We thank the two anonymous reviewers for their extensive general and specific comments that addresses important issues which help us to improve the manuscript significantly.

List of all relevant changes made the manuscript

Editor Decision Comments to the Author:

As rev. #1 pointed out, one important constraint of SWAT is that runoff generation is approached by the CN method. You mention a 2nd option, i.e. Green-Ampt infiltration. I acknowledge that these approaches are inherent in SWAT and the authors cannot add a new approach, which might be more oriented towards the runoff generation processes in this region. As suggested by rev. #1, this problem needs to be discussed, both where SWAT and its results are presented and possibly in the overall discussion. You may discuss, e.g.: what are the main runoff generation processes in that region (Hortonian overland flow? and/or Dunne overland flow, i.e. sat. excess?)? Do you have an expert opinion on this? How do those processes vary in time, depending on the rainfall type/intensity and on the seasons? What about connectivity of the overland flow generated on the hillslopes or field with the channel system. Be aware that the issue of connectivity (or overland water retention before reaching the channel system) is NOT included in the (original) CN-approach neither Gren&Ampt. How does SWAT, or how do you, approach this problem? Is this parametrized in the CN values, e.g. are your CN-values kind of "effective" values? I think it is well worth to discuss this.

Reply from authors: These points are critical and much relevant to improve the quality of the manuscript. Therefore, critical discussions were added as shown in the marked up manuscript on page 10, L10-L25 and on page 23 and 24.

Although, there is no any detail research carried out on the Blue Nile basin to investigate about the runoff generation processes, Liu et al. (2008) investigated the rainfall-runoff processes at three small watersheds located inside and around Upper Blue Nile basin, namely: Mayber, AnditTid and Anjeni. Their analysis showed that, unlike in temperate watersheds, in monsoonal climates a given rainfall volume at the onset of the monsoon produces a different run-off volume than the same rainfall at the end of the monsoon .Liu et al. (2008) and Steenhuis et al. (2009) showed that the ratio of discharge to precipitation minus evapotranspiration (Q/(P- ET)) increases with cumulative precipitation from the onset of monsoon and, consequently, the watersheds behave differently depending on the amount of stored moisture in the watershed. Hence, they suggested that saturation excess processes play an important role in watershed response.

Furthermore, the infiltration rates measured in 2008 by Engda (2009) were compared with rainfall intensities in the Maybar and Andit Tid watersheds. In Andit Tid watershed, which has an area of less than 500 ha, only 7.8 % of the rainfall intensity available for the period 1986-2004 were found higher than the lowest soil infiltration rate measured at 10 locations, 2.5 cmhr-1. A similar analysis was performed in the Maybar watershed (with a catchment area of 113 ha) by (Derib, 2005). The infiltration rates measured from 16 measurements at the Maybar watershed ranged from 19 to 600 mm hr-1with an average value was 24 cm hr-1 and the median was 18 cmhr-1. The average daily rainfall intensity for seven years (from 1996 to 2004) was 8.5 mm hr-1. Hence, from these infiltration measurements, he suggested that infiltration excess run-off is not a common feature in these watersheds.

(Easton et al., 2010) developed a modified version of the commonly used SWAT model. This new version of SWAT including water balance (SWAT-WB), calculates run-off volumes based on the available storage capacity of a soil and distributes the storages across the watershed using a soil topographic wetness index (Easton et al., 2008), where run-off occurs in watersheds dominated by saturation-excess processes (White et al., 2011). The model was tested in the UBNRB including at gauging station El Diem. The model was able to capture the dynamics of the basin response well (NSE=0.87, r^2 =0.92) at El Diem station. Similar result was obtained by (Gebremicael et al., 2013) using standard SWAT-CN model (NSE= 0.84, r^2= 0.92) for daily streamflow at El Diem. From these results one may notice that the standard and modified SWAT model perfectly simulates the runoff processes in the UBNRB. The primary difference between the CN based SWAT and the water balance based SWAT-WB is that, SWAT-WB has ability to predict the spatial distribution of runoff source areas which has important implications for watershed intervention, where information on the location and extent of source areas is critical to effectively managing the landscape, to provide clean water supplies, enhance agricultural productivity, and reduce the loss of valuable top soil(Easton et al., 2010). Furthermore, (Collick et al., 2009; Steenhuis et al., 2009) developed a water balance model that fits to the runoff generation processes of the Blue Nile watersheds. Despite their simplicity and improved watershed outlet predictions they fail to predict the spatial location of the run-off generating areas and has no any tool to accommodate LULC map for impact assessment.

In Standard SWAT, hydrologic processes are first simulated at the landscape (HRU) level and subsequently routed at the subbasin level where each subbasin has an associated reach. However, spatial connectivity and interactions among HRUs are ignored, instead aggregating the cumulative output of each spatially discontinuous HRU group at the subwatershed outlet, which is then directly routed to the channel. This lack of definition of landscape position makes implementation of spatially-targeted management difficult to incorporate in the model. To overcome the spatial limitations of the HRU approach, efforts were made by different authors. For instance, a grid-based version of the SWAT model (Rathjens et al., 2015), landscape simulation on a regularized grid (Rathjens and Oppelt, 2012) and (Arnold et al., 2010) and (Bosch et al., 2010) present and assess new model developments that will allow these limitations to be addressed. Arnold et al. (2010) present an enhancement to the SWAT model that allows landscapes to be subdivided into catenas comprised of upland, hillslope, and floodplain units and flow to be routed through these catenas. Although, current SWAT applications utilizing the standard HRU-based approach are limited by the absence of a spatially-explicit landscape position for HRUs, SWATgrid, developed to overcome this limitation, remains largely untested and computationally demanding. Therefore, SWAT-CN method is chosen for this study, because it is tested in many watersheds of Ethiopia by different researchers such as (Gashaw et al., 2018; Gebremicael et al., 2013; Setegn et al., 2008; Woldesenbet et al., 2017b) and 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 require sub daily precipitation as a model input that can be difficult to obtain in data scare region like UBNRB.

Your section “Input data sources” is not detailed enough and needs further expansion. And please add / include a sub-section explaining more in detail variable-types, data sources, measurement methods, and their related uncertainty etc.. One needs a table with comprehensive data explanations, (e.g. which variables, spatial and temporal coverage, station locations, temporal resolutions, and data problem/gaps. What variables and in what resolutions in time and space where finally used in the statistical assessment and in the modelling?

Reply from authors: accepted and the corrections are shown in the revised manuscript on page 5 and 6.

PLEASE, improve the quality of the language significantly. One must not expect that the reviewers or the editor does such corrections. I feel sorry for the reviewers, if I see them writing a sentence like: “The paper should be carefully revised since in the current form it is very difficult to understand”. If I would have realized this in advanced, I might initially not have accepted the manuscript for review. Thus, please do your job and present an acceptable language and style. If the revised version will not be presented in a very well acceptable language and grammar quality, I will finally reject the manuscript. But, I am sure, you can improve this.

Reply from authors: accepted and the authors tried at their best to improve the quality of the language significantly.

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Rathjens, H., Oppelt, N., 2012. SWATgrid: An interface for setting up SWAT in a grid-based discretization scheme. Computers & geosciences, 45: 161-167.

Rathjens, H., Oppelt, N., Bosch, D., Arnold, J.G., Volk, M., 2015. Development of a grid-based version of the SWAT landscape model. Hydrological processes, 29(6): 900-914.

Steenhuis, T.S., Collick, A.S., Easton, Z.M., Leggesse, E.S., Bayabil, H.K., White, E.D., Awulachew, S.B., Adgo, E., Ahmed, A.A., 2009. Predicting discharge and sediment for the Abay (Blue Nile) with a simple model. Hydrological processes, 23(26): 3728-3737.

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 have been made in the revised manuscript as suggested.

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. This issue is the concern of both anonymous refree #2 and editor as well. Hence, it is critically discussed under section 4.3 (SWAT section on page 13), section 5.4 (results on the climate impact on page 24) and conclusion section on page 26 in the marked up manuscript. Please see the responses for the editor's comment #1 above.

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 corrected as shown in the marked up manuscript on page 18, L7-L13.

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 evapotranspiration, infiltration rate of the soil property, 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 have made our efforts to improve the quality of the manuscript. The mentioned confusing sentence have been corrected as shown in the marked up manuscript on page 16, L20-L23.

"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 ".

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 have been corrected.

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 on page 33, 34 and 35 respectively in the marked up manuscript.

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 R^2, 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". This is shown on page 20, L7-L9 in the marked up manuscript.

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". This is shown on page 20, L26-L33 and on page 21, L1-L3.

On pae 1, l3, "UBNRB" It is not recommended to use abbreviations in the title.

Reply from authors: accepted and corrected.

On page 1 l15, "UBNRB" Abbreviation not introduced

Reply from authors: accepted and replaced by study area as shown in the marked up manuscript on page1, L15.

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 corrected as shown in the in the marked up manuscript on page 1, L25.

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 corrected as shown in the marked up manuscript on page 1, L26.
.

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 corrected in the marked up manuscript on page 1, L29.
.

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. We have been corrected the introduction section as suggested. It is shown in the marked up manuscript on page 2-4.

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 corrected as explained above.

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

Reply from authors: accepted and corrected as explained above.

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 political context have been deleted from the manuscript. This is shown in the marked up manuscript on page 2-4.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 2, L21.

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

Reply from authors: accepted and corrected as shown in the revised manuscript with on page 2, L21.

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 corrected as shown in the revised marked up manuscript on page 2, L23.

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 corrected as shown in the revised marked up manuscript on page 3, L17-19.

,....."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 corrected as shown in the revised manuscript on page 3, L20.
On page2, l25, delete "from" and replace by "in"

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 3, L21.
On page2, l25, add "a" significantly increasing.... add "trend"

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 3, L20.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page3, L22.

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 corrected as shown in the revised marked up manuscript on page 3, L23.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 3, L24-25.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 3, L25.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript onpage3, L28..

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 3, L35-page 4, L3.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page3, L35-page 4, L3.

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 corrected as shown in the revised marked up manuscript on page 4, L11-12.
.

On page 3, l10, delete " between longitudes 34.30^0 and 39.45^0E and latitudes 7.45^0 and 12.45^0N"

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 4, L15-16.

On page3, l11 Add "catchment"
Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 4, L16.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 4, L22

On page3, l15 add "annual"

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 4, L22.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 5, L1.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 5, L11
On page4, l6 delete "was" and replace by "were"

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 5, L25.

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 corrected as shown in the revised marked up manuscript on page 6, L4.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 6, L6.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 6, L6.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page.5- page 7.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 7, L18-20.

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 and 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 corrected as shown in the revised marked up manuscript on page 7, L21-L25.

This is corrected as "However, the existence of positive serial correlation in a time series data affects the result of MK test. If serial correlation exists in a time series data, the MK test rejects the null hypothesis of no trend detection more often than specified by the significance level ".

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 from the manuscript, as shown in the revised marked up manuscript on page 8.

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 explanations on Kappa statistic have been added as shown in the revised marked up manuscript on page 10, L28-30 and page 11, L1-L4.

The added texts are repeated here for facilitating review.

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

$$K = \frac{N \sum_{i=1}^{i=r} x_{ii} \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})}$$

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 corrected, as shown in the revised marked up manuscript on page 11, L27-28.

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 corrected. See our response to your comments #2 methodology section above. We have added the necessary critical reflection and added discussions when necessary. Please see page 24, L12-L19 in the revised marked up manuscript. It is well known that SWAT-CN model relies with a statistical relationship between soil moisture condition and CN value obtained from plot data in the United States with a temperate climate that was never tested in monsoonal climate where two extreme soil moisture conditions exhibited. In monsoonal climates, long period of rain can lead to prolonged soil saturation while during the dry period the soil dries out completely which may not happen in temperate climates (Steenhuis et al., 2009). Therefore, standard SWAT-CN method has limitation when applied in monsoonal climates.

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 corrected, as shown in the revised marked up manuscript on page 14, L2.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 14, L11

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 14, L15.

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 corrected, as shown in the revised marked up manuscript on page 14, L17.

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

Reply from authors: accepted and corrected as shown in the revised marked up manuscript on page 14, L24-25.

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 corrected as shown in the revised marked up manuscript on page 15, L2.

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

Reply from authors: accepted and corrected as shown in the revised manuscript on page 15, L9-L12.

We have changed the mentioned sentences as follows

“To analyze the response of streamflow and water balance components to the combined effects of LULC and climate change at decadal time periods, the SWAT model was separately calibrated and validated for each decades using the corresponding LULC map and weather data Table 2. The DEM and soil data sets remained unchanged. ".

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 corrected, as shown in the revised marked up manuscript on page 14, L30

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 have been rephrased in the revised manuscript as shown on page 16 and 17. Figure 1 is modified. The new information of this study as compared to the previous studies are presented below.

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 have been added in the revised marked up 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:

$\beta = \text{Median}\left[\frac{x_j - x_k}{j-k}\right]$ 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 following the comment.

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 rainfall 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 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".

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 confusion "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 shown in the marked up manuscript on page 34..

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 have been corrected as shown in the revised marked up manuscript on page 22, L10-L13 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. It is shown in the revised marked up manuscript on page 22, L20-L30

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Anonymous Referee #2

The submitted study presents results on the effect of LULC and climate change on the streamflow in the Upper Blue Nile River Basin using a statistical and a modelling approach. The topic of the study is in general relevant and the approach provides also new insights relevant to readers of HESS. However, there are many shortcomings in the paper of methodological and structural nature but also in regard of format, language and style.

Main shortcomings:
1. An overall discussion of the results is completely missing. Very interesting findings like the recovery of landcover during a certain period and its reflection in time series are not discussed at all. Some discussions are added to the results section but not in a coherent or comprehensive way.

Reply from authors: accepted. We have added more necessary discussion as suggested,. The added discussion points are shown in the marked up manuscript on page 19, L21-L30.

2. There are several methodological shortcomings, some of them explained like the use of ground truth data. Others like how gaps in data records have been filled or the problems of the curve number approach for a LULC study are not discussed. Therefore an additional chapter within a new discussion section on all the uncertainties and how they impact the interpretation of the data is crucial for the paper.

Reply from authors: accepted and corrections were made accordingly. We have added more necessary discussion on the suggested aspects in the revised manuscript, see page 5 L26-L30 and page 6, L1-L19 in the revised marked up manuscript.

To facilitate review, the added texts are repeated here

As it is mentioned in the manuscript on page 5, L26-30 and page 6 L1-19, we used spatial interpolation of 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 neighboring 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 neighboring stations were selected, the two methods (IDWM and LR) were tested to fill in missing hydro-meteorological 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 (R^2) 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.

We have added a discussion point regarding to the problems of CN approach as shown in the marked up manuscript on page 13, L23-31 and on page 25,L29-34. Please see the authors response for the editor's comment #1 above.

3. The language and the style of the paper is in general poor. The paper should be carefully revised since in the current form it is very difficult to understand.

Reply from authors: accepted and we tried to improve the language of the manuscript carefully.

4. Figure 4: It seems that there a processing relics in the reclassified imagery. In figure a) on the western side of the map is a rectangular section with forest, that completely disappears in b). In b) there is a rectangular forest cover in the northern part of the country which again disappears completely in c). In d) a forest cover with completely linear edges (N-S) appears on the eastern side of the map. How can these be explained and if these are problems with the classification method, does it not add a lot of uncertainty to the results?

Reply from authors: accepted and we explained and discussed the possible causes of these errors in the revised manuscript on page20, L11-20.

Although, the image classification has very good accuracy, uncertainties could be expected for the following reasons. Firstly, as elsewhere in Ethiopia, LULCs change rapidly over space, and image reflectance may be confusing due to the topography and variation in the image acquisition date. Landsat images were not all available for one particular year or one season; thus images came from a mix of years, and from a variety of seasons might have errors. Secondly, the workflow associated with LULC classification, which involve many steps and can be a source of uncertainty. The errors are observed in the classified LULC map as shown in Figure 4. Overall the land cover mapping is reasonably accurate, providing a good base for land cover estimation and can be used for hydrological impact analysis as the uncertainty to the results are minimal for such large scale study area.

Minor comments:
Abstract P1/L19f: from 12.2% to 15.6% is no decrease And from 67.5% to 63.9% is no increase. Introduction: There are many statements without any source, e.g.: catchment are etc, 200 million people rely directly on the Nile river, 94% unbalanced water , Ethiopia only using 5% of water,...

Reply from authors: accepted and corrected.

We made a comparison from the base line 1973 LULC map, which has a forest coverage of 17.4 % and cultivated land coverage of 62.9%. Hence, forest decreased to 14.4 % in 1985, 12.2% in 1995 and 15.6% in 2010. The same is true for cultivated land. A major revision was made for introduction part as shown on page 2-page4 in the marked up manuscript.

P1/L29: What do you mean with largest river? P2/L4: is this sentence stated here as fact not the research topic? P2/L11: here and often after acronyms are not explained in the right order P2/L16: These are not few studies and many are missing. Please add all current literature.

Reply from authors: accepted and corrected. Major revision was made for introduction section.

P2/21: Belg is mentioned here for the first time but only explained in later in the manuscript.

Reply from authors: accepted and corrected on page 3 L19 as shown in the marked up manuscript with changes highlighted

2. Study area: P3/14: Rainfall distribution should be mentioned P3/L15: mean, max and min mentioned but only 2 numbers provided.

