizing big projects!

Reply from authors: accepted and will be corrected in the revised.

On page2, l10, get rid of poverty sounds colloquial. Maybe better "to reduce poverty"

Reply from authors: accepted and will be corrected in the revised. Please see the above revisions of the introduction section.

On page 2, l11, "UBNRB" Abbreviation has not been introduced in the introduction so far and is also spelled wrongly. "However, as the Upper Blue Nile River Basin (UBNRB)...

Reply from authors: accepted and will be corrected in the revised. Please see the above possible revisions of the introduction section above.

On page 2, l21, Explain what the Belg season is. Not every reader will be familiar with the rainy seasons in Ethiopia.

Reply from authors: accepted and will be corrected in the revised manuscript. For in-

stance,....."statistically non-significant increasing trends at annual and seasonal rainfall series except a short rainy period (Belg season) from the month of February to May"

On page2, l24 change "flow" to streamflow

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l25, delete "from" and replace by "in"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l25, add "a" significantly increasing.... add "trend"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l26, correct the citation (Rientjes et al., 2011) into Rientjes et al.,(2011)

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 2, l26, Add (Lake Tana catchment, the Blue Nile headwaters) into..." reported that low flows in the Gilgel Abay sub-basin"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l27, Add "by" after "specifically" and delete " decrease for" and add "in"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l28, delete "in" and replace by "by"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l32, add "the" to ....

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l33 delete " single factor" and change "flow" to "streamflow"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page2, l34 add "." after "(Tekleab et al., 2014)" and replace "by" by "of the"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page3, l7 delete " satellite remote sensing" and replace by "analysis of LULC maps derived from satellite remote sensing products" and delete " SWAT hydrological model" and add "hydrological modelling"

Reply from authors: accepted and will be corrected in the revised manuscript. ...."the UBNRB through a combined analysis of statistical trend test of the precipitation, analysis of LULC change derived from satellite remote sensing and hydrological modeling during the period 1971-2010".

On page 3, l10, delete " between longitudes 34.300 and 39.450E and latitudes 7.450 and 12.450N"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page3, l11 Add "catchment"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page3, l14 correct "UNBRB" into "UBNRB"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page3, l15 add "annual"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page3, l20 BCM has not been introduced so far.

Reply from authors: accepted and will be corrected in the revised manuscript

On page 4, l2 correct "2011" into "2010"

Reply from authors: accepted and will be corrected in the revised manuscript On page4, l6 delete "was" and replace by "were"

Reply from authors: accepted and will be corrected in the revised manuscript

On page4, l8, delete "GIS input" and You have to introduce the SWAT model here by providing the full name and the reference(s).

Reply from authors: accepted and will be corrected in the revised manuscript

On page4, l8, add "a" a Digital Elevation Model....

Reply from authors: accepted and will be corrected in the revised manuscript

On page4, l9, add " and corresponding parameterization" after soil data...

Reply from authors: accepted and will be corrected in the revised manuscript

On page 4, l21-23, language needs to be improved

Reply from authors: accepted and language will be improved in the revised manuscript. Section 3 will be modified as follows.

Section 3. Input data sources In this study, long time series (1971-2010) hydro-meteorological data were used for trend analysis. The streamflow data set was collected from the Federal Ministry of Water Irrigation and Electricity of Ethiopia. Daily climate data were obtained from the Ethiopian National Meteorological Agency (ENMA). The monthly, seasonal and annual hydro-meteorological data were aggregated from the daily time series data. After intensive and rigorous analyses of measured data, considerable time series data were missed in most stations, as a result the available data constrained us to focus only for 15 stations in which data are relatively more complete.

