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Discussions

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

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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 and will be corrected. We will add more necessary discussion as suggested in the revised manuscript,

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 will becorrected. We will add more necessary discussion on the suggested aspects in the revised manuscript.

As it is mentioned in the manuscript on page 4, L23/24, we used the following approaches to fill the gaps.

In this study, 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. (2017), 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 (R2) and Nash-Sutcliffe efficiency coefficient (NSE) between observed and estimated values for the target stations. Equally weighted statistical metrics is applied to compare the performance of selected approaches at target stations to establish ranking. A score was assigned to each candidate approach according to the individual metrics; e.g. the one achieving the smallest RMSE and MAE, or NSE, has got score 1, and so on. The final score is obtained by summing up the score pertained to each candidate approaches at each stations. The best method is the one having the smallest score.

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

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

3. 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 will revise 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 will explain the possible causes of these errors in the revised manuscript. 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 will correct the revised manuscript. 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 will be made for introduction part in the revised 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 . Major revision will be made for introduction section. In P1/L29, we mean the longest river.

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

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

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 we will correct as follows . "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 (2016) showed that the UBNRB has a mean areal annual rainfall of 1452 mm, and a mean annual minimum and maximum temperature of 11.4 oC

and 24.7 oC 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 we will correct the revised manuscript. We will add more necessary details and discussion as suggested. 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 we will delete the detail description of Mann Kendall test. We used the XLSTAT add-ins tool from excel (www.xlstat.com).

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 we will show the borders of the image in the revised manuscript. The following Table S02 presents an overview of all used Landsat images.

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 will be corrected. We wanted to say that no significant landcover change only on the points where we took GPS reading 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".

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

Reply from authors: accepted and will be corrected. We will add an explanation of the possible causes for the improvement of this study and disagreement with the previous studies, as shown here

We will add the following texts in the revised manuscript.

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.

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. 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.

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 will modify the manuscript accordingly. 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 we will extend the discussion.

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

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

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: accepted. We will add more necessary details and explanations in the revised manuscript.

It is true that the climate is changing especially temperature in the UBNRB. Studies carried out in the UBNRB such as Mengistu et al. (2014) confirmed that the annual 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. So, we will correct it in the revised manuscript.

In order to analyze the evaporation effects on streamflow associated to LULC change, we applied "A fixing -changing approach"(Yan et al., 2013). 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. 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. Moreover, the single effect of climate change on the streamflow showed that surface run-off increased and base flow decreased due to the increasing of rainfall intensity from 17.3 mm to 19.6 mm and extreme events (R20mm) from 15 days to 35 days during the period from 1970s to 2000s.

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 expansion of cultivated land and reduction of forest coverage increases surface runoff and reduce base flow and vies versa. Moreover, the increase of rainfall intensity and extreme rainfall events might increase surface runoff and reduce base flow. Surface water is not any more used for agriculture in areas where there is limited water storage facilities like UBNRB and therefore base flow is the reliable sources for irrigation to increase agricultural production. Hence, the increasing of surface water and reduction of base flow negatively affects the socio-economic developments of the basin. Hence, protecting and conserving the natural forests is highly recommended, not only for increasing the base flow available for irrigation but also reducing soil