Reply from authors: accepted and corrected as shown in the revised manuscript with changes highlighted on page 4, L22-L25.

There is considerable spatial variability of rainfall over the UBNRB. A central and south-eastern area is characterized by relatively high rainfall (1400-2200 mm) and less than 1200 mm rainfall occurred in most of the eastern and north-west parts of the basin (BCEOM, 1998). Mekonnen and Disse (2018) showed that the UBNRB has a mean areal annual rainfall of 1452 mm, and a mean annual minimum and maximum temperature of 11.4 ^{o}C and 24.7 ^{o}C respectively". The two numbers explains the mean annual maximum and mean annual minimum temperature not the mean, max and min separately. The word "annual" was missed.

3. Input data sources: P4/L20ff: It is crucial to understand which gaps have been filled how. Please provide table summarizing gaps. How did you evaluate the best performance. This is a very critical point of the study and needs to be discussed.
Reply from authors: accepted and corrected. We have added more necessary details and discussion as suggested. Please see page 6, L1-L19 in the marked up manuscript. Please see our response to your major comment #2 above. We provided the table summarizing gaps (Table S01).

4.1. Trend analysis Often R or Python Packages have been used to do this basic trend analysis. Please provide the source if this has been used for this study as well since this helps the reader to understand the method. P5/L16: It is not necessary to describe the Mann Kendall test in detail since this is a standard method.

Reply from authors: accepted and corrected. We used the XLSTAT add-ins tool from excel (www.xlstat.com). The unnecessary details on MK test have been deleted as it is shown in the marked up manuscript on page 8 and page 9 as suggested.

4.2.1 Landsat image acquisition Please provide a table at least in the suppl. Mat. Which images have been used for which period. This is a potential source of large uncertainties. Please show the borders of the images in figure 4.

Reply from authors: accepted and supplemental table S02 is provided which gives an overview for all Landsat images used. Sources of uncertainties for landsat image classification have been discussed as shown in the marked up manuscript on page 19, L5-L14.

4.2.2 Pre-processing and processing images P7/L12: How can you assume that there were no significant landcover changes between 2017 and 2010. It is wrong and has strong implications on the result and is therefore methodological not acceptable.

Reply from authors: accepted and corrected. Our apologies for confusion. Our intention was to articulate that no significant landcover change on the points where we took GPS readings for training and validation. The description has been corrected as "The ground control points were collected in 2017 in order to classify the 2010 landsat image and those points were taken in areas where there was no landcover change between 2017 and 2010. This was done by detailed consultation of elderly people who have better knowledge and lived in nearby areas for long period of time and also supported by high resolution Google Earth maps and with the prior local knowledge of the first author". The modifications are shown on page 10, L14-L18 in the revised manuscript.

5.1.1 Rainfall: All this has been done, so please shorten.

Reply from authors: accepted and corrected. We explained the possible causes for the disagreements of the previous studies with our study, as shown in the marked up manuscript on page 17, L7-L19.Please see authors response for the anonymous referee#1 comment on page 10, L27-L39 above.

5.1.2 Streamflow: This changes can also be explained by a change in temporal rainfall distribution, e.g. increase of extremes. Therefore the conclusion that the change can be solely attributed to LULC change is not compulsory and therefore not correct.

Reply from authors: accepted and corrected. The mismatch of trend magnitude between rainfall and streamflow could be attributed to the combined effect of LULC and climate change, associated with evapotranspiration, infiltration rate of the soil property, rainfall intensity and extreme events. Please see on page 18, L7-L13 in the revised manuscript.

5.2. LULC change analysis: You are suing a 2010 image with 2017 data. This is wrong and cannot be done.

Reply from authors: accepted and we corrected. Please see the reply for comment #4.2.2.

P13/L18-25: This is a short discussion and should be extended and part of a discussion section. E.g. it should be checked if these results are also reflected in the streamflow.

Reply from authors: accepted and discussed in detail on the results of combined and single impacts of LULC on streamflow and water balance components as shown on the marked up manuscript on page 21 and 22.

6. Conclusions: P16/L4-16: The first section only repeats old research findings.

Reply from authors: accepted and corrected as shown in the marked up manuscript on page 24, L28-L32.

P16/L28-P17/L7: It is not true that the climate did not change. Even if it would hold true that precipitation did not change, this is certainly false for temperatures. In the Ethiopian climate, evaporation is one of the main drivers of streamflow and this is not reflected at all. This statement alone makes the results and the interpretation questionable and vulnerable.

Reply from the authors: correction accepted. We have added more necessary details and explanations in the revised manuscript as shown in the marked up manuscript on page 25 and page 26.

Table 8: Here you can see an extreme change in PET which is not discussed. Same holds for the extreme trend of Qb/Qt from 20.6 to 3.2 and back to 20.

Reply from authors: accepted and we have added more discussion points on this regard on page 21, L5-L31. Please see our responses above.

The added texts are repeated here to facilitate review
This indicate that 1.8 % forest cover loss and 1 % increased cultivated land combined with 2.2 % increased rainfall from the 1970s to the 2000s led to a 16.9 % increase in simulated streamflow. 1990s was the period when the highest deforestation and expansion of cultivated land reported; meanwhile it is the time when the rainfall intensity and number of rainfall events has significantly increased compared to the 1970s and 1980s, as shown in Table 4. Hence, the increased mean annual streamflow could be ascribed to the combined effects of LULC and climate change. In the case of (Qs/Qt), the increasing pattern could be ascribed to the increasing of rainfall intensities and expansion of cultivated land and decreasing of forest coverage, which might adversely affect soil water storage, and decrease rainfall infiltration, thereby increase water yield or streamflow. In contrary, the decreasing of (Qb/Qt) has positive relation with the increasing of evapotranspiration linked to both LULC and climate factors (Table 8). This hypothesis can be explained with the change in CN2 parameter values obtained during the calibration of the four SWAT model runs.

The CN2 parameter value which is a function of evapotranspiration derived from LULC, soil type, and slope, increased in the 1980s and 1990s from 1970s could be associated with the expansion of cultivated land and shrinkage of forest land. The increasing of CN2 results to generate more surface runoff and less baseflow. Hence, it is important to note that LULC change affects CN2 parameter, as a result alters the simulation of water balance component using SWAT model especially evapotranspiration, surface run-off and base flow. Another important contributing factor for the decreasing of surface run-off and increasing of base flow ration in the 2000s from 1990s could be the placement of soil and water conservation (SWC) measures. According to Haregeweyn et al. (2015), various nationwide SWC initiatives have been undertaken since the 1980s such as Food-for-Work (FFW) (1973–2002), Managing Environmental Resources to Enable Transition to more sustainable livelihoods (MERET, 2003–2015), Productive Safety Net Programs (PSNP, 2005–present), Community Mobilization through free-labor days (1998–present), and the National Sustainable Land Management Project (SLMP, 2008–2018). The effectiveness of the initiatives were evaluated by (Haregeweyn et al., 2015) and come up with the conclusion that community labour mobilization seems to be the best approach. It can reduce a mean seasonal surface run-off by 40 %, with large spatial variability, ranging from 4 % in Andit Tid (northwest Ethiopia) to 62 % in Gununo (south Ethiopia).

Figure 1: Some points are hidden behind triangles and the colour cannot be identified. What is the "value" I assume metres above sea level, but please indicate. Gabay and Gumatra cannot be distinguished.

Reply from authors: accepted and corrected. Please see the modified Figure 1.

Figure 2: Years with commas.

Reply from authors: accepted and corrected. Please see the modified Figure 2.

Figure 4: See main shortcomings.

Reply from authors: accepted. We tried to explain the short comings. Please see our responses to your major comment #4 above.

Figure 6: Make scale uniform since otherwise they cannot be compared.

Reply from authors: accepted and corrected. Please see the corrected figure 6.

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Short comments by **Dr Elagib**
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Page 1 lines 18 to 19. “The LULC change detection findings indicate the conversion of forest land to cultivated land during the period 1973-2010”. Comment Analysis of systematic transitions in Jedeb (Teferi et al. 2013), and Tana & Beles (Woldesenbet et al. 2017a) indicated that cultivation land is gained mainly from open grazing land though natural forest coverages is decreased over times.

Reply from authors: In this study, systematic transition analysis of LULC was not carried out as it is not our primary objective. However, the study result revealed that cultivated land increased and forest coverage decreased from 1973 to 2010 while the other LULC classes remained unchanged or the change is not significant.

Page 1 line 19. “Natural forest decreased from 17.4% to 14.4%, 12.2% and 15.6%” Comment What does ‘Natural forest’ here means, only natural or does it include plantations? There is a significant area that has undergone eucalyptus plantation, especially at upstream sub-catchments.

Reply from authors: correction accepted and correction made on the revised manuscript.
Plantation can be on a large scale for afforestation or on small plots as household woodlots for fuel wood, construction material, for charcoal production as a means of income generation. However, community plantations are rarely of sufficient size to distinguish on the image and allow representation of forest. Other large scale plantations were mapped as forests from which they are distinguishable on the images. Hence, Natural forest includes both natural and eucalyptus plantation.

Page 1 lines 23 to 25. “The single effect of LULC change on streamflow analysis suggested that LULC change significantly affects surface run-off and base flow. This could be attributed to the 5.1 % reduction in forest coverage and 4.6% increase in cultivated land.” Comment Woldesenbet et al. (2017a) indicated that cultivation land and woody shrubs at Tana and Beles watersheds are the main LULC classes which are significantly affecting surface runoff and groundwater components.

Reply from authors: In this study, the classification was carried out on the basis of the main landcovers (cultivated land, forest land, bushes and shrubs and water). As shown in the LULC change detection analysis, the area coverage of bushes and shrubs remained unchanged or the change is insignificant. Hence, in this study, the change for surface runoff and base flow could be due to the change in forest coverage and cultivated land coverage.

Page 2 lines 3 to 4. “The direct and indirect impacts brought by both LULC and climate change 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.” Comment As your trend analysis for streamflow indicated significantly increasing trend during observed period, how come water is scarce due to LULC and climate change?

Reply from authors: In this study, we carried out both streamflow and rainfall trend analysis only for Upper Blue Nile River Basin (UBNRB), which is less than 5.2 % of the area coverage of the Nile basin. According to (Philip J. et al., 2016), in the year of 2012, 257 million people live**d** within the Nile Basin boundary and the population of Nile Basin countries grew by over four fold in 50 years between 1960 and 2010. As a result, the demand for food, energy and water has been escalating. Per capita water availability has been declining. For instance, on average 82 Billion Cubic Meter (BCM) of water is withdrawn from Nile waters every year for irrigation. The Growing agricultural production will further increase pressure on land and water resources. It is well known that the temporal and spatial distribution of the rainfall of the Nile basin is highly variable as a result the hydrology of the basin is exhibiting highly seasonal flows. So, storage facilities are needed to have stable flow for the growing demands of water but significant water will be lost due to evaporation. At present, on the average an estimated 17.6 BCM of water evaporates from major dams in the Nile Basin(Philip J. et al., 2016).

Under a high Representative Concentration Pathway (RCP), temperature is expected to rise between 3^{o}c to 6 ^{o}C at the end of 21st century across much of Africa while projected rainfall change over sub-Saharan Africa in the mid- and late 21st century is uncertain (IPCC, 2014). As a result of temperature rising more water will be lost due to evaporation and irrigation water requirement will increase . Therefore, the increasing trend of streamflow of the UBNR cannot be a guarantee for water availability of the Nile basin, while water demand continues to rise steadily due to population growth and economic development and due to climate change.

Page 2 31 to 34. “Although, substantial progress has been made in assessing the impacts of LULC and climate change on the hydrology of UBNRB, most studies focused on single aspects i.e., either analysing the statistical trend of precipitation and streamflow or analysing impacts of single factor LULC or climate change on the flow (Gebremicael et al., 2013; Rientjes et al., 2011; Tekleab et al., 2014). Impacts by combined effects of LULC and climate changes are not well understood because their contributions are difficult to separate and vary regionally (Yin et al., 2017).” Comment A very recent study by Woldesenbet et al. (2017a) has assessed the impacts of individual LULC classes on water balance components for Tana and Beles sub-basins. This study is totally overlooked in the present discussion manuscript. Not only combined effect of historical LULC and climate changes, but also combined impacts of future LULC and climate change are not well reported in the upper Blue Nile Basin.

Reply from authors: correction accepted. We found that the mentioned manuscript reinforces the discussion and improve the quality of the paper. We have cited this paper in our revised manuscript.

Page 4 lines 12 to 18. “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-mapsanddatabases/faounesco-soil-map-ofthe-world/en/) was used for SWAT model. The soil information such as soil textural and physiochemical properties needed for the SWAT model was extracted from Harmonized World Soil Database vl.2, a database that combines existing regional and national soil information (http://www.fao.org/soilsportal/soil-survey/soilmaps-and-databases/harmonized-world-soil-databasevl2/en/) in combination with..” Comment Worqlul et al. (2018) indicated that accurate spatial information of soil data is significant in hydrological modeling of LULC change. Federal Ministry of Water Irrigation and Electricity of Ethiopia has better soil map. Besides, the soil physical parameters could also be incorporated from many recent irrigation and hydropower design reports in the basin.

Reply from authors: We understand that the Ministry of Water Irrigation and Electricity of Ethiopia has prepared better soil map. However, it missed soil physical parameters which are crucial for SWAT. If our study was focused on Tana and Beles sub-basins, it would not be a problem to collect soil physical parameters from recently studied irrigation and hydropower design reports, as many of these projects are located in these sub-basins. In our case, it is hardly possible to collect such information from design reports and from measurements due to the large area coverage of the study area and lack of sufficient design reports across the basin. Previous study done by Polanco et al. (2017) used the same sources of soil information for the same study area and achieved good results, which suggests the usefulness of FAO soil map and the Harmonized World Soil Database.

Page 4 lines 23 to 24. “Filling missed or gap records was the first task for any further meteorological data analysis. This task was performed using the inverse distance weighing (IDW) and regression methods, the best performed method was chosen ..” Comment Poor station network and missing records of significant length are one of the problems of meteorological data in the study region. For this region, Woldesenbet et al. (2017b) suggested that the coefficient of correlation method is better than the inverse distance weighting method for filling in gaps in daily rainfall and temperatures. They also indicated that the rainfall and temperature data are not satisfying the preconditions for using multiple linear regressions.

Reply from authors: In this study, spatial interpolation such as the inverse distance weighting method (IDWM) and linear regression techniques (LR) were used for filling gaps as it is mentioned in the manuscript on page 4, L22-24. Similar methods were also applied in many other studies such as by Uhlenbrook et al. (2010) for the Gilgel Ababy sub-basin of the study area. 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. A geographic distance of 100 km were considered to select neighboring stations due to the poor station network. 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 neighboring stations were selected, the two methods (IDWM and LR) were tested to fill in missing hydro-meteorological 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 (R^2) and % bias. 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 % bias, 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.

Page 8 lines 23 to 29. “Finally, after classifying the raw images of Landsat into different landcover classes, change detection which requires the comparison of independently produced classified images (Sing, 1989) was performed by the post-classification method. The post-classification change detection comparison was conducted to determine changes in LULC between two independently classified maps from images of two different dates.” Comment Systematic transition from one LULC classes, net gain, losses and swap (Teferi et al. 2013) might help to understand the changes from one LULC classes to another rather than comparing percentage changes in individual LULC classes (which does not indicate spatial changes).

Reply from authors: As it is clearly indicated on page 4, L9-13 of the manuscript, the main objective of the study is not to detect the systematic transition of LULC change but rather to detect the combined and single effect of LULC and climate change on streamflow. Hence, we did not carry out a systematic transition of LULC classes as it has no significant impact on our objective. Thank you for your understanding. Your comments are indeed good points. We will add them in our revised manuscript

Page 13 lines 14 to 16. “The highest gain in bushes and shrubs was (0.3%) from 1973 to 1985, while the highest gain in forest coverage (3.4%) was recorded during the period 1995-2010. Water coverage remained unchanged from 1973 to 2010.” Comment This might be due to eucalyptus plantation at homestead for fuel consumption or construction poles.

Reply from authors: correction accepted. Yes, it is clearly mentioned in the manuscript on page 19 L4-L9 "The increased forest coverage and the reduction in cultivated land over the period 1995 to 2010 shows that the environment was recovering from the devastating drought and the reduction of forest clearing for firewood and for cultivation due to population growth. This could be due to the afforestation programme initiated by the Ethiopian government. As a result, eucalyptus plantation at homestead level significantly increased for fuel consumption or as income generating goods (for construction material, producing charcoal) ".

Page 13 lines 18 to 19 “The increased forest coverage and the reduction in cultivated land over the period 1995 to 2010 shows that the environment was recovering from the devastating drought and forest clearing for firewood and cultivation due to population growth.” Comment Besides, farmers start converting cultivation land to eucalyptus plantation (See Teferi et al. 2013; Woldesenbet et al. 2017a).

Reply from authors: accepted and correction made as shown in the revised manuscript on page 19, L22-23.