We used spatial interpolation such as the inverse distance weighting method (IDWM) and linear regression techniques (LR) as a candidate approach to fill the gaps. Similar approaches or methods were applied by Uhlenbrook et al. (2010) for the Gilgel Ababy sub-basin, which is the head water of UBNRB. The selection and quantity of adjacent stations are critically important to the accuracy of the estimated results. As mentioned by Woldesenbet et al. (2017a), different authors used different criteria to select neighboring stations. Because of low station density of the study area, for most stations, a geographic distance of 100 km were considered to select neighbouring stations. If no station is located within 100 km of the target station, the search distance is increased until the minimum of one suitable station is reached. After the neighbouring stations were selected, the two methods (IDWM and LR) were tested to fill in missing hydrometeorological datasets. The performance of the candidate approaches was evaluated using the statistical metrics such as root mean square error (RMSE), mean absolute error (MAE), correlation coefficient (R2) and Nash-Sutcliffe efficiency coefficient (NSE) between observed and estimated values for the target stations. Equally weighted statistical metrics is applied to compare the performance of selected approaches at target stations to establish ranking. A score was assigned to each candidate approach according to the individual metrics; e.g. the one achieving the smallest RMSE and MAE, or NSE, has got score 1, and so on. The final score is obtained by summing up the score pertained to each candidate approaches at each stations. The best method is the one having the smallest score.

The spatially distributed data for the Soil and Water Assessment Tool (SWAT) hydrological model, which was developed by the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) (Arnold et al., 1998) includes a Digital Elevation Model (DEM), soil data and corresponding parameterization and LULC maps. A Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) of 90 metres resolution from the Consultative Group on International Agricultural Research-Consortium for Spatial Information (CGIAR-CSI; http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp) was used to delineate the watershed and to analyse the drainage patterns of the land surface terrain. The soil map developed by the Food and Agriculture Organization of the United Nations (FAO-UNESCO) at a scale of 1:5,000,000 downloaded from (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-ofthe-world/en/) was used for SWAT model. The soil information such as soil textural and phys-

iochemical properties needed for the SWAT model was extracted from Harmonized World Soil Database v1.2, a database that combines existing regional and national soil information (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-databasev12/en/) in combination with information provided by FAO-UNESCO soil map (Polanco et al., 2017). The LULC maps, representing one of the most important driving factors to affect surface run-off and evapotranspiration in a basin were produced from satellite remote sensing Landsat images for 1973, 1985, 1995 and 2010.

On page 4, l30 and on page 5, l1 This sentence needs rephrasing!

Reply from authors: accepted and will be corrected in the revised manuscript It can be rephrase as "Its advantage over the parametric tests, such as t-test, is that the MK test is more suitable for non-normally distributed, censored, missing data, which are frequently encountered in hydrological time series (Yue and Wang, 2004)"

On page5, l4-5, And what does this mean in the context of this study, knowing that discharge time series are normally autocorrelated? You are partly explaining this in the following paragraph. You may consider to merge the paragraphs.

Reply from authors: accepted and will be corrected in the revised manuscript This can be corrected as "However, the existence of positive serial correlation in a time series data affects the MK test. If there exists serial correlation in a time series data, the Mk test rejects the null hypothesis of no trend detection more often than specified by the significance level (von Storch, 1995), if there exists serial correlation in a time series data".

On page 5, l5-6, What do you mean by "which is actually true"? Are you simply confirming that the statement of von Storch is true?

Reply from authors: We wanted to give an emphasis that MK test rejects the null hypothesis of no trend wrongly when there exists serial correlation in the time series data. This means that under actual condition, the time series data has no trend but MK test detects a trend because of serial correlation.

On page 5, l24, I am not sure whether it is useful to repeat the underlying statistics in such detail as was published by Mann and Kendall. It would be meaningful only if the authors would have developed any new method based on the existing methods. But it seems they are simply applying methods that already exist. On page 5, l8, correct into 0, if x = 0 NOT 0, if x 0 =

Reply from authors: accepted and removed the details of MK test from the manuscript

On page7, l20, "Kappa" Since the kappa statistics are also mentioned later on, some explanation should be included here. Not every reader will be familiar with this parameter.