Page 13 lines 21 to 25. “To summarize, during the period from 1973 to 2010, forest coverage declined by 1.8%, with both bushes and shrubs, as well as cultivated land increasing by 0.8% and 1% respectively from the original 1973 level. This result agrees well with other local level studies (Gebrernicael et al., 2013; Rientjes et al., 2011; Teferi et al., 2013), which reported the dramatic changes in the natural vegetation cover resulting from the agricultural land.” Comment Another recent study (Woldesenbet et al. 2017a) is overlooked.

Reply from authors: accepted and corrected. We have cited as shown in the revised manuscript on page 19, L26.

Page 16 lines 28 to 30. “The combined results from three different approaches, namely statistical trend test, semi-distributed SWAT modelling and LULC change analysis, are consistent with the hypothesis that LULC change has modified the run-off generation process, which has caused the increase in streamflow of the UBNRB while the climate has remained unchanged.” Comment In fact, the climate of Lake Tana and Beles watersheds have become wetter and warmer for the period 2010-2013 (Woldesenbet et al. 2017b).

Reply from authors: accepted and corrections made in the revised manuscript shown on the marked up manuscript on page 25, L19-L26. Studies carried out in the UBNRB such as Mengistu et al. (2014) confirmed that at the annual scale, maximum and minimum temperatures significantly increased in over 33% of the Basin (in northern, central, southern and southeastern parts) at a rate of 0.1 and 0.15 °C per decade, respectively.

Page 17 lines 2 to 5. The limitation of this study could be due to the uncertainty of the SWAT model, as the SWAT model does not adjust CN2 for slopes greater than 5%, which could be significant in areas where the majority of the area has a slope greater than 5%, such as UBNRB. Therefore, we suggest adjusting the CN2 values for slope > 5% outside of the SWAT model for further research. Comment The steeper the slope, the higher the CN2. On one hand, adjusting the CN2 values for slope greater than 5 % might increase the values of CN2. On the other hand, intensive terracing on the basin might counterbalance the increase in CN2 due to steeper slopes.

Reply from authors: The hypothesis could be true but regretfully we cannot prove the hypothesis as it is beyond the scope of this study. This is a good and very interesting issue to investigate in another future study. Thank you very much.

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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

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Abstract: Understanding the response of land use/land cover (LULC) and climate change has become a priority issue for water ~~-~~management and water resource utilization of the Nile basin. This study assesses the long-term trends of rainfall and streamflow to analyse the response of LULC and climate changes on the hydrology of the ~~UBNRB~~study area. The MK-test showed statistically insignificant increasing trends for annual, monthly and long rainy season rainfall series while no trend for daily, short rainy and dry season rainfall series. However, the Pettitt test could not detect any jump point in basin wide rainfall series except for daily rainfall time series. ~~The Mann-Kendal (MK) trend tests showed no statistically significant changes in daily, monthly and annual rainfall.~~ In contrast, the result of MK-test for daily, monthly, annual and seasonal (long and short rainy season and dry season) time series streamflow showed a positive trend and the trend magnitude is statistically significant. ~~Tests for mean annual and seasonal streamflow showed a statistically significant and increasing trend.~~ Landsat satellite images for 1973, 1985, 1995 and 2010 were used for LULC change detection analysis. The LULC change detection findings indicate that~~e~~ expansion of cultivated land and the reduction of forest coverage were significant before the period 1995. After 1995, the forest coverage began to increase while the cultivated land getting ~~conversion of forest land to cultivated land during the period 1973-2010~~reduced. ~~Natural~~ Statistically, forest coverage ~~decreased~~ changed from 17.4 % to 14.4 %, 12.2 % and 15.6 % while cultivated land ~~increased~~ changed from 62.9 % to 65.6 %, 67.5 % and 63.9 % from 1973 to 1985, 1995 and 2010 respectively.

The hydrological ~~(SWAT)~~ model result showed that mean annual streamflow increased by ~~15.6~~16.9 % between the 1970s and the 2000s due to the combined effect of LULC and climate change. The single effect of LULC change on streamflow analysis suggested that LULC change ~~significantly~~ affects surface run-off and base flow. This could be attributed to the 5.1 % reduction in forest coverage and 4.6 % increase in cultivated land. Effects of climate change revealed that the increased rainfall intensity and number of extreme rainfall events from 1971 to 2010 have ~~greatly~~ significantly affected the surface

run-off and base flow~~ of UBNRB~~. The single impacts of climate change is significant as compared to the impacts of LULC change for the hydrology of UBNRB.

1. Introduction

~~The Nile basin, having the world's largest river (6700 km and catchment area of 3.3 million km2, is characterized by the limited water resource where climatic and hydrological extremes such as floods and droughts hit the basin population severely and regularly associated with scarce hydro-climatic data (Gebrekristos, 2015).~~

~~Over 200 million people are estimated to rely directly on the Nile river for their food and water supplywith projected increases on water demands and water uses. The direct and indirect impacts brought by both LULC and climate change 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. To date, Ethiopia has utilized insignificant amount less than 5~~2~~% of the Blue Nile water, as compared to downstream countries Sudan and Egypt.~~

~~The Nile River plays an important role~~ The Abay (Upper Blue Nile) River in Ethiopia contributes more than 60 % of the water resources of the Nile river (McCartney et al., 2012). ~~.Meanwhile~~Hence, the Ethiopian government has ~~planned and~~ carried out a series of studies to tap this huge potential water resource aiming to significantly increase large reservoir for water storage in the Upper Blue Nile River ~~b~~Basin (UBNRB) both for irrigation and hydropower development, in order to support national development and to reduce ~~and get rid of~~ poverty (BCEOM, 1998). As a result, large scale irrigation and hydropower projects has been planned and realized along the main stem of Blue Nile river such as Grand Ethiopian Renaissance Dam (GERD), the largest dam in Africa when it is completed. ~~as (UBNR) is a transboundary river~~However, its hydrology is influenced by high variations in climate and altitude/topography, land use/cover (LULC) change exhibiting highly seasonal flows. Therefore, ~~its development and management should be agreed and reached consensus between shared countries~~ effective planning, management and regulation of water resource developments is required to prevent conflict between competing water users particularly downstream countries such as Sudan and Egypt. Conflict can be reduced and benefits maximized if careful management of water resource is established. ~~Tackling all these complexities, and developing the better water resource development strategies~~

This can be achieved only ~~possible~~ by understanding the hydrological processes -and sources impacting water quantity such as ~~of the basin.~~ LULC and climate -change 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.*, 2017a). 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.

A literature review shows that there are few sub-basin and basin level studies carried out in the UBNRB, with most studies focusing on trend analysis of precipitation and streamflow~~.~~ Considering precipitation, most studies e.g.,(Bewket and Sterk, 2005; Cheung et al., 2008; Conway, 2000; Gebremicael et al., 2013; Melesse et al., 2009; Rientjes et al., 2011; Seleshi and Zanke, 2004; Teferi et al., 2013; Tekleab et al., 2014; Tesemma et al., 2010) reported no significant trend in annual and seasonal precipitation totals within the Lake Tana sub-basin. ~~where there are relatively better hydro-meteorological data~~, ~~while~~ While Mengistu et al. (2014) reported statistically non-significant increasing trends at annual and seasonal rainfall series except ~~Belg(season (~~a short rainy season (Belg) from February to May~~)~~.

For the streamflow ~~from the~~of the UBNRB, (Gebremicael et al., 2013) reported statistically significant increasing long-term mean annual streamflow at the El Diem gauging station. However, (Tesemma et al., 2010) reported no statistically significant ~~long-term~~ trend ~~in~~ for the long-term annual streamflow ~~from the UBNRB~~ at ElDiem gauging station, but a significantly increasing trend at Bahirdar and Kessie stations. At the sub-basin scale, Rientjes et al. (2011) reported a decreasing trend ~~that~~ for the low streamflows ~~in the~~of Gilgel Abay sub-basin (Lake Tana catchment, the Blue Nile head waters) ~~decreased~~ during the period (1973–~~2001~~2005), specifically by 18.1 % and 66.6 % ~~decrease for~~in the periods 1982–2000 and 2001–2005, respectively. However, for the same periods, the high streamflows show an increase ~~in~~ by 7.6 % and 46.6 % due to LULC change and seasonal variability of rainfall.

Although, substantial progress has been made in assessing the impacts of LULC and climate change on the hydrology of the UBNRB, only few studies have attempted to assess the attribution of changes in the water balance to LULC and climate change. Woldesenbet et al. (2017b), used an integrated approach comprising SWAT hydrological modeling and partial least squares regression (PLSR) to quantify the contributions of changes in individual LULC classes to changes in hydrological components in two watersheds namely: Lake Tana ~~n~~and Beles sub basins. (Woldesenbet et al., 2017b) reported that expansion of cultivation land and decline in woody shrub/woodland appear to be major environmental stressors affecting local water resources such as increasing surface run-off and decreasing of ground water in both watersheds but the impacts of climate change is missing. most studies focused on single aspects i.e., either analysing the statistical trend of precipitation and streamflow or analysing impacts of single factor LULC or climate change on the flow (Gebremicael et al., 2013; Rientjes et al., 2011; Tekleab et al., 2014; Woldesenbet et al., 2017b). Impacts by combined effects of LULC and climate changes are not well understood because their contributions are difficult to separate and vary regionally (Yin *et al.*, 2017a). However, proper water resource management requires an in-depth understanding on the aggregated and disaggregated effects of LULC and climate changes on streamflow and water balance components as the interaction between LULC, the climate characteristics and the underlying hydrological processes are complex and -dyanmic (Yin *et al.*, 2017a). as they are the most significant drivers of environmental change in the Nile basin.

Therefore, the objectives of this study are as follows (i) assess the long-term trend of rainfall and streamflow (ii) analyse the LULC change (iii) examining the streamflow responses to combined and isolated effects of LULC and climate changes in the UBNRB. through This can be done using a combined analysis of statistical trend test, satellite remote sensing LULC mapchange detection of LULC derived from satellite remote sensing and SWAT hydrological modelling during the period 1971-2010.

2. Study area

The UBNRB is located in the northwest of Ethiopia, between longitudes 34.300 and 39.450E and latitudes 7.450 and 12.450N, with an approximate catchment area of 172,760 km^2. Topography of the basin is typically characterized by highlands, hills, valleys and occasional rock peaks with elevations that range from 500 m.a.s.l to above 4000 m.a.s.l (Figure 1). According to BCEOM (1998), the larger portion of the basin (2/3) lies in the highlands of Ethiopia with annual rainfall ranging from 800 mm to 2,200 mm. A central and south-eastern area is characterised by relatively high rainfall (1400-2200 mm) and less than 1200 mm rainfall occurred in most of the eastern and north-west parts of the basin. Mekonnen and Disse (2016) Mekonnen *et al.* (2018) showed that the UNBNRB has a mean areal annual rainfall of 1452 mm, and a mean annual minimum and maximum temperature of 11.4 ^{o}C and 24.7 ^{o}C respectively.

The climate of the study area is characterized by tropical climate and dominated by its high altitude. The climate is also governed by the movement of the Inter-Tropical Convergent Zone (ITCZ) (Conway, 2000; Mohamed et al., 2005). According to the classification of NMA (2013) classified the climate, there are into three seasons in Ethiopia. The main rainy season (Kiremt) lasts generally from June to September during which south-west winds bring rains from the Atlantic Ocean. About 70-90 % of total rainfall occurs during this season. A dry season (Bega) lasts from October to January and the short rainy season (Belg) lasts from February to May. namely, Belg (short rainy season), Kiremt (main rainy season) and Bega (dry season). Belg is a short rainy period from February to May, Kiremt is the period from June to September and Bega is the period from October to January. According to BCEOM (1998), the average annual discharge is estimated about 49.4 Billion Cubic Meter (BCM), with the low flow month (April) equivalent to less than 2.5 % of that of the high flow month (August), at the Ethio-Sudan border (El Diem). The analysis of this study revealed that the long-term (1971-2010) mean annual volume of flow at El Diem is 50.7 BCM, with the low flow (dry season) contributing 21.1 % and the short rainy season accounting for about 6.2 %, while most flow occurred during the rainy season, contributing about 73 % (Table 1Table 1Table 1Table 1Table 1Table 1Table 1Table 1). The land cover of the basin essentially follows the divide between highland and lowland. The highlands are predominantly covered by farmlands (about 90 %), bush and shrubs. The lowlands, in contrast, are still largely untouched by development, so that as a result, woodlands, bush and shrub lands are the dominant forms of land cover (BCEOM, 1998).

3. Input data sources

In this study, non-parametric Mann-Kendal (MK) (Kendall, 1975; Mann, 1945) statistics and Soil and Water Assessment Tool (SWAT) developed by the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) (Arnold et al., 1998) are used for statistical trend analysis and water balance modelling respectively. Details about the methods are described under section 4. The input datasets used for SWAT model can be categorised into weather and streamflow data and spatially distributed datasets.

3.1 Weather and streamflow data

The daily weather variables used in this study for trend analysis and for driving water balance model are precipitation, minimum temperature (Tmin), and maximum air temperature (Tmax), relative humidity (RH), hours of sunshine (SH) and wind speed (WS). These weather data were obtained from the Ethiopian National Meteorological Agency (ENMA) for the period 1971-2010., long time series (1971-2011) hydro-meteorological data were used for trend analysis. The daily streamflow data for over 25 gauging stations was collected from the Federal Ministry of Water Irrigation and Electricity of Ethiopia for the period 1971-2010.

The streamflow data set was collected from the Federal Ministry of Water Irrigation and Electricity of Ethiopia. Daily precipitation, minimum and maximum air temperature, relative humidity, hours of sunshine and wind speed data at 15 stations from 1971-2010 were obtained from the Ethiopian National Meteorological Agency (ENMA). The monthly, seasonal and annual hydro-meteorological data was aggregated from the daily time series data. After intensive and rigorous analyses of weather data, considerable time series data were missed in most stations (see Table s01) due to civil war, defected and outdated devices. As a result, the available data constrained us to focus only for 15 stations (Figure 1) in which rainfall data are relatively more complete. All 15 stations were used for trend analysis while the 10 stations which have complete climate variables such as Tmax, Tmin, RH, WS and SH were used as input for SWAT model Figure 1.

We have used spatial interpolation such as the inverse distance weighting method (IDWM) and linear regression techniques (LR) to fill the gaps. Similar approaches or methods were applied by Uhlenbrook et al. (2010) for the Gilgel Abbaby sub-basin, which is the head water of UBNRB. The selection and number of adjacent stations are critically important for 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 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 percent bias (% bias) 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 % bias 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 monthly, seasonal and annual weather data were aggregated from the daily time series data after filling the gaps. While filling the missing data uncertainty is expected due to the low station density, poor coorelations and considerable missing records. Similar techniques and approaches were used for the analysis and filling the missed records of streamflow data.

3.2 Spatial Data:

Required spatially distributed data for SWAT model includes tabular and spatial soil data, tabular and spatial land use /cover information, and elevation data.

~~The spatially distributed (GIS input) data for the Soil and Water Assessment Tool (SWAT) hydrological model, (Arnold et al., 1998) includes a Digital Elevation Model (DEM), soil data 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. Subbasin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

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 physiochemical 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 evapo-transpiration in a basin were produced from satellite remote sensing Landsat images for 1973, 1985, 1995 and 2010 at a scale of 30x30 m resolution. Detail image processing and classification approaches is described under section 4.2.

~~After the raw rainfall and discharge data had been collected, the data was screened and corrected. In many stations, pronounced length of time series data was missed and hence stations with long time series and relatively little time missing records were selected. Filling missed or gap records was the first task for any further meteorological data analysis. This task was performed using the inverse distance weighing (IDW) and regression methods, the best performed method was chosen. .~~

4. Methodology

4.1 Trend Analysis

The non-parametric Mann-Kendal (MK) (Kendall, 1975; Mann, 1945) statistics is chosen to detect trends for ~~hydrologic~~ precipitation and streamflow time series data as it is widely used for effective water resource planning, design and management (Yue *et al.*, 2004). ~~MK tests do not require any assumptions about the distribution of the variables and it is effective when the sample data are serially independent.~~ Its advantage over the parametric tests, such as t-test, is that the ~~non-parametric tests are~~MK test is more suitable for non-normally distributed, and ~~censored,~~ missing data, which are frequently encountered in hydrological time series (Yue *et al.*, 2004). ~~All the trend results in this paper have been evaluated at the 5 % level of significance to ensure an effective exploration of the trend characteristics within the study area.~~ However, ~~the MK test result is affected by a serial correlation of the time series, if there is a~~the existence of positive serial correlation in a time series data ~~in the time series leads~~affects the result of MK test~~. According to von Storch (1995), the test will suggest that a significant trend in a time series leads to~~. ~~a disproportionate rejection of~~ If serial correlation exists 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).~~, which is actually true.~~

In order to limit the influence of serial correlation on the MK test, pre-whitening was proposed by von Storch (1995). And also, ~~and~~ the Effective or Equivalent Sample Size (ESS) method developed by Hamed and Rao (1998) has ~~also~~ been proposed to modify the variance. However, the study by (Yue et al., 2002) reported that von Stroch's pre-whitening is effective only when no trend exists and the rejection rate of the ESS approach after ~~correction~~ modifying the variance is much higher than ~~that it should be~~the actual (Yue et al., 2004). Then, Yue et al. (2002) proposed trend-free pre-whitening (TFPW) prior to applying the ~~Mann-Kendall~~ MK trend test in order to minimize ~~the~~ it's limitation ~~of the MK test~~. This study therefore employed TFPW to remove the serial correlation ~~, in order~~and to detect a ~~significant~~ trend in a time data series with significant serial correlation. Further details can be found in (Yue et al., 2002). All the trend results in this paper have been evaluated at the 5 % level of significance to ensure an effective exploration of the trend characteristics within the study area.

~~MK calculates Kendall's statistics (S), the number of positive differences minus the number of negative differences, , to indicate an increasing or decreasing trend(Gilbert, 1987) using eqn.1-eqn.4. Positive values of those parameters indicate a general tendency towards an increasing trend, while negative values show a decreasing trend. Furthermore, a two-tailed probability (p-value) was computed and compared with the user-defined significance level (in this study 5%) in order to identify the trend of variables. When the calculated P-value is greater than the defined significance level (5%), then it indicates acceptance of null hypothesis (no trend) and the reverse is true.~~

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(k_j - k_x) \qquad (1)$$

~~If S is a positive number, it indicates, increasing trend. If S is a negative number, then observations made later tend to decrease. Where n is the data record length, k_j and kx are data sequential values, and the function sgn(x) the sign of all n(n - 1)/2 possible differences of $K_j - K_x$ where j > x is defined as~~

$$\mathrm{sgn}(x) = \begin{Bmatrix} 1, \ \text{if } x > 0 \\ 0, \ \text{if } x\ 0 = \\ -1, \ \text{if } x < 0 \end{Bmatrix} \qquad (2)$$

~~According to Mann (1945) and Kendall (1975), when n > 8, the statistic S is approximately normally distributed with the mean and the variance as follows:~~

~~The mean of S is E(s)=0, and the variance δ^2~~

$$\delta^2 = \frac{\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)\}}{18} \qquad (3)$$

~~Where p is the number of tied groups in the data set and t_j is the number of data points in the j^{th} tied group. The statistic S is approximately normally distributed provided that the following Z transformation is employed~~

~~$$Z = \begin{cases} \frac{S-1}{\sigma}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sigma}, & \text{if } S < 0 \end{cases} \quad (4)$$~~

~~A positive (negative) value of Z indicates that the data tend to increase (decrease) with time. If the computed value of $|Z| > Z_{1-(\alpha/2)}$, the null hypothesis (H0) is rejected at α level of significance in a two-sided test.~~

Change point test

The Pettitt test is used to identify if there is a point change or jump in the data series (Pettitt, 1979). This method detects one unknown change point by considering a sequence of random variables X 1, X 2, …, XT that may have a change point at N if Xt for t = 1, 2, …, N has a common distribution function F1(x) and Xt for t = N + 1, …, T has a common distribution function F2(x), and F1(x) ≠ F 2(x).

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:

$$\beta = \text{Median}\left[\frac{x_j - x_k}{j-k}\right] \text{ for all } k < j, \quad ....2~~2222221~~$$

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).

4.2 Remote sensing ~~L~~land use/cover map ~~analysis~~

4.2.1. Landsat image acquisition

Landsat images of the year 1973, 1985, 1995 and 2010 ~~–~~were accessed free-of-charge from the US Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) via http://glovis.usgs.gov. The Landsat image scenes were selected based on the criteria of acquisition period, availability and percentage of cloud cover. According to the recommendation of (Hayes and Sader, 2001), images needed to be acquired for the same acquisition period, in order to reduce scene-to-scene variation due to sun angle, soil moisture, atmospheric condition and vegetation phenology differences. Hence, cloud free images were collected for the dry months of January ~~and~~ to -May. However, as the basin covers large area, each period of LULC map ~~composed~~ comprised of 16 Landsat scenes, therefore, it was difficult to ~~get~~ access all the scenes in a dry season of a single year. Hence, images were acquired ~~of~~ ±1 year for each time period and also some images were acquired in the month of November and December. For 1973, for example, 16 Landsat MSS image scenes were acquired ~~in~~ (10 images in the month of January, 4 images in the month of December and 2 images in the month of November) in1973 (±1 years) and merged to arrive at one LULC representation for selected years. Please see supplement Table s02for the detail of landsat images.

4.2.2 Pre-processing and processing images

Several standard pre-processing methods including geometric ~~correction~~ and radiometric correction were implemented to prepare the LULC maps from Landsat images. Even though there are many different classification methods, supervised and unsupervised classifications are the two widely used methods for landcover classification from remote sensing images. Hence, ~~I~~in this study, a hybrid supervised/unsupervised classification approach was carried out to classify the images ~~from~~ of 2010 (LandsatTM). Firstly, Iterative Self-Organizing Data Analysis (ISODATA) clustering was performed to determine the spectral classes or land cover classes of the image. Secondly, polygons for all of the training samples based on the identified LC classes were digitized using ground truth data and then the samples for each land cover type were aggregated. Finally, a supervised classification was performed using a maximum likelihood algorithm in order to extract four LULC classes.

A total of 488 ~~ground truth data (GCPs~~ Ground Control Points (GCPs) regarding landcover types and their spatial locations were collected from field observation in March and April, 2017 using a Global Positioning System (GPS). Reference data (GCPs) were collected and taken from areas where~~assuming that~~ there had not been any significant landcover change between 2017 and 2010 by interviewing local elderly people, supplemented by using high resolution Google Earth Images and priori-knowledge of the first author.~~. Locations where ground truth data were taken, were selected carefully by interviewing local elderly people and using the prior knowledge of the first author.~~ As many as 288 points were used for accuracy assessment and 200 points were used for developing training sites to generate a signature for each land cover type. The accuracy of the classifications was assessed by computing the error matrix (also known as confusion matrix) that compares the classification result with ground truth information as suggested by DeFries and Chan (2000). A confusion matrix lists the values for known cover types of the reference data in the columns and for the classified data in the rows (Banko, 1998) as shown in Table 5**.** From the confusion matrix~~, one basic accuracy measure is overall accuracy, which is calculated by dividing the correctly classified pixels (sum of the values in the main diagonal) by the total number of pixels checked. Besides the overall accuracy, classification accuracy of individual classes such as user's accuracy and producer's accuracy are used. four measures of accuracy are estimated such as overall accuracy, user's accuracy, producer's accuracy and the kappa statistic.~~ Another discrete multivariate technique of use in accuracy assessment is called KAPPA (Congalton, 1991). The statistical metrics for KAPPA analysis is a Kappa coefficient~~-~~, which is another measure of the proportion of agreement or accuracy. The Kappa coefficient is computed as

$$K = \frac{N\sum_{i=1}^{i=r} x_{ii} \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \quad \text{...} \; 3~~3333332~~$$

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.

Once the landcover classification of the year 2010 Landsat image is completed and its accuracy is checked, the NDVI differencing technique (Mancino *et al.*, 2014) was applied to classify the images of 1973, 1985 and 1995. This technique was chosen to increase the accuracy of classification as it is hard to find an accurately classified digital or analogue LULC map of the study area during the period of 1973, 1985 and 1995. ~~a~~And also, the information obtained from the elders are more subjective and its reliability is questionable when there is considerable time gap. ~~In order to increase the accuracy, w~~We first calculated the NDVI from the Landsat MSS (1973) and three pre-processed Landsat TM images (1985, 1995, 2010) following the general normalized difference between band TM4 and band TM3 images eqn. ~~5~~3. The resulting successive NDVI images ~~for the time periods~~ were subtracted each other to assess the ΔNDVI image with positive (vegetation increase), negative (vegetation cleared) and no change on a 30 ~~m~~ x 30 m pixel resolution (eqn.~~6~~4-~~8~~6). The Landsat MSS 60m x 60m pixel size data sets were resampled to a 30 m x 30 m pixel size using the 'nearest neighbour' ~~resampling~~ technique in order to have similar pixel sizes for the different images without altering the original pixel values of the image data.

$$\mathbf{NDVI} = \frac{(\mathbf{TM4-TM3})}{(\mathbf{TM4+TM3})} \;\mathbf{or}\; \frac{(\mathbf{MSS_3-MSS_2})}{(\mathbf{MSS_3+MSS_2})} \qquad (4~~4444443~~)$$

$$\mathbf{\Delta NDVI_{1995/2010} = NDVI_{1995} - NDVI_{2010}} \qquad (5~~5555554~~)$$

$$\mathbf{\Delta NDVI_{1985/1995} = NDVI_{1985} - NDVI_{1995}} \qquad (6~~6666665~~)$$

$$\mathbf{\Delta NDVI_{1973/1985} = NDVI_{1973} - NDVI_{1985}} \qquad (7~~7777776~~)$$

The ~~difference image~~ ΔNDVI image was then reclassified using a threshold value calculated as μ ± n*σ; where μ represents the ΔNDVI pixels value mean, and σ the standard deviation. The threshold identifies three ranges in the normal distribution: (a) the left tail (ΔNDVI < μ - n*σ); (b) the right tail (ΔNDVI > μ + n*σ); and (c) the central region of the normal distribution (μ - n*σ < ΔNDVI < μ + n*σ). Pixels within the two tails of the distribution are characterized by significant landcover changes, while pixels in the central region represent no change. To be more conservative n=1 was selected for this study to narrow the ranges of the threshold for reliable classification.

The standard deviation (σ) is one of the most widely applied threshold identification approaches for different natural environments based on different remotely sensed imagery (Hu *et al.*, 2004; Jensen, 1996; Lu *et al.*, 2004; Mancino *et al.*, 2014; Singh, 1989) as cited by Mancino *et al.* (2014). ~~To be more conservative n=1 was selected for this study to narrow the ranges of the threshold for reliable classification.~~

ΔNDVI pixel values (2010-1995) in the central region of the normal distribution ($\mu - n\cdot\sigma < \Delta NDVI < \mu + n\cdot\sigma$) represent an absence of landcover change between two different periods (i.e. 1995 and 2010), therefore, pixels of 1995 corresponding to no landcover change can be classified as similar to the 2010 landcover classes. Pixels with significant NDVI change are again classified using supervised classification, taking signatures from the already classified no change pixels. Likewise, landcover classification of 1985 and 1973 images was performed based on the classified images of 1995 and 1985 respectively.

Finally, after classifying the raw images of Landsat into different landcover classes, change detection which requires the comparison of independently produced classified images (Singb, 1989) was performed by the post-classification method. The post-classification change detection comparison was conducted to determine changes in LULC between two independently classified maps from images of two different dates. Although this technique has some limitations, it is the most common approach as it does not require data normalization between two dates (Singh, 1989) because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between two dates.

4.3 SWAT hydrological model

The Soil and Water Assessment Tool (SWAT) is an open-source-code, ~~physically-based,~~ semi-distributed model with a large and growing number of model applications in a variety of studies ranging from catchment to continental scales (Allen *et al.*, 1998; Arnold *et al.*, 2012; Neitsch *et al.*, 2002). It enables to evaluates the impact of LULC and climate change on water resources in a basin with varying soil, land use and management practices over a set period of time (Arnold *et al.*, 2012).

In SWAT, the watershed is divided into multiple sub-basins, which are further subdivided into hydrological response units (HRUs) consisting of homogeneous land-use management, slope and soil characteristics (Arnold *et al.*, 2012; Arnold *et al.*, 1998). HRUs are the smallest units of the watershed in which relevant hydrologic components such as evapo-transpiration, surface run-off and peak rate of run-off, groundwater flow and sediment yield can be estimated. Water balance is the driving force behind all the processes in the SWAT calculated using eqn.97.

$$SW_t = SW_o + \sum_{I=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \quad (88888887)$$

where SWt is the final soil water content (mm H_2O), SW_o is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface run-off on day i (mm H_2O), Ea is the amount of evapo-transpiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

Run-off is calculated separately for each HRU and routed to obtain the total run-off 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) Figure 2. However, spatial connectivity and interactions among HRUs are ignored, instead, the cumulative output of each spatially discontinuous HRUs at the subwatershed outlet is directly routed to the channel (Pignotti et al., 2017). This lack of spatial connectivity among HRUs makes implementation and impact analysis of spatially-targeted management such as soil and water conservation structure difficult to incorporate in the model. To overcome this problem, efforts were made by different authors. For instance, a grid-based version of the SWAT model (Rathjens et al., 2015), landscape simulation on a regularized grid (Rathjens *et al.*, 2012). Moreover, (Arnold et al., 2010) and (Bosch et al., 2010) further modify SWAT model that allows landscapes to be subdivided into catenas comprised of upland, hillslope, and floodplain units and flow to be routed through these catenas. However, SWATgrid, developed to overcome this limitation, remains largely untested and computational demanding (Rathjens et al., 2015).

Hence, the standard SWAT The CN method was chosen in this study because it is tested in many watersheds of Ethiopia such as (Gashaw *et al.*, 2018; Gebremicael *et al.*, 2013; Setegn *et al.*, 2008; Woldesenbet *et al.*, 2017b) and 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 require sub daily precipitation as a model input that can be difficult to obtain in data scare region like UBNRB. This study focused on the effects of LULC and climate change on the water balance components of the basin, which includes the component of inflows, outflows and the change in storage. Precipitation is the main inflow, while evapo-transpiration (Et), surface run-off (Qs), lateral flow (Ql), and base flow (Qb) are the outflows. SWAT has three storages, namely, soil moisture (SM), shallow aquifer (SA) and deep aquifer (DA). Water movement from the soil moisture storage to the shallow aquifer is due to percolation, whereas, water movement from the shallow aquifer reverse upward to the soil moisture storage is Revap. For a more detailed description of the SWAT model, reference is made to Neitsch *et al.* (2011) Neitsch et al. (2011).

The SWAT model setup and data preparation can be done using arcSWAT tools in the arcGIS environment, while parameter sensitivity analysis, model calibration and validation was performed using the SWAT-CUP (Calibration and Uncertainty Procedures) interface Sequential Uncertainty Fitting (SUFI-2) algorithm (Abbaspour, 2008). During model setup, the observed ~~monthly~~ daily weather and streamflow data~~discharge~~ of the given period was divided in to three ~~separate data sets~~ different periods, the first to warm up the model, the second to calibrate the model and the third to validate the model.

The first step in SWAT is the determination of the most sensitive parameters for a given watershed using global sensitivity analysis option (Arnold *et al.*, 2012). The second step is the calibration process adjusting the model input parameters necessary to match model output with observed data, thereby reducing the prediction uncertainty. Initial parameter estimates were taken from the default lower and upper bound values of the SWAT model database and from earlier studies in the basin e.g.(Gebremicael *et al.*, 2013). The final step, model validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to independent observed data not used in the calibration.

In this study both manual and automatic calibration ~~strategy~~ strategies were ~~was~~ applied to attain the minimum differences between observed and simulated streamflows in terms of surface flow, peak and total flow following the steps recommended by Arnold *et al.* (2012). For the purpose of impact analysis, ~~In this study,~~ we divided the simulation periods of (1971-2010) in~~-~~to four decadal periods, hereafter referred as ~~namely~~ the 1970s (1971-1980), 1980s (1981-1990), 1990s (1991-2000) and 2000s (2001-2010), as shown in Table 2~~, ~~.~~in order to analyse the combined and isolated impacts of LULC and climate changes for the basin.~~ The models performance for the streamflow ~~were~~ was then evaluated using statistical methods (Moriasi *et al.*, 2007) such as the Nash–Sutcliffe coefficient of efficiency (NSE), the coefficient of determination (R^2) and the relative volume error (RVE %), which are shown by eqn.8~~10~~-10~~2~~. Furthermore, graphical comparisons of the simulated and observed data, as well as water balance checks were used to evaluate the model's performance.

$$\mathbf{R^2} = \frac{[\sum(Q_{m,i}-\bar{Q}_m)(Q_{s,i}-\bar{Q}_s)]^2}{\sum(Q_{m,i}-\bar{Q}_m)^2 \sum Q_{s,i}-\bar{Q}_s{}^2} \qquad (9\text{~~9999998~~})$$

$$\mathbf{NSE} = 1 - \frac{\sum(Q_m-Q_s)_i{}^2}{(Q_{m,i}-\bar{Q}_m)^2} \qquad (10\text{~~1010101010109~~})$$

$$\mathbf{RVE}\ (\%) = 100 * \frac{\sum_{i=1}^{n}(Q_m-Q_s)_i}{\sum_{i=1}^{n} Q_{m,i}} \qquad (11\text{~~11111111111110~~})$$

where $Q_{m,i}$ is the measured ~~flow data~~streamflow in m^3s^{-1}, Q_m is the mean ~~n~~ values of the measured ~~data~~streamflow (m^3s^{-1}), $Q_{s,i}$ is the simulated ~~flow data~~streamflow in m^3s^{-1}, and Q_s is the mean ~~n~~ values of simulated data in m^3s^{-1}.