Reply from authors: accepted and the below explanations on Kappa statistic will be added in the revised manuscript. The to be added texts are as follows Another discrete multivariate technique of use in accuracy assessment is called KAPPA (Cohen, 1960). The result of performing a KAPPA analysis is a KHAT statistic (an estimate of KAPPA), which is another measure of agreement or accuracy. The KHAT statistic is computed as

K= (N$\sum_(i=1)^(i=r) x_ii \sum_(i=1)^r (x_(i+) * x_(+i)))/(N^2 - \sum_(i=1)^r (x_(i+) * x_(+$

where r is the number of rows in the matrix, xii is the number of observations in row i and column i, x i+ and x +i are the marginal totals of row i and column i, respectively, and N is the total number of observations

On page 8, l13-14, This sentence (or an explanation of the n value) should be moved to the end of the previous paragraph.

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 9, l21, The curve number method, developed for soils in the US, has often

been criticized, because of a lack of physical reality in the formulation of the method and its limited applicability to soils outside the US. It governs surface runoff and infiltration, two variables that are of high importance in this study. I am missing a critical reflection here or even better in the discussion section. Maybe in addition in the conclusions.

Reply from authors: accepted and we will add the limitation of CN method. Moreover, explanation on surface run-off and infiltration will be added. See our response to your comments #2 methodology section above

On page 10, l1, "three separate data sets" I assume not three separate data sets but three periods of the same data set where the first (warm up) is not considered in the analysis.

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 10, l12, correct "strategy was" into "strategies were"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 10, l14, correct "in to" to "into"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 10, l16, correct " The models performance for the streamflow were then" into " The model performance for the streamflow was then"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 10, l23, correct "flow data" into "streamflow" and delete "n" mean n values

Reply from authors: accepted and will be corrected in the revised manuscript.

On page10, l29 and on page 11, l1, delete " the simulation results represented “real runoff” affected by the combination of LULC and climate changes"

Reply from authors: accepted and will be corrected in the revised manuscript.

On page 11, l5-6, Strange formulation. Also the following sentences should be reformulated or grammatically corrected.

Reply from authors: accepted and will be corrected in the revised manuscript “To analyze the response of streamflow and water balance components to the combined effects of LULC and climate change for different decadal time periods, the SWAT model was separately calibrated and validated for each decades using the corresponding LULC map and weather data(Yin et al., 2017). The DEM and soil data sets remained unchanged. The difference between the baseline and altered periods simulations represents the combined effects of LULC and climate changes on streamflow and water balance components".

On page 11, l19-20 "precipitation data set" I assume you mean weather data of the 1970s not only precipitation?

Reply from authors: accepted and precipitation will be replaced by "weather" in the revised manuscript.

On page11,l28, Many sentences in Section 5.1.1 need rephrasing, because they are grammatically incorrect and difficult to understand. Moreover, the locations of the weather stations are not given in the map (Fig. 1) which makes it impossible to understand where in the catchment trends are significant and where not. I would expect an interpretation with geographical context in the manner of: "In the north-east of the UBNRB, the trends are significant ..." This would make the analysis much more useful. The precipitation trend analysis sounds a bit like a repetition or confirmation of results of other studies, without bringing in some new information. Maybe there is, but it is not carefully explained and should be more elaborated. The authors state for instance that the "Pettit test showed a jump point with increasing trend." However, there is no explanation of what the jump point really is, when it occurred etc.

Reply from authors: accepted and section 5.1.1 will be rephrased in the revised manuscript as shown below. Figure 1 is revised. The new information of this study

as compared to the previous studies are presented below highlighted with yellow color.

5.1.1 Rainfall The summary of the MK trend tests result for the rainfall of the 15 selected stations located inside and around the UBNRB revealed a mixed trend (increasing, decreasing and no change). For daily time series, the computed probability values (p-value) for seven stations was greater while for eight stations it was less than the given significance level (α=5 %). This means no statistically significant trends existed in seven stations but a monotonic trend was occurred in the remaining 8 stations. Spatial distribution of daily precipitation showed that positive trends occurred only at 6 stations, of which 4 stations concentrated in the northern and central highlands (Bahirdar, Dangila, Debre Markos and G/bet), the other two stations (Assosa and Angergutten) are located in the south-west and southern lowlands but Alemketema and Nedjo stations respectively located in the East and South-West showed a decreasing trend (Figure1). On a monthly basis, the MK trend test result showed that no statistically significant trend existed in all 15 stations. On an annual time scale, MK trend test could not find any trend in 11 stations while four stations (Alemketema, Debiremarkos, Gimijabet and Shambu) exhibited a trend. The trend analysis result of the annual rainfall time series has a good agreement with (Gebremicael et al., 2013), who carried out trend analysis for 9 stations of UBNRB and reported no significant change of annual rainfall during the period 1973-2005 for 8 stations except Assosa station. Hence, it is interesting to note that the time scale of analysis is critical factor to determine the given trends.