4.4 SWAT simulations

In this study, three different approaches were used for SWAT simulation aimed at assessingIn order to assess the individual and combined effects of LULC and climate change on streamflow and water balance components, three different approaches were applied . The first approach is to assess the response of streamflow to included simulations to attributed changes in streamflow to combined LULC and climate change. the simulation results represented "real runoff" affected by the combination of LULC and climate changes. WWe divided the simulation analysis period (1971–2010) into four equal periods (four decade), periods when the hydrological regime within a catchment is expected to be changed due to land use changes (Marhaento *et al.*, 2017; Yin *et al.*, 2017b) to accommodate gradual changes in land use. The first period 1970s (1971–1980) was regarded as the baseline period and the other periods 1980s, 1990s and 2000s(1981–1990, 1991–2000, and 2001–2010) were regarded as altered periods. LULC maps of 1973, 1985, 1995 and 2010 produced from Landsat images were used to represent the LULC patterns of the period 1970s (1971-1980), 1980s (1981-1990), 1990s (1991-2000) and 2000s (2001-2010),, 1980s, 1990s and 2000s –respectively. To analyze the response of streamflow and water balance components caused by the combined effects of LULC and climate change at decadal time periods, the SWAT model was separately calibrated and validated for each decades using the respective LULC map and weather data (Table 2). The DEM and soil data sets remained unchanged. The LULC and climate data for each model ran were in the same period (i.e 1970s, 1980s, 1990s and 2000s) see Table 2. Tthe SWAT models has been calibrated/validated and optimal parameter values for the 6 most sensitive parameters has fixed each four periods of model run. The differences between the simulation result of the baseline and altered periods represent the combined effects of LULC and climate changes on streamflow and water balance components. Once the SWAT models are calibrated and validated for the four-decadal time period, streamflow and water balance components are simulated. This approach enables us to investigate how the parameter values) alter following the combined LULC and climate changes and also help us analyse the combined impacts of LULC and climate. change on streamflow and water balance components

The second approach included simulations to attribute only for LULC changes, aimed to investigate whether LULC change is the main driver for changes in water balance components. To identify the hydrological impacts caused by LULC only, "A fixing -changing" method was used (Marhaento *et al.*, 2017; Woldesenbet *et al.*, 2017b; Yan *et al.*, 2013; Yin *et al.*, 2017a). The calibrated and validated SWAT model and its parameter settings in the baseline period was forced by weather data from the baseline period 1973-1980 while changing only the LULC maps of 1985, 1995, and 2010, keeping the DEM and soil data constant as suggested by (Hassaballah *et al.*; Marhaento *et al.*, 2017; Woldesenbet *et al.*, 2017b; Yin *et al.*, 2017a). The method assumes that applying the calibrated model parameters values for the altered periods using updated LULC maps will enable the simulation of impacts of LULC change on mean annual streamflow and water balance components (Hassaballah *et al.*, 2017; Li *et al.*, 2009; Marhaento *et al.*, 2017; Wagner *et al.*, 2013). We ran the calibrated SWAT model for the baseline period (1970s) four times using achanging only LULC map of the year 1973, 1985, 1995 and 2010 and a

~~precipitation~~ remained ~~a~~ constant weather data set of the 1970s~~, then we applied the calibrated model parameters for the altered periods using updated LULC maps but with the same precipitation data~~(Table 2). ~~in order to investigate the attribution of changes to mean annual water balance component ratios, as a result of LULC change. In this case, the values of those 6 most sensitive parameters remained constant for both baseline and altered periods of SWAT simulation processes~~.

The third approach is similar to the second approach but the simulations are attributed only for climate changes. A model was run again four times, corresponding to the LULC periods using a unique LULC map of the year 1973 ~~and its parameter values~~ but altering the four different periods of ~~climate~~ weather data sets (1970s, 1980s, 1990s and 2000s).

5. Results and discussions

5.1 Trend test

5.1.1 Rainfall

The summary ~~results~~ 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 the rainfall over the UBNRB.~~ For daily time series, the computed probability values (p~~P~~-value) for seven stations was greater while for eight stations it was less than the given significance level (α=5 %)~~,~~. ~~which~~ This means ~~that~~ no statistically significant trends existed in seven stations ~~,~~but a monotonic trend was occurred ~~while~~ in the remaining 8 stations. ~~eight other~~ 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 Figure 1. The other two stations, Alemketema and Nedjo respectively located in the East and South-West of UBNRB show a decreasing trend. On ~~a~~ monthly basis, ~~the p-value for~~ the MK trend test result showed that no statistically significant trend existed in all 15 stations. ~~was larger than the given significance level, which showed that no statistically significant trend existed in every stations~~. On an annual time scale, MK trend test could not find any trend in 11 stations ~~larger whereas~~ while four stations (Alemketema, Debiremarkos, Gimijabet and Shambu) exhibited ~~a p-value less than the significance level~~a trend. ~~(all showed an upward trend except Alemketema).~~ The trend analysis result of the annual rainfall time series has a good ~~Theis result tallies~~ agreement ~~well~~ with previous study by ~~earlier studies in the basin at station level such as that of~~ Gebremicael *et al.* (2013)~~.Gebremicael et al. (2013)~~, who reported no significant change of annual rainfall in 8 out of 9 stations during the period 1973-2005. ~~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.~~ . 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 ~~as computed by the MK and Pettitt tests~~ using MK test and Pettitt test respectively as summarized in Table 3 and Figure 3~~respectively~~. 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~~'s~~ test could not detect any jump point in basin wide rainfall series except for daily time series rainfall. ~~Both MK test and test, indicate that there was no statistically significant trend~~ .

~~change at basin-wide rainfall at monthly, annual and seasonal time scales after applying TFPW, however, at daily time scale, Pettitt test showed jump point with increasing trend. This result is in line with the earlier studies in the basin such as~~ Previous studies carried out the trend analysis of the basin-wide rainfall ~~(Conway, 2000; Gebremicael et al., 2013; Tesemma et al., 2010)~~ such as (Conway, 2000; Gebremicael *et al.*, 2013; Tesemma *et al.*, 2010), ~~. Those studies~~ reported that ~~there was~~ no significant change of annual and seasonal rainfall series over the ~~Upper Blue Nile~~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. 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 9 stations from the period 1970-2005. However, in this study, we used daily observed rainfall data from 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 from station data.

5.1.2 Streamflow

~~The trend analysis of daily, monthly, seasonal and annual streamflow was computed by the MK and Pettitt tests summarized in Table after applying TFPW.~~ The result of MK-test for daily, monthly, annual and seasonal (long and short rainy season and dry season) time series streamflow showed a positive trend and the trend magnitude is statistically significant as summarised in Table 3. Meanwhile, the Pettitt test detects change point for daily, annual and short rainy season streamflows but cannot detect change point for monthly, long and dry seasons streamflow Figure 3. The change point~~s~~ detected by Pettitt test for annual rainfall series is occurred in 1995 while for daily and dry seasons are respectively in 1985 and 1987. ~~T~~the ~~flow of El Diem station at daily, annual, and long rainy seasons time series showed a significant increase over the last 40 years while the mean monthly streamflow at El Diem did not show any clear pattern. This~~ The result obtained from MK test has a good agreement ~~agreed~~ with the previous study carried out by Gebremicael et al. (2013), which reported an increasing trend~~e~~ in the observed annual, short and long rain seasons stream~~-~~flow at the El Diem gauging station but disagree with the result of dry season streamflow. ~~-at the El Diem.~~ Furthermore, the increasing trend of long rainy season streamflow~~s~~ well agree with the result of Tesemma et al. (2010), but disagree with the results of ~~-~~short rainy season and annual flows. ~~-Kessi and Bahirdar sub-basins but disagreed with the result of~~ (Tesemma et al., 2010), reported that the short rainy season and the annual flows are constant for the analysed period of 1964–2003. This disagreement is likely attributed to the difference of analysis period as can be seen from Figure 3, the last seven years (2004–2010) had relatively higher ~~-~~streamflow records. ~~who reported that there has been no significant pattern in the observed annual flow at El Diem.~~

Although, the results of MK test for the annual and long rainy season rainfall and streamflow show increasing trend~~s~~ 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 (Table 3). Moreover, for the short rainy season~~,~~ streamflow shows statistically significant positive increasing while the rainfall shows no change. ~~–Since the seasonal and annual rainfall over the basin during the 1971–2010 period did not show any significant changes, the increasing annual flow of the UBNRB at El Diem –~~ The mismatch of trend magnitude between rainfall and streamflow could be attributed to the ~~an~~ combined effect of LULC and climate change, associated with evapotranspiration, infiltration rate by changing soil properties rainfall intensity and extreme events.
~~-within the basin over the last 40 years (1971–2010).~~

5.2 LULC change analysis

~~The confusion matrix, used to measure the accuracy of the classified images by comparing spatially coincident ground control points and pixels of the classified image, was established using 288 ground control points (GCPs) which are not used in the classification of the 2010 image.~~ According to the confusion matrix report, ~~80%~~ overall accuracy of 80 %, producer's accuracy values for all classes ranged from 75.4 % to 100 %, user's accuracy values ranged from 83.7 % to 91.7 % and the kappa coefficient (k) of 0.77 were attained for the 2010 classified image as shown in Table 5. Monserud (1990) ~~as cited by Rientjes et al. (2011)~~ suggested a kappa value of <40 % as poor, 40–55 % fair, 55–70 % good, 70–85 % very good and >85 % as excellent. According to these ranges, the classification in this study has very good agreement with the validation data set and met the minimum accuracy requirements to be used for ~~the~~ further change detection and impact analysis.

The classified images of the basin (Figure 4) have shown different LULC proportion at four different time periods as shown in Figure 5. In 1973, the UBNRB was dominated by cultivated land (62.9 %), followed by bushes & shrubs (18 %), forest (17.4 %), and water (1.74 %). In 1985, the cultivated land increased to (~~to~~ 65.6 %), followed by bushes & shrubs (18.3 %), while forest decreased to (~~to~~ 14.4 %), and water remained unchanged at (~~at~~ 1.7 %). In 1995, cultivated land further increased to (67.5 %), followed by bushes & shrubs (18.5 %), forest further decreased (to 12.2 %), and water remained unchanged (1.7

%). In 2010, cultivated land decreased to (~~to~~ 63.9 %), bushes and shrubs increased to (18.8 %), forest increased to (15.6 %) and water remained unchanged at (1.7 %). ~~-~~During the entire 1973–2010 period, cultivated land, along with bushes & shrubs remained the major proportions as compared to the other LULC classes. The highest gain (2.7 %) and the largest loss (-3.6 %) in cultivated land occurred during the 1973–1985 and 1995-2010 periods respectively. The highest gain in bushes and shrubs was (0.3 %) from 1973 to 1985, while the highest gain in forest coverage (3.4 %) was recorded during the period 1995–2010. Water coverage remained unchanged from 1973 to 2010.

Although, the image classification has very good accuracy, uncertainties could be expected for the following reasons. Firstly, as elsewhere in Ethiopia, LULCs change rapidly over space, and image reflectance may be confusing due to the topography and variation in the image acquisition date. Landsat images were not all available for one particular year or one season; thus images came from a mix of years, and from a variety of seasons might have errors. Secondly, the workflow associated with LULC classification, which involve many steps and can be a source of uncertainty. The errors are observed in the classified LULC map as shown in Figure 4. In Figure 4 (a) on the western side of the map is a rectangular section with forest, that completely disappears in 4(b). In 4(b) there is a rectangular forest cover in the northern part of the country which again disappears completely in 4(c). In 4(d) a forest cover with linear edges (North-South) appears on the eastern side of the map. That being recognised, overall the land cover mapping is reasonably accurate, providing a good base for land cover estimation and for providing basic information for the objective of hydrological impact analysis.

The rate of expansion of cultivated land before 1995 was high as compared to after 1995. Conversely, the area devoted to forest land decreased in the 1985 and 1995 from the baseline 1973. However, after 1995, the forest began to increase while the cultivated land decreased. The increased forest coverage and the reduction in cultivated land over the period 1995 to 2010 ~~shows~~ showed that the environment was recovering from the devastating drought and forest clearing for firewood and cultivation due to population growth has minimiz~~y~~ed. This could be due to the afforestation programme initiated by the Ethiopian government and due to the extensive soil and water conservation measure carried out by the community. ~~During the period from 1995 to 2010~~Since 1995, eucalyptus tree plantation expanded significantly across the country at homestead level for fire wood, construction material, for producing charcoal and for generating income (Woldesenbet *et al.*, 2017b). To summarize, ~~during~~ in the period ~~from 1973 to~~ 2010, forest coverage declined by 1.8 %, with increasing of both bushes and shrubs, as well as cultivated land ~~increasing~~ by 0.8 % and 1 % respectively from the original 1973 level. This result agrees well with other ~~local level~~ studies (Gebremicael *et al.*, 2013; Rientjes *et al.*, 2011; Teferi *et al.*, 2013; Woldesenbet *et al.*, 2017b), ~~which~~ who reported the ~~dramatic changes~~a significant conversion of ~~in the~~ natural vegetation cover ~~resulting from the~~into agricultural land.

5.3 SWAT model calibration and validation

The most sensitive parameters of the SWAT model to simulate streamflow were identified using global sensitivity analysis of SWAT-CUP and their optimized values were determined by the calibration process recommended by Arnold *et al.* (2012). Parameters such as SCS curve number (CN2), base flow alpha factor (ALPHA_BF), soil evaporation compensation factor (ESCO), threshold water depth in the shallow aquifer required for return flow to occur (GWQMN), groundwater "revap" coefficient (GW_REVAP) and the available water capacity (SOL_AWC) were found to be the most sensitive parameters for the flow predictions.

Figure 6 ~~showed~~ shows the calibration and the validation results of monthly streamflow hydrographs and this result revealed the model well captured the monthly hydrographs. This was again verified by the statistical performance measures of R^2, NSE and RVE (%) as presented in Table 6. For the calibration period, the values of R^2, NSE and RVE (%) from the four model is ranged from 0.~~78~~ 79 to 0.91, 0.~~73~~ 74 to 0.91 and ~~-0.7~~-3.4 % to 4 % and for the validation period it ranged from 0.84 to 0.94, 0.~~84~~ 82 to 0.92 and -7.5 % to 7.4 % respectively. According to the rating of Moriasi *et al.* (2007), the performance of the SWAT model over UBNRB can be categorized as very good, although underestimation was observed in the base flow simulation.

The optimal parameter values of the calibrated ~~model for the~~ four model runs are shown in Table 7. A change was obtained for CN2 parameter values, ~~such change indicates changes of~~which can be attributed to the catchment response behaviour. For instance, an increase in the CN2 value in the 1980s and 1990s from 0.89 to 0.91 and 0.92 as compared to 1970s respectively, indicate a reduction in forest coverage and expansion of cultivated land~~ which align with the result of LULC classification maps~~. In contrary, a decrease in CN2 value was ~~observed~~ 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.

5.4 Effects of combined LULC and climate change on streamflow and water balance components

The simulation result of the four independent decadal time scale calibrated and validated SWAT model runs ~~result~~ indicate~~s~~ ~~that streamflow and water balance changed due to~~ the combined effect of both LULC and climate change during the last 40 years' time (Table 8). From the simulation result, ~~At basin level, the MK trend analysis showed increasing trend for the mean annual and long rainy season streamflow but no trend for short rainy season streamflow at 5% significance level. This was also confirmed by SWAT simulation result. The mean annual streamflow and water balance components simulated by SWAT for the four simulation period is shown in Table 8. In general, m~~Mmean annual streamflow increased by ~~15.6~~16.9 % between the period 1970s and the 2000s. However, the rate of change ~~mean annual streamflow changed~~ is different~~ly~~ in different decades. For example, it increased by ~~2.1~~3.4 % and ~~,~~ ~~6.8~~9.9 % ~~and 6%~~ during the period 1980s~~,~~ and 1990s ~~and 2000s~~ 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 % ~~during 2000s~~ 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, ~~while~~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. The result for surface runoff agrees with the previous study done by (Gebremicael et al., 2013) but disagree for baseflow. They reported surface runoff (Qs) contribution to the total river discharge has increased by 75%, while the baseflow (Qb) flow has decreased by 50% from the period 1970s to 2000s.

This indicate that 1.8 % forest cover loss and 1 % increased cultivated land combined with 2.2 % increased rainfall from the 1970s to the 2000s led to a 16.9 % increase in simulated ~~-~~streamflow. 1990s was the period when the highest deforestation and expansion of cultivated land reported; meanwhile it is the time when the rainfall intensity and number of rainfall events has significantly increased compared to the 1970s and 1980s, as shown in Table 4. Hence, the increased mean annual streamflow could be ascribed to the combined effects of LULC and climate change. In the case of (Qs/Qt), the increasing pattern could be ~~mainly~~ ascribed to the increasing of rainfall intensities and expansion of cultivated land and decreasing of forest coverage, which might adversely affect soil water storage, and decrease rainfall infiltration, thereby increase water yield or streamflow. In contrary, the decreasing of (Qb/Qt) has positive relation with the increasing of evapotranspiration linked to both LULC and climate factors (Table 8). This hypothesis can be explained with the change in CN2 parameter values obtained during the calibration of the four SWAT model runs.

~~This result can be attributed to the dimension of the combined effect of the LULC and climate change on the streamflow.~~ The CN2 parameter value which is a function of evapotranspiration derived from LULC, soil type, and slope, increased ~~-~~in the 1980s and 1990s from 1970s could be associated with the expansion of cultivated land and shrinkage of forest land. The increasing of CN2 results to generate more surface runoff and less baseflow.

Another important contributing factor for the decreasing of surface run-off and increasing of base flow ration in the 2000s from 1990s could be the placement of soil and water conservation (SWC) measures. According to Haregeweyn et al. (2015), various nationwide SWC initiatives have been undertaken since the 1980s such as Food-for-Work (FFW) (1973–2002), Managing Environmental Resources to Enable Transition to more sustainable livelihoods (MERET, 2003–2015), Productive Safety Net Programs (PSNP, 2005–present), Community Mobilization through free-labor days (1998–present), and the

National Sustainable Land Management Project (SLMP, 2008–2018). The effectiveness of the initiatives were evaluated by (Haregeweyn *et al.*, 2015) and come up with the conclusion that community labour mobilization seems to be the best approach. It can reduce a mean seasonal surface run-off by 40 %, with large spatial variability, ranging from 4 % in Andit Tid (northwest Ethiopia) to 62 % in Gununo (south Ethiopia).

~~1990s was the period when the highest deforestation and expansion of cultivated land was reported; meanwhile the rainfall intensity and number of rainfall events has significantly increased compared to the 1970s and 1980s, as shown in Table 4. However, it is difficult to identify which variable (the LULC or the climate) most significantly affects the streamflow and its water balance components at this stage. Consequently, further analysis was carried out, by changing the LULC and holding climate data constant and vice versa. The results of this simulation are discussed in sections 5.5 and 5.6 below.~~

5.5 Effects of a single change in LULC on streamflow and water balance components

~~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~~ To identify the hydrological impacts caused by LULC only, ~~the~~"A fixing -changing" method was used (Yan *et al.*, 2013). The calibrated and validated SWAT model and its parameter settings 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, keeping the DEM and soil data constant as suggested by (Hassaballah et al.). The result from Figure 7 indicated that Qs/Qt ratio changed from 40.7 % to 4~~7.7~~1.2 %, ~~53.1~~41.1 % and ~~39~~ 40.9 % respectively by using the LULC maps from 1973, 1985, 1995 and 2010 whereas the Qb/Qt ratio changed from 17.1 % to ~~10.1~~16.8 %, ~~3.3~~16.5 % and ~~23.4~~ 16.9 % respectively. The highest Qs/Qt ratio (~~53.1~~41.9 %) and the lowest Qb/Qt ratio (~~3.3~~16.5 %) was recorded with the LULC map of 1995. This could be attributed to the 5.1 % reduction in forest coverage and 4.6 % increase in cultivated land with the 1995 LULC map as compared to the 1973 LULC map.

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). The annual Ea losses from seasonal crops are smaller than Ea losses from forests, as seasonal crops only transpire relatively shorter time period than perennial trees transpire (Yan et al., 2013). As a result, 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. Furthermore, this deforestation may cause a reduction in canopy interception of the rainfall, decreases 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). Here, the change of evapotranspiration caused by the LULC change is minimal as a result the change for surface runoff and baseflow is not significant. ~~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. Based on the SWAT model result, this study provides a strong indication that changes in LULC altered the water balance in the UBNR basin. Findings show that LULC change due to deforestation and expansions of cultivated area has increased surface run-off but reduced base flow.~~

5.6 Effects of single climate change on streamflow and water balance components

The impacts of climate change are analysed by running the four models using a unique LULC map of 1973 with its model parameters ~~but~~ while changing only the weather ~~four different~~ data sets ~~of precipitation~~from ~~(~~1970s, 1980s, 1990s and 2000s~~)~~. The simulated water balance components shown in Figure 7, indicate that the Qs/Qt ratio increased from 40.7 % to 45.2 %, 45.6 % and 46.2 % during the period 1970s, 1980s, 1990s and 2000s respectively, while, the Qb/Qt ratio changed from 17.1 % to 13.5 %, 14.9 % and 12.7 % ~~during~~ for the same simulation periods. ~~The highest surface run-off fraction and lowest base flow fraction was recorded with climate data of 2000s. The increasing of surface run-off and decreasing of base flow during the simulation period in this study is attributed to increasing of rainfall intensity and extreme rainfall events in the UBNRB (as can be seen in Table 4). The 99-percentile precipitation increased from 17.3 mm to 19.6 mm and R20mm increased from 15 days to 35 days during the period from 1970s to 2000s.~~ The decreasing of the ratio of (Qb/Qt) for the altered periods as compared to the baseline period could be attributed to the increasing of evapotranspiration from ~~1615~~872 to 854, 906 and 884 mm respectively in 1970s, 1980s, 1990s and 2000s which can be linked to temperature and amount of rainfall. However, it is important to know the dominant rainfall-runoff process of the study area to fully understand the effect of climate change on the water balance components.

Although, there is no any detail research carried out on the Blue Nile basin to investigate about the runoff generation processes, Liu et al. (2008) investigated the rainfall-runoff processes at three small watersheds located inside and around Upper Blue Nile basin, namely: Mayber, AnditTid and Anjeni. Their analysis showed that, unlike in temperate watersheds, in monsoonal climates, a given rainfall volume at the onset of the monsoon produces a different run-off volume than the same rainfall at the end of the monsoon. Liu et al. (2008) and Steenhuis et al. (2009) showed that the ratio of discharge to precipitation minus evapotranspiration (Q/(P- ET)) increases with cumulative precipitation from the onset of monsoon. This suggesting that saturation excess processes play an important role in watershed response.

Furthermore, the infiltration rates measured in 2008 by Engda (2009) were compared with rainfall intensities in the Maybar and Andit Tid watersheds located inside and around UBNRB. In Andit Tid watershed, which has an area of less than 500 ha, the measured infiltration rates at 10 locations were compared with rainfall intensities considered from the period 1986-2004. The analysis showed that only 7.8 % of rainfall intensities were found higher than the lowest soil infiltration rate of 2.5 cm hr^{-1}. A similar analysis was performed by Derib (2005) in the Maybar watershed (with a catchment area of 113 ha). The infiltration rates measured from 16 measurements were ranged from 19 to 600 mm $hr^{-1}$with an average value of 24 cm hr^{-1} and the median was 18 $cmhr^{-1}$ while the average daily rainfall intensity from 1996 to 2004 was 8.5 mm hr^{-1}. Hence, from these infiltration measurements, he suggested that infiltration excess run-off is not a common feature in these watersheds.

From the above discussion points, it is to be noted that surface runoff could increase with the increasing of total rainfall amount regardless of rainfall intensity. However, in this study, the mean annual rainfall amount was decreasing from 1970s to 1980s (1428 and 1397 mm respectively) while the (Qs/Qt) ratio increased from 40.7 % to 45.2 %. Similarly, the mean annual rainfall amount in 1990s (1522 mm) was higher than the mean annual rainfall amount in 2000s (1462 mm) while the (Qs/Qt) increased from 45.6 % to 46.2 %. In contrary, climate indexes such as 99-percentile rainfall, SDII (ratio of total precipitation amount to R1mm) and R20mm are increasing consistently from the period 1970 to 2000s as shown in Table 4. This indicates that the increasing of surface run-off might be due to increasing of rainfall extreme events and rainfall intensity. In other words, this study revealed that infiltration excess of overland flow dominates rainfall-runoff processes in the UBNRB not for saturation excess of overland flow. The contradiction from the previous studies might be either due to the limitation of SWAT- CN method when applied in monsoonal climates or due to the overlooked of tillage activities which has significant impact on the soil infiltration rate by the previous studies. At the beginning of the rainy season, extensive tillage activities carried out across the basin, as a result soils get disturbed which can increase infiltration rate and finally decrease the amount of rainfall converted to runoff.

Although, the CN method is easy to use, provides acceptable results in many cases for discharge at the watershed outlet, researchers have concerns over its use in watershed models (Steenhuis et al., 1995; White et al., 2011). SWAT-CN model relies with a statistical relationship between soil moisture condition and CN value obtained from plot data in the United States with a temperate climate that was never tested in monsoonal climate where two extreme soil moisture conditions exhibited. In monsoonal climates, long period of rain can lead to prolonged soil saturation while during the dry period the soil dries out completely which may not happen in temperate climates (Steenhuis *et al.*, 2009). Hence, further research is necessary that considers bio-physical activities such as tillage and seasonal effects to soil moisture at representative watersheds of the basin for assessing the rainfall-runoff processes properly.

6. Conclusions

The objectives of this study were to understand the long-term variations of ~~climate~~ rainfall and ~~hydrology~~ streamflow of the UBNRB using statistical techniques (MK and Pettitt tests), and to assess the combined and single effects of climate and LULC change using a semi-distributed hydrological model (SWAT). ~~The MK and Pettitt tests showed no statistically significant change of the annual and seasonal rainfall over the UBNRB between 1971 and 2010. However, both tests showed a statistically significant increasing trend of streamflow for annual, long and short rainyseason but no trend~~ 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 areal 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. ~~during the dry season.~~

The LULC change detection was assessed by comparing the classified images and the result showed that the dominant process is largely the expansion of cultivated land and decrease in forest coverage. The rate of deforestation is high during the period 1973-1995, this is probably due to the severe drought~~s~~ occurred in ~~1984/85~~mid 1980s and due to large population increase as a result expansion of agricultural land. On the other hand, forest coverage increased by 3.4 % during the period 1995 to 2010. This indicates that the environment was recovering from the devastating drought of 1980s and ~~forest clearing~~regenerating of forests as the result of afforestation programme initiated by the Ethiopian government and ~~large scale~~due to soil and water conservation activities done by the communities. ~~During the period from 1995 to 2010 the planting of multipurpose eucalyptus trees expanded significantly across the country in order to generate income, as well as to produce fire wood, charcoal and construction materials.~~

The SWAT model was used to ~~simulate~~ analyse the combined and single effects of LULC and climate changes on the monthly streamflow at the basin outlet (El Diem station, located on the Ethiopia-Sudan border). The result showed that the combined effects of the LULC and climate changes increased the mean annual streamflow by ~~15~~16.~~5~~9 % from the 1970s to the 2000s. The increased mean annual streamflow could be ascribed to the combined effects of LULC and climate change. The LULC change alters the catchment responses as a result SWAT model parameter values could be changed.~~The high reduction in forest coverage and expansion of cultivated land during the 1973 to 1995 period caused a larger fraction of rainfall to be transformed to surface run-off and led to a reduction in the ratio of base flow.~~ For instance, the expansion of cultivation land and the shrinkage of forest coverage from 1973 to 1995~~,~~ has changed the CN2 parameter values from 0.89 in 1973 to 0.91 and 0.92 in the 1985 and 1995 respectively. The increasing of CN2 value might increase surface run-off and decrease base flow. Similarly, the increase in rainfall intensity and extreme precipitation events led to a substantial increase in Qs/Qt and a substantial decrease in Qb/Qt and ultimately increases in the streamflow during the 1971-2010 simulation period.

~~The smaller contribution of LULC change may be due to the fact that the SWAT model does not adjust CN2 for slope, which might be significant in areas where the majority of the area has a slope greater than 5%, such as the UBNRB.~~

~~The combined results from three different approaches, namely statistical trend test, semi-distributed SWAT modelling and LULC change analysis, are consistent with the hypothesis that~~The "fixing-changing" approach result using SWAT model revealed that the single effect of LULC change could potentially altered the streamflow generation processes. Expansion of cultivated land might reduce evapotranspiration because transpiration for seasonal crops is less than the transpiration of perennial trees (Yan et al., 2013) as a result surface run-off increased. Alternatively, reduction of forest coverage 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). In general, 5.1 % reduction in forest coverage and 4.6 % increase in cultivated land led to 9.9 % increase of mean annual streamflow from 1973 to 1995. ~~LULC change has modified the run-off generation process, which has caused the increase in streamflow of the UBNRB while the climate has remained unchanged.~~

~~These findings can be useful for basin-wide water resources management in the Blue Nile basin, as it provides a better understanding of the trends of rainfall, and streamflow, as well as the combined and single effects of climate and LULC change on the streamflow for the UBNRB.~~ This study provides a better understanding and substantial information how climate and LULC change affects streamflow and water balance components separately and jointly, which is useful for basin-wide water resources management. The SWAT simulation indicated that the impacts of climate change is substantial ~~than~~as compared to the impacts of LULC change as it is shown in Figure 7. Surface water is not any more used for agriculture and for plant consumption in areas where there is limited water storage facilities like UBNRB where as base flow is the reliable sources for irrigation to increase agricultural production. Hence, the increasing of surface water and reduction of base flow caused by both LULC and climate changes negatively affects the socio-economic developments of the basin.

~~Hence~~Therefore, protecting and conserving the natural forests and expanding soil and water conservation activities are~~is~~ highly recommended, not only for ~~maintaining the streamflow~~increasing the base flow available for irrigation but also reducing soil erosion. By doing so, the productivity might be increased, livelihoods and regional water resource use cooperation might be improved. However, ~~The limitation of~~ this study ~~could be~~might have limitations due to the uncertainties of Landsat image classification and ~~uncertainty of~~ the simulation of SWAT model. In order to improve the accuracy of LULC classification from Landsat images, further efforts such as the integration of other images together with Landsat images through image fusion techniques (Ghassemian, 2016) is required. ~~as t~~The SWAT model does not adjust CN2 for slopes greater than 5%, which could be significant in areas where the majority of the area has a slope greater than

5%, such as UBNRB. Therefore, we suggest adjusting the CN2 values for slope > 5 % outside of the SWAT model for further researchmight improve the results. Moreover, further research that involves rainfall intensity, infiltration rate and event-based analysis of hydrographs and critical evaluation of rainfall-runoff processes in the study area might improve the limitation of this study. Finally, the authors would like to point out that the impacts of current and future water resource developments should be investigated in order to establish comprehensive and holistic water resource management in the Nile basin.

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Table 1: Areal long term (1971-2010) mean annual and seasonal rainfall and streamflow of UBNRB

	Amount				Contribution (%)				
Station	Kiremit	Belg	Bega	Total	Kiremit	Belg	Bega	Mean	Area (km^2)
Flow (m^3s^{-1})	3506.3	300.4	1018.4	4825.1	72.7	6.2	21.1	1608	172,254
Flow (BCM)	36.4	3.1	10.6	50.7					
Rainfall (mm)	1070.1	140.8	238.9	1449.8	73.8	9.7	16.5		

Kiremit: long rainy season, Belg: Short rainy season, Bega: Dry season

Table 2: Data sets for the baseline and altered periods for the SWAT simulation used to analyse the combined and single effect of LULC and climate changes on streamflow and water balance components

Model run No.	Combined effect		Isolated LULC change effect		Isolated climate change effect		
	Climate data set	LULC map	Climate data set	LULC map	Climate data set	LULC map	Remark
1	1970s	1973	1970s	1973	1970s	1973	Base period
2	1980s	1985	1970s	1985	1980s	1973	altered period1
3	1990s	1995	1970s	1995	1990s	1973	altered period2
4	2000s	2010	1970s	2010	2000s	1973	altered period3

Table 3: MK and Pettitt test for the rainfall and streamflow of UBNRB after TFPW at different time scale

	stream flow					Rainfall				
	p-value					p-value				
Time scale	After*	Before*	Sen's slope:	Change point	Pettit test	After*	Before *	Sen's slope:	Change point	Pettit test
Daily	< 0.0001	< 0.0001	0.013	1987	Increasing	0.387	0.953	0.000	1988	Increasing
Monthly	< 0.0001	0.031	0.378		No change	0.010	0.640	0.009		No change
annually	< 0.0001	0.009	9.619	1995	Increasing	0.006	0.260	1.886		No change
Kiremit	< 0.0001	0.014	20.30		No change	0.010	0.348	1.364		No change
Belg	< 0.0001	0.004	3.593	1985	Increasing	0.822	0.935	0.068		No change
Bega	0.000	0.214	4.832		No change	0.527	0.755	0.169		No change

Time scale	Rainfall				Flow			
-	P	Sen's slope	r1	Pettitt test	P	Sen's slope	r1	Pettitt test
Daily	0.88	0.000	-0.24	Increase	< 0.0001	0.009	-0.264	Increasing
Monthly	0.148	0.077	0.45	No change	0.736	0.042	0.455	No change
Annually	0.348	1.432	0.003	No change	0.031	9.335	-0.039	Increasing
Kiremit	0.427	1.249	-0.01	No change	0.05	19.466	0.001	Increasing
Belg	0.792	-0.209	0.012	No change	0.289	1.239	0.003	Increasing
Bega	0.631	0.332	0.039	No change	0.219	4.746	0.051	No change

r1:lag1 auto correlation coefficient* before and after TFPW, p: probability at 5% significance level

Table 4: Summary of precipitation indices of the UBNRB at decadal time series

Indices	1970s	1980s	1990s	2000s
Mean (mm)	4.17	4.05	4.42	4.16
95 percentile (mm)	12.57	12.52	13.66	13.31
99 percentile (mm)	17.34	17.77	19.44	19.65
1-day max (mm)	27.15	25.67	32.24	32.38
R20mm (days)	16	15	30	35
SDII (mm/day)	7.22	7.38	7.66	7.77

SDII is the ratio of total precipitation (mm) to R1mm ~~precipitation~~(days).