The basin wide rainfall trend and change point analysis was again carried out at daily, monthly, seasonal and annual time scale using MK test and Pettitt test respectively as summarized in Table 3 and Figure 3. The MK-test showed increasing trends for annual, monthly and long rainy season rainfall series while no trend for daily, short rainy and dry season rainfall series. The magnitude of trends for annual, monthly and long rainy season rainfall series are not significant as explained by the values of Sen’s slope. However, the Pettitt test could not detect any jump point in basin wide rainfall series except for daily rainfall series.

Previous studies carried out the trend analysis of the basin-wide rainfall such as (Conway, 2000; Gebremicael et al., 2013; Tesemma et al., 2010), reported that no significant change of annual and seasonal rainfall series over the UBNRB. This disagreement could be due to the number of stations and their spatial distribution over the basin, time period of the analysis, approach used to calculate basin wide rainfall from gauging stations and sources of data. Tesemma et al. (2010) was used monthly rainfall data downloaded from Global Historical Climatology Network (NOAA, 2009) and the 10-day rainfall data for the 10 selected stations obtained from the National Meteorological Service Agency of Ethiopia from 1963-2003. Conway (2000) was also constructed basin-wide annual rainfall of UBNRB for the period 1900-1998 from the mean of 11 gauges each with less than 25 years length of record (only three gauges have continuous records back to pre-1910). Furthermore, (Conway, 2000) employed simple linear regressions over time to detect trends in annual rainfall series without removing the serial autocorrelation effects. Gebremicael et al. (2013), also used only for 9 stations from the period 1970-2005. However, in this study, we used daily observed rainfall data for 15 stations collected from Ethiopian Meteorological Agency from 1971-2010. The stations are more or less evenly spatially distributed over UBNRB. We applied widely used spatial interpolation technique (Thiessen polygon method) to calculate basin-wide rainfall series.

On page12, l11, The parameters Sen's slope and r1 in Table 3 are not explained.

Reply from authors: accepted and explanations will be added in the revised manuscript. Sen's slope refers to the magnitude of the trend while r1 refers to serial autocorrelation.

Sen's slope estimator The trend magnitude is estimated using a non-parametric median based slope estimator proposed by (Sen, 1968) as it is not greatly affected by gross data errors or outliers, and it can be computed when data are missing. The slope estimation is given by:

β=Median[(X_j-X_k)/(j-k)] for all k < j, ...1 Where 1 < k < j < n, and β is considered

as median of all possible combinations of pairs for the whole data set. A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series. All MK trend test, Pettitt change point detection and Sen's slope analyses were conducted using the XLSTAT add-ins tool from excel (www.xlstat.com).

On page 12, l17, I don't fully agree with the analysis in section 5.1.2.

If there is a significant increasing trend in daily and annual streamflow, why are the patterns at the monthly time step not clear? I would like to see a graphic proving this statement and a more elaborated discussion on this issue.

It might be true that the significance of rainfall increase over the basin is low, but figures 3a) and 3c) show that there is a positive trend. The 1970s are used as a baseline in this study, which is fine for the analysis of LULC change. However, Fig 3a) clearly shows that the 1970s are much dryer on average than the periods representing the 1990s and 2000s. Hence, the last sentence in this section is not entirely true and increasing annual streamflow cannot be attributed mainly to LULC change.