Table 5: Confusion (error) matrix for the 2010 land use/cover classification map

LULC class	Water	Forest	Cultivated	Bushes and Shrubs	Row total	Producers' accuracy
Water	44	0	0	0	44	100
Forest	1	46	6	8	61	75.4
Cultivated land	2	3	77	15	97	79.4
Bushes and shrubs	1	3	9	73	86	84.9
Column total	48	52	92	86	288	
User's accuracy (%)	91.7	88.5	83.7	84.9		
Over all accuracy(%)	0.8					
Kappa	0.77					

Table 6: Statistical performance measure values of the SWAT model

Period		R^2	NSE	RVE (%)
	Calibration (1973-1977)	0.79	0.74	-3.41
1970s	Validation (1978-1980)	0.84	0.83	7.18
	Calibration (1983-1987)	0.80	0.74	-0.72
1980s	Validation (1988-19909	0.86	0.82	0.73
	Calibration (1993-1997)	0.91	0.91	1.79
1990s	Validation (1998-2000)	0.87	0.84	-3.56
	Calibration (2003-2007)	0.86	0.86	3.99
2000s	Validation (2008-2010)	0.94	0.92	-7.51

Period	-	R^2	NSE	RVE(%)
	Calibration (1973-1977)	0.81	0.77	-2.4
1970s	Validation (1978-1980)	0.82	0.89	10.5
	Calibration (1983-1987)	0.78	0.74	0.9
1980s	Validation (1988-19909	0.83	0.84	-6.8
	Calibration (1993-1997)	0.91	0.91	-0.85
1990s	Validation (1998-2000)	0.87	0.88	-6.6
	Calibration (2003-2007)	0.86	0.86	4.2
2000s	Validation (2008-2010)	0.87	0.86	-18.0

Table 7: SWAT sensitive model parameters and their (final) calibrated values for the four model runs.

Parameter	Optimum value			
	1970s	1980s	1990s	2000s
R-CN2	0.88	0.91	0.92	0.9
a-Alpha-BF	0.028	0.028	0.028	0.028
V-GW_REVAPMN	0.7	0.45	0.7	0.34
V-GWQMN	750	750	750	750
V-REVAPMN	550	450	425	550
a-ESCO	-0.85	-0.85	-0.85	-0.85
R-SOL_AWC	6.5	6.5	6.5	6.5

R:- value from the SWAT database is multiplied by a given value, V:- Replace the initial parameter by the given value, a:- Adding the given value to initial parameter value.

Table 8: Water balance components analysis in the Upper Blue Nile River Basin (mm/year) by considering LULC and climate change over respective periods. All streamflow estimates are for El Diem station.

Water balance components-	1970s	1980s	1990s	2000s
Surface flow (Qs)	112.8	143.4	168.6	141.4
Lateral flow (Ql)	116.8	113.35	125.9	117.6
Base flow (Qb)	47.3	29.6	9.8	64.7
PET (mm)	1615.1	1627.3	1614.7	1732.9
Ea (mm)	871.6	852.6	904.3	885
Precipitation (P)	1428.1	1397.1	1522.2	1462.5
Total yield (Qt)	276.9	286.3	304.3	323.7
Qs/Qt (%)	40.7	50.1	55.4	43.7
Qb/Qt (%)	17.1	10.3	3.2	20.0
Ea/P (%)	61.0	61.0	59.4	60.5
Qt/P (%)	19.4	20.5	20.0	22.1

Water balance component	1970s	1980s	1990s	2000s
Surface flow (Qs)	100.2	143.4	168.6	141.4
Lateral flow (Ql)	117.3	113.35	125.9	117.6
Base flow (Qb)	56.42	29.6	9.8	64.7
Revap	270.8	257.2	310.6	241
PET	1615.1	1627.3	1614.7	1732.9
Ea	871.9	852.6	904.3	885
Precipitation (P)	1428.1	1397.1	1522.2	1462.5
Qt	273.96	286.3	304.3	323.7
Qs/Qt(%)	36.6	50.1	55.4	43.7
Qb/Qt(%)	20.6	10.3	3.2	20.0
Ea/P(%)	61.1	61.0	59.4	60.5
Qt/P(%)	19.2	20.5	20.0	22.1

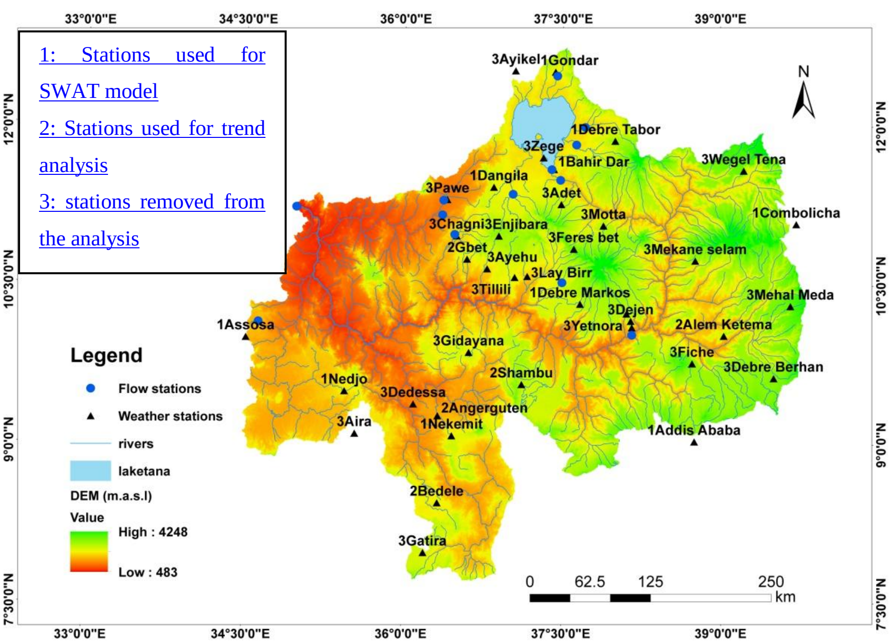


Figure 1 : Locations of study area and meteorological and discharge stations, with the Digital Elevation Model (DEM) data as the background

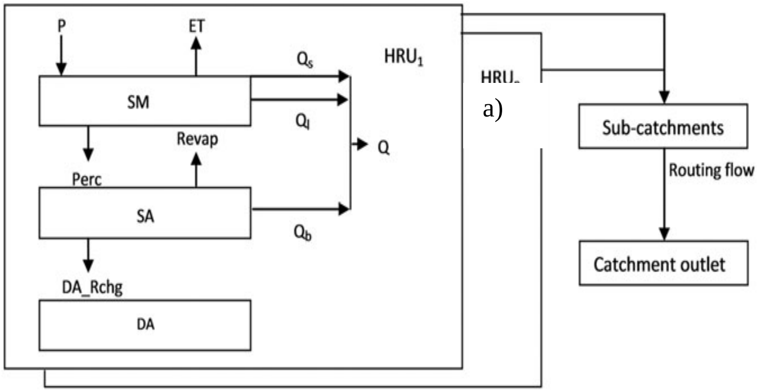
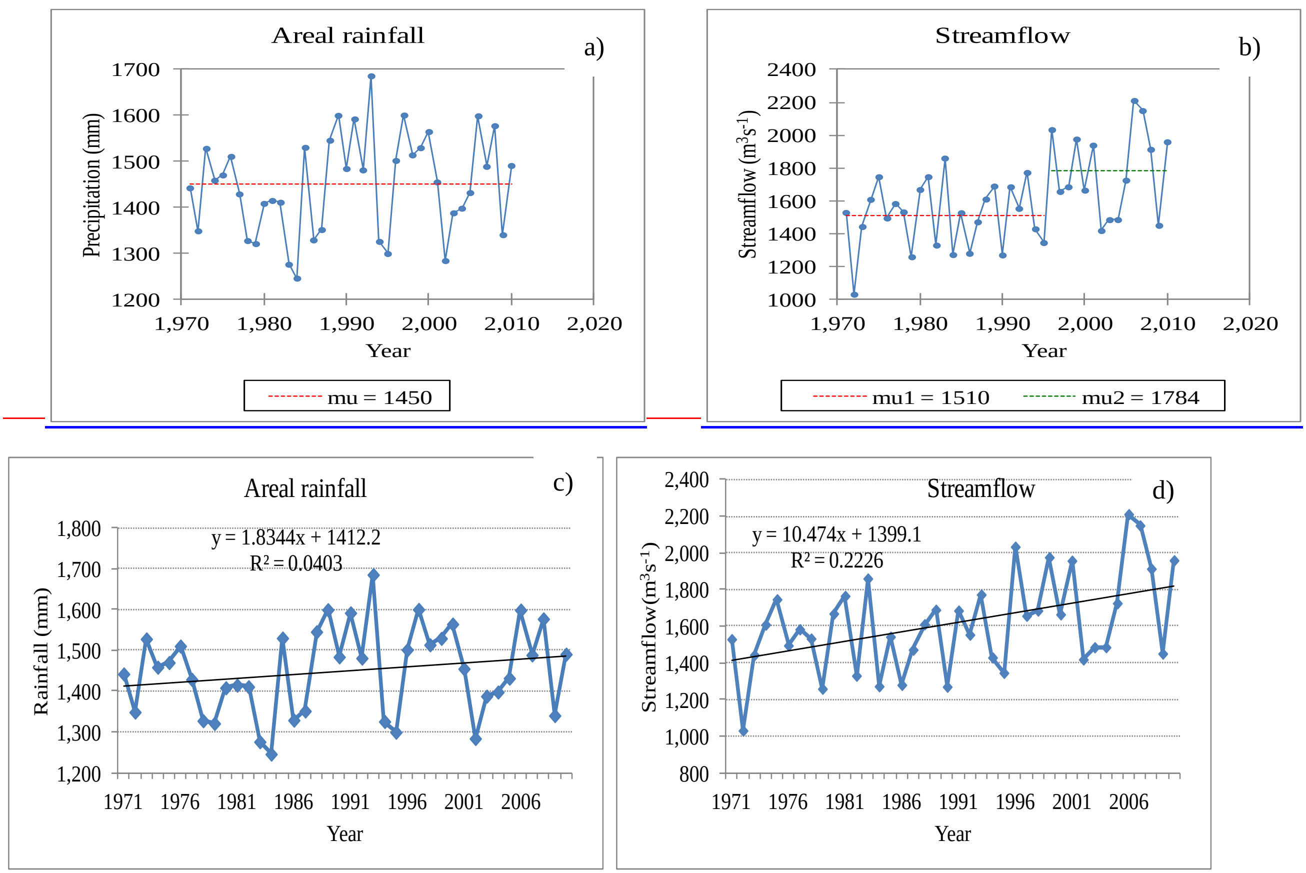


Figure 2: Schematic representation of the SWAT model structure from (Marhaento *et al.*, 2017)



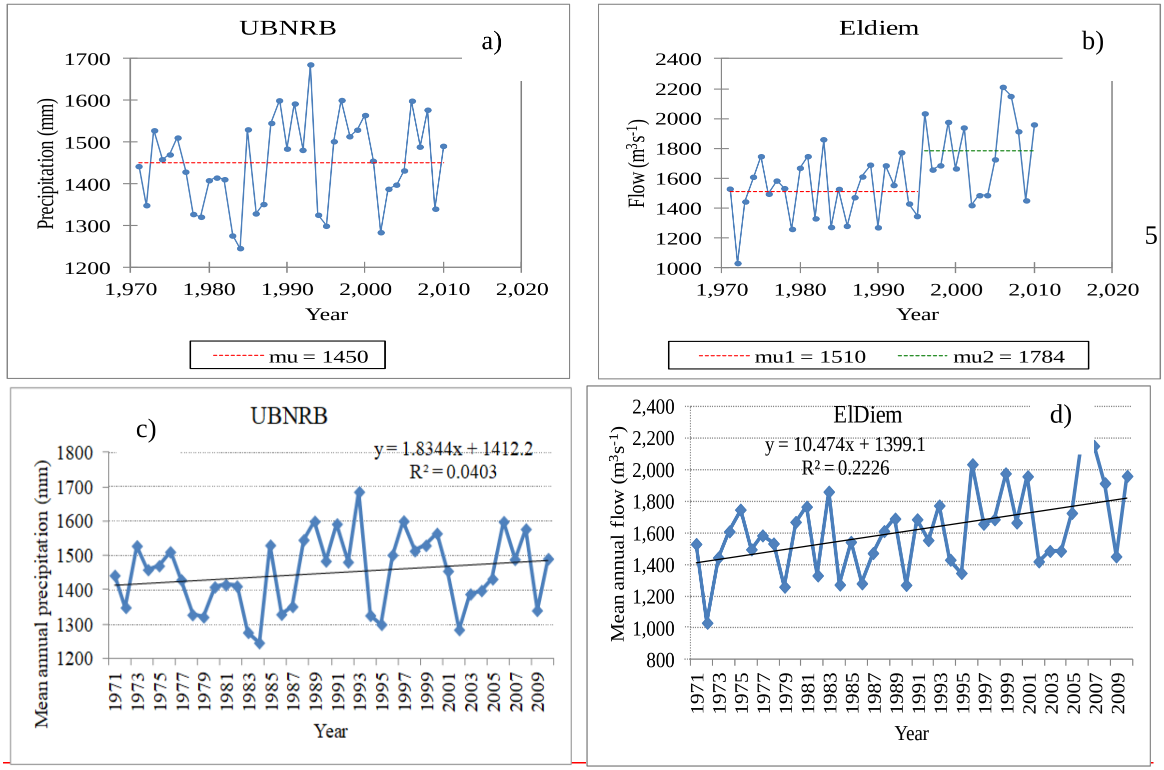
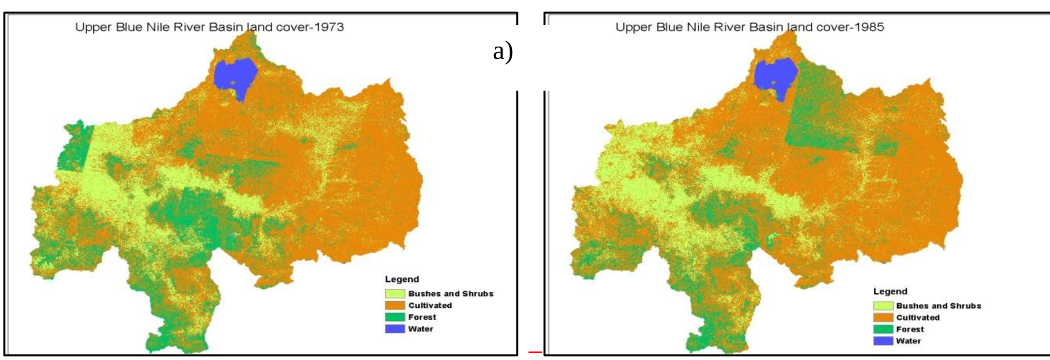


Figure 3: The Pettitt homogeneity test a) annual rainfall, b) annual flow of the UBNRB, C) linear trend of mean annual rainfall and d) linear trend of mean annual streamflow.