Reply from authors: accepted and corrected. The result of MK-test for daily, monthly, annual and seasonal time series streamflow showed a positive trend and the trend is statistically significant for annual, long and short rainy season streamflow but insignificant for daily and monthly (Table 3). Meanwhile, the Pettitt test detects change point for daily, annual, long and short rainy season streamflows but cannot detect change point for monthly and dry season streamflow. We have updated Table 3 to address this comment. Please see Table 3 in the supplement

Regarding to Figure 3 a), The MK trend test detects increasing trends for the annual rainfall but the magnitude of the trend is not significant as calculated by Sen's slop. However, the Pettitt test could not detect a jump point as shown in Table3. The last sentence also corrected as " Although, the results of MK test for the annual and long rainy season rainfall and streamflow show increasing trend for the last 40 years in the

UBNRB, the magnitude of Sen's slope for streamflow is much larger than the Sen's slope of rainfall. Moreover, for the short rainy season streamflow shows statistically significant positive increasing while the rainfall shows no change. The mismatch of trend magnitude between rainfall and streamflow could be attributed to the combined effect of LULC and climate change, associated with decreasing actual evapotranspiration (Ea) and increasing rainfall intensity and extreme events".

The Pettitt test result for basin-wide daily, monthly, annual and seasonal precipitation and for daily, monthly, annual and seasonal streamflow series is presented in Figure S01 and Figure S02 respectively

On page 13, l1, delete "Monserud (1990) as cited by Rientjes et al. (2011)"

Reply from authors: accepted and will be deleted from the revised manuscript.

On page 14, l5-6, These values do not correspond with the values given in Table 6

Reply from authors: accepted and Table 6 is corrected. Please see our response for major comments 1.2 above.

On page14, l13, "observed" is the wrong term! The change of the CN2 value has been made by the modeller, because it led to better simulation results.

Reply from authors: accepted and corrected as "attained". In contrary, a decrease in CN2 value was "attained" during the period 1990s to 2000s from 0.92 to 0.9, attributed to the increase in forest coverage and reduction in cultivated land.

On page 14, l19, I can't see the short rainy season in the results. Same is true for the following sentence. How do the SWAT simulations confirm this? There is only one flood peak per year.

Reply from authors: accepted and corrected. The MK test shows an increasing trend for daily, monthly, annual and seasonal (long and short rainy and dry seasons) and the trend magnitude is statistically significant for annual, long and short rainy season

streamflow (Table 3). The misleading "SWAT simulation confirms this" will be deleted in the revised manuscript.

On page 14, l22, "18.15%" Wrong equation has been applied to calculate the relative changes between 1970 and 2000.

The correct equation is: (|1970-2000|)/1970*100 = 18.15

The authors calculated the change probably like this: (2000-1970)/2000*100

Reply from the authors: accepted and corrected. Accordingly Table 8 has been corrected. The relative change has also been corrected as " Mean annual streamflow increased by 16.9 % between the period 1970s and the 2000s. However, the rate of change of mean annual streamflow is different in different decades. For example, it increased by 3.4 % and 9.9 % during the period 1980s and1990s respectively from the baseline period 1970s". Please see the authors response for your major comment 1.2 above.

On page 14, l24, "2.1%, 6.8% and 6%" These numbers are also wrong! See comment and equation in line above. Reply from authors: accepted and corrected. Please see the above explanation.

On page 14, l26-29, correct 19.4% into 19.2%, add "the" into..ratio of surface, correct 40.7% into 36.6%, add "in the 1990s and decreased to 43.7 in the 2000s." after "55.4%", add "ration" after "streamflow", correct "17.1%" into "20.6%" and add "but has increased to 20% in the period 2000s" after "1990s"

Reply from authors: accepted and the texts are corrected. The numbers in the text were correct but Table 8 was wrong. As suggested, Table 8 has been corrected as above.

Mean annual streamflow increased by 16.9 % between the period 1970s and the 2000s. However, the rate of change of mean annual streamflow is different in different decades. For example, it increased by 3.4 % and 9.9 % during the period 1980s and1990s respectively from the baseline period 1970s.

The ration of mean annual streamflow to mean annual precipitation (Qt/P) increased from 19.4 % to 22.1 %, and actual evaporation to precipitation (Ea/P) decreased from 61.1 % to 60.5 % from the 1970s to 2000s. Moreover, the ration of surface run-off to streamflow (Qs/Qt) has significantly increased from 40.7 % to 50.1 % and 55.4 % in the 1980s and 1990s respectively and decreased to 43.7 % in the 2000s. In contrast, the base flow to streamflow ration (Qb/Qt) has significantly decreased from 17.1 % to 10.3 % and 3.2 % respectively during the period 1980s and 1990s but has increased to 20 % in the period 2000s.

On page 15, l4-l9, " Once the SWAT model had been calibrated and validated for the baseline period, the SWAT model again ran four times for the baseline period and for three altered periods using updated LULC maps. Firstly, with the LULC map of 1973; secondly with LULC map of 1985; thirdly with LULC map of 1995; and fourthly with LULC map of 2010. Then the outputs from the four different LULCs were compared. We note that the climate data for the period 1973-1980 and calibrated parameter values for the 6 sensitive parameters remained constant while the LULC was changed for all four models to identify hydrological impacts of changes in LULC explicitly as suggested by (Hassaballah et al.). " From my point of view, the following sentence explains the procedure in a much easier way: To identify the hydrological impacts caused by land use only, the SWAT model and its parameter settings calibrated and validated in the baseline period was forced by weather data from the baseline period 1973-1980 while changing only the LULC maps from 1985, 1995, and 2010.

Reply from authors: accepted and will be corrected in the revised manuscript as it is suggested.

On page 15, l14-l17, " In the other hand, expansion of cultivated land and reduction in forest coverage affects the properties of top soil that cause a lower permeability and less infiltration as a result fraction of precipitation converted to surface run-off is

increasing while the fraction of base flow is getting reduced." Too many information in this sentence. I would split it into at least two sentences. The statement that expansion of cultivated land and reduced forest coverage lead to less infiltration is not generally true. It might be the case in the SWAT model but certainly not in reality. Isn't it simply because of changed CN values which govern the behaviour of surface runoff generation and infiltration?

Reply from authors: accepted and the sentence will be deleted and revised as follows..

On a basin scale, over a decadal time period, water gains mainly from precipitation, and the losses are mainly due to run-off and evapotranspiration(Oki et al., 2006). In the fixing-changing approach, the change in streamflow due to LULC was essentially the change in the evapotranspiration between the two periods, as the amount of precipitation was constant (1970s) and the change in the water storage during the two periods was similar (Yan et al., 2013). Actual mean annual evapotranspiration (Ea) simulated by SWAT model was 871.6 mm at the baseline. It decreased to 871.4 mm and 871 mm in the 1985 and 1995 respectively and increased to 872.1 mm in the 2010. This could be due to simultaneous expansion of cultivated land and shrinkage in forest coverage in the LULC map of 1985 and 1995 from the base line 1973. So, it causes the increase CN parameter value (which govern the behaviour of surface runoff generation and infiltration), as a result surface runoff increased. Furthermore, the annual Ea losses from seasonal crops are smaller than the Ea losses from forests, as seasonal crops only transpire relatively shorter time period than perennial trees transpire in the UBNRB (Yan et al., 2013). This deforestation may cause a reduction in canopy interception of the rainfall, decrease the soil infiltration by increasing raindrop impacts and reduce plant transpiration which can significantly increase surface run-off and reducing base flow (Huang et al., 2013).

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Please also note the supplement to this comment:

https://www.hydrol-earth-syst-sci-discuss.net/hess-2017-685/hess-2017-685-AC2-supplement.pdf

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-685, 2017.

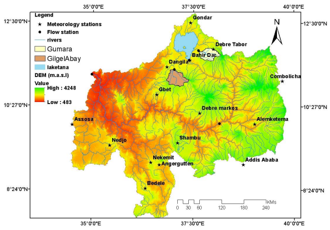

Figure 1 : Locations of study area and meteorological and discharge stations, with the Digital Elevation Model (DEM) data as the background

Fig. 1.