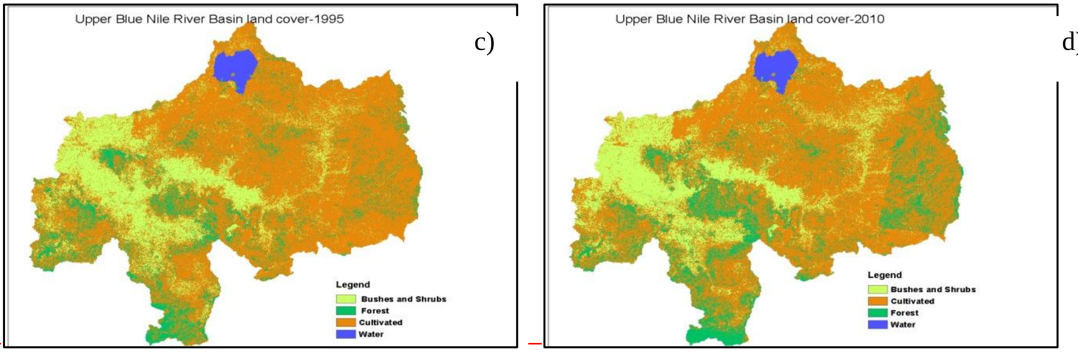


Figure 4: Landcover map of UBNRB derived from Landsat images a) 1973, b) 1985, c) 1995 and d) 2010

a) b)

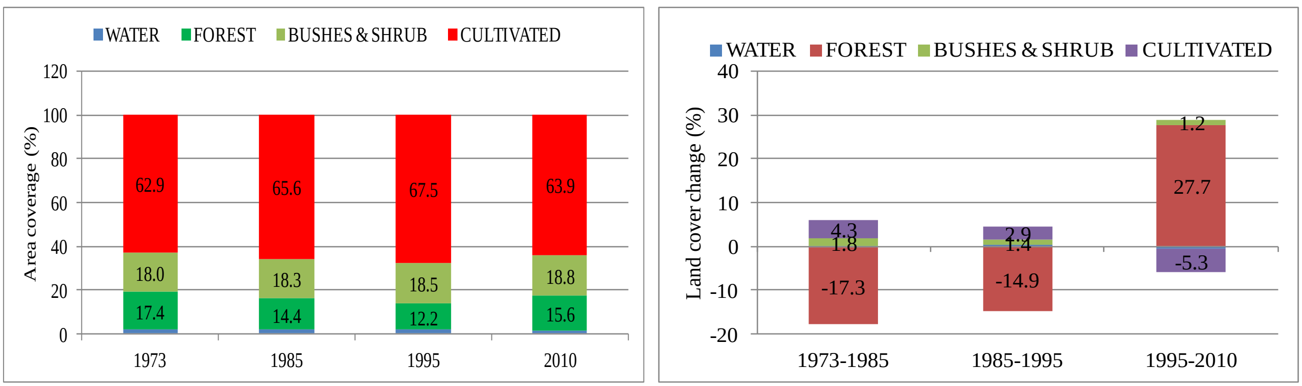
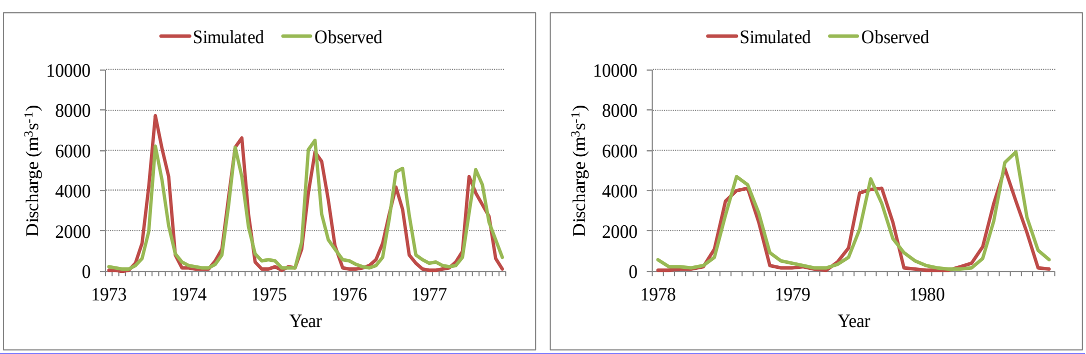
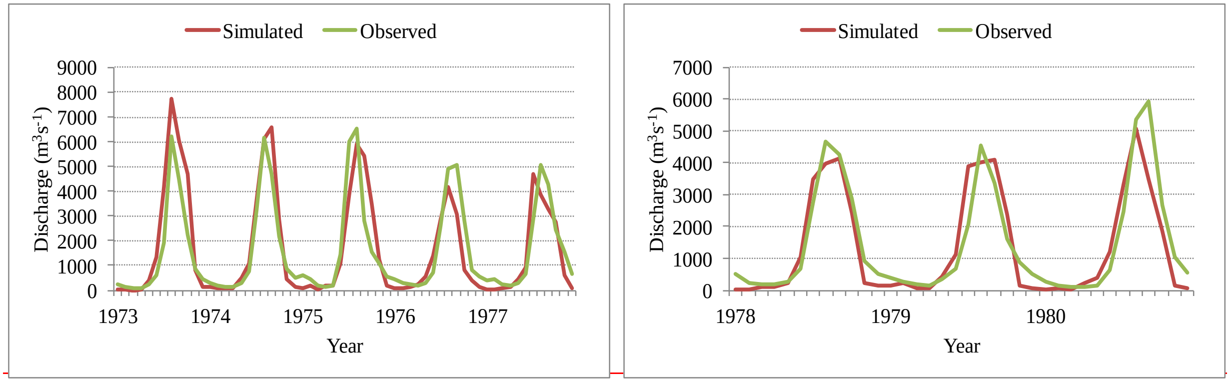


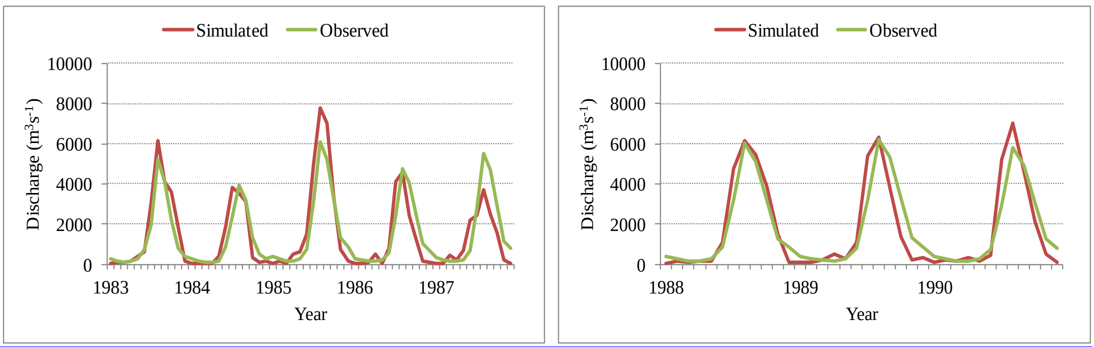
Figure 5: a) LULC composition, b) LULC change in the UBNRB during the period from 1973 to 2010

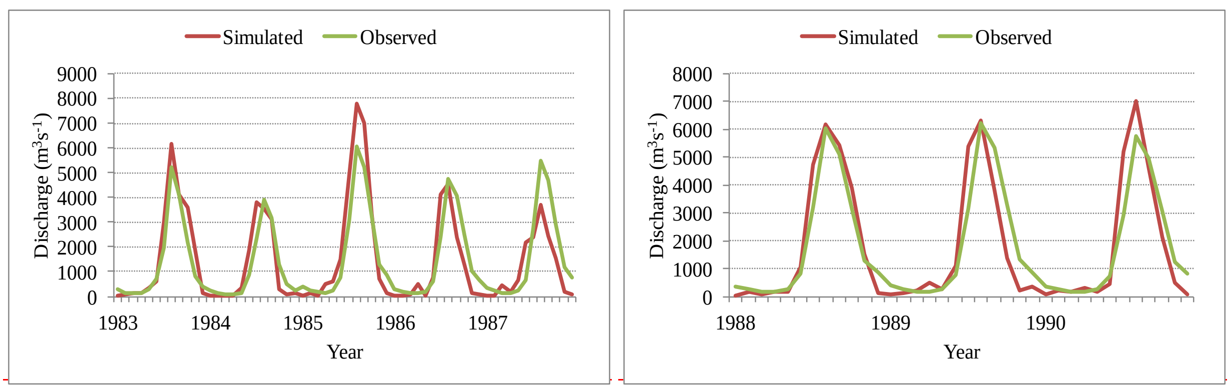
a)



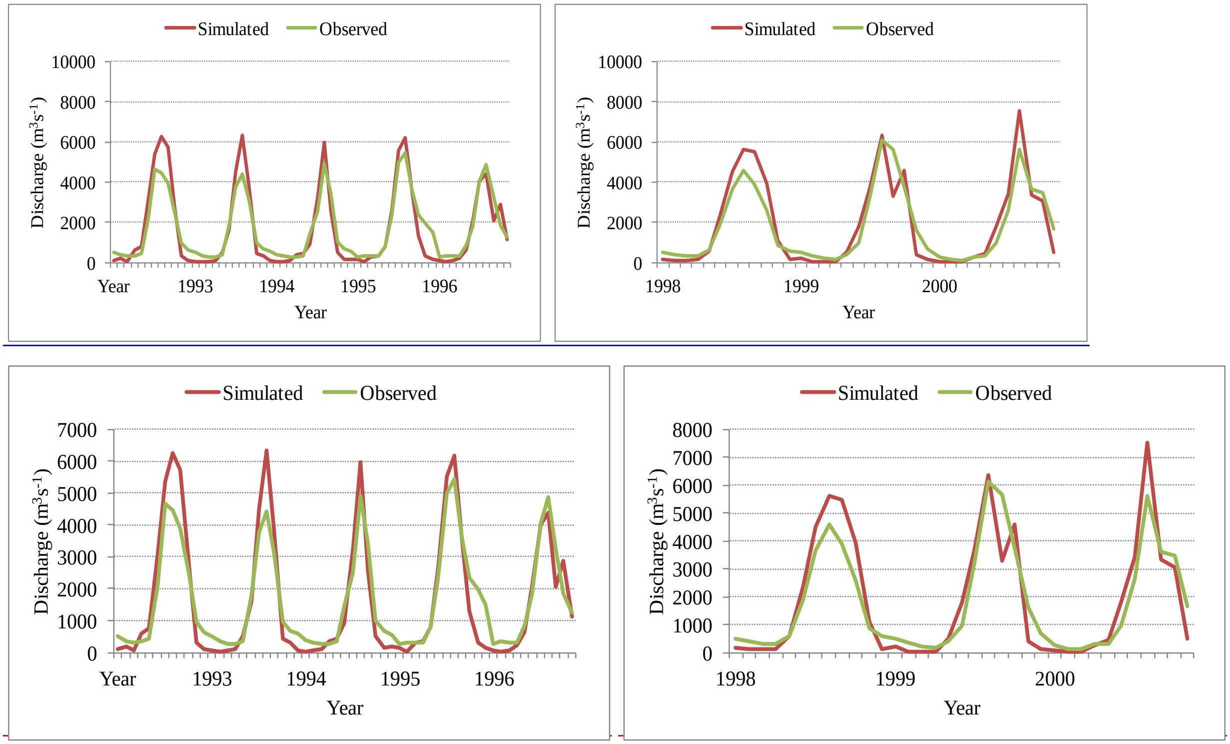

Simulated
Observed
Discharge (m^{3}s^{-1})
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1973
1974
1975
1976
1977
Year
Simulated
Observed
Discharge (m^{3}s^{-1})
0
1000
2000
3000
4000
5000
6000
7000
1978
1979
1980
Year

b)


Simulated
Observed
Discharge (m^{3}s^{-1})
0
2000
4000
6000
8000
10000
1983
1984
1985
1986
1987
Year
Simulated
Observed
Discharge (m^{3}s^{-1})
0
2000
4000
6000
8000
10000
1988
1989
1990
Year


Simulated
Observed
Discharge (m^{3}s^{-1})
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1983
1984
1985
1986
1987
Year
Simulated
Observed
Discharge (m^{3}s^{-1})
0
1000
2000
3000
4000
5000
6000
7000
8000
1988
1989
1990
Year

c)


Simulated
Observed
Discharge (m³s⁻¹)
Year
1993
1994
1995
1996
1998
1999
2000

d)

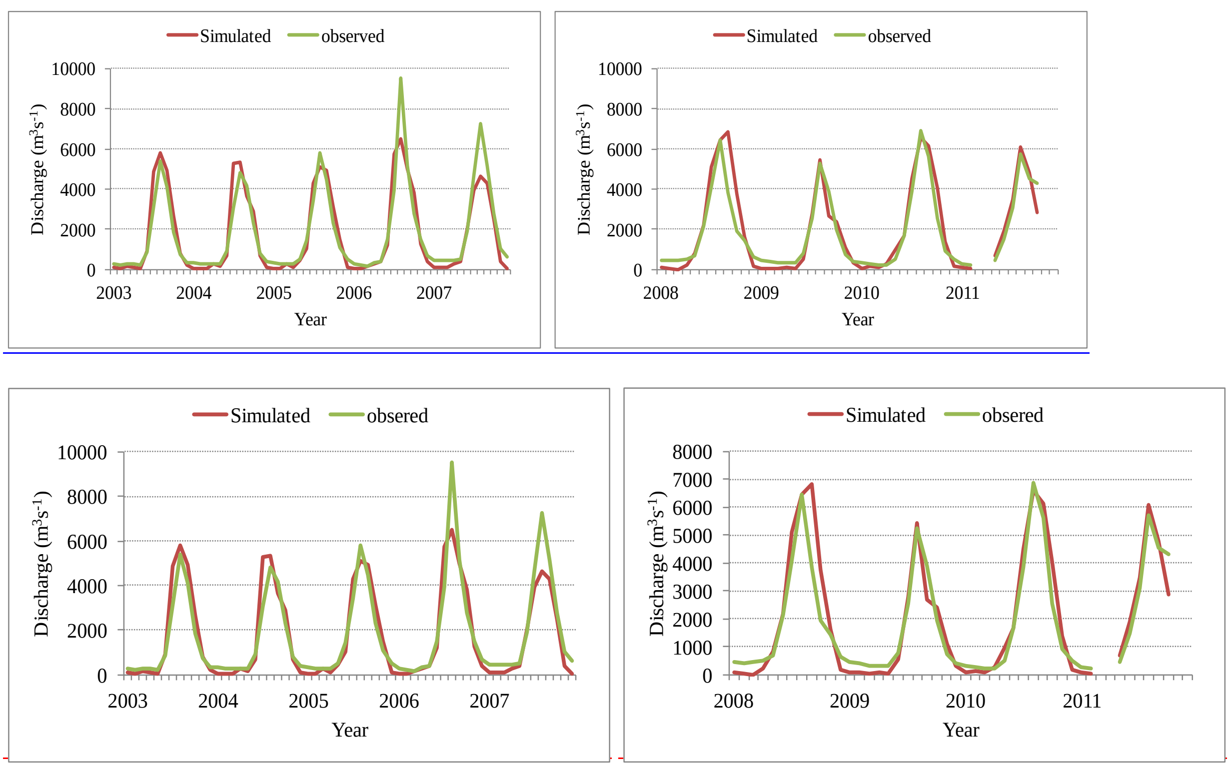
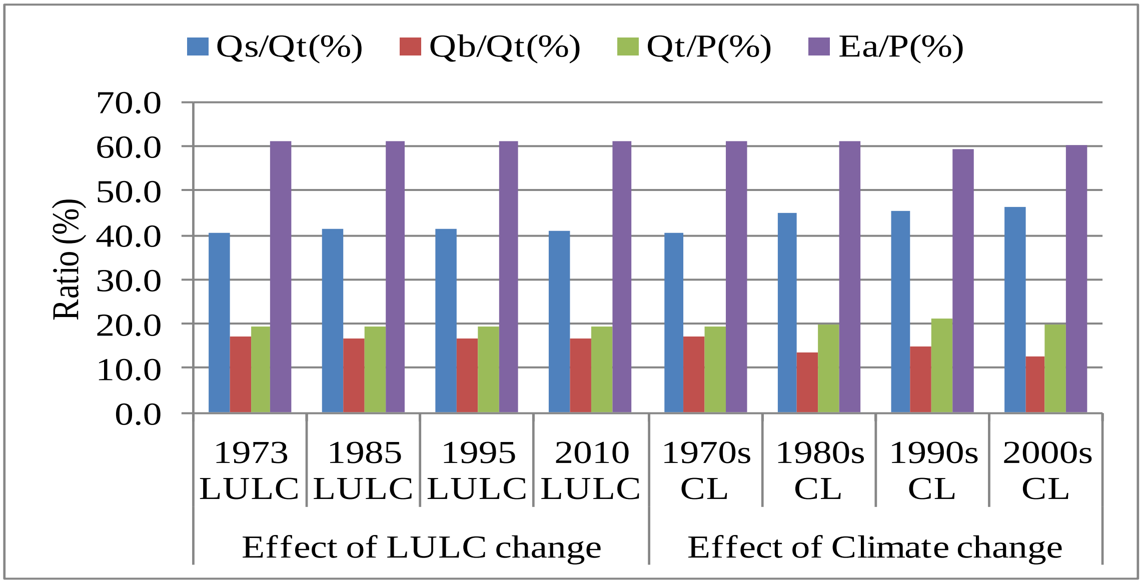

Simulated
observed
obsered
Discharge (m³s⁻¹)
Year
2003
2004
2005
2006
2007
2008
2009
2010
2011

Figure 6: Calibration and validation of the SWAT hydrological model (left and right) respectively a) 1970s, b) 1980s, c) 1990s and d) 2000s monthly time scale



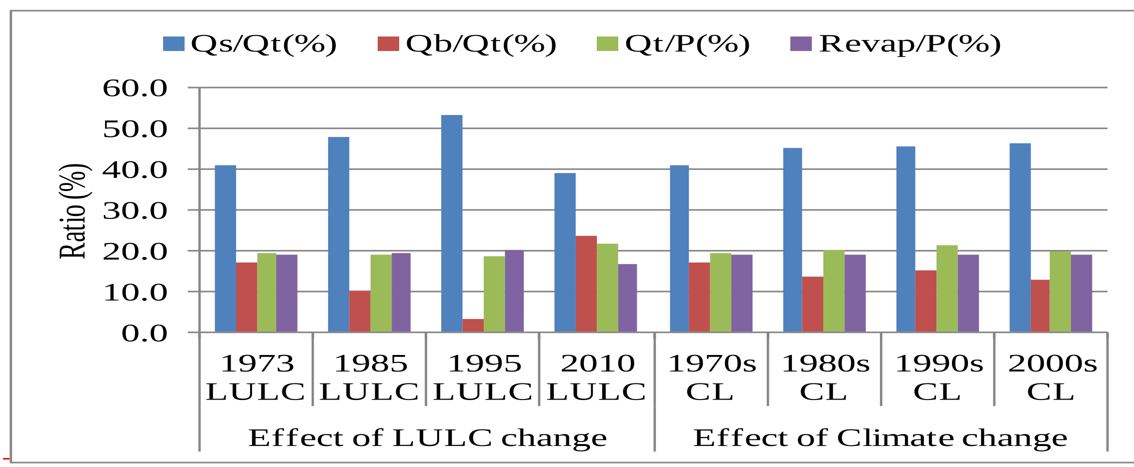


Figure 7: Ratio of water balance component analysis at El Diem station using a single effect (LULC/climate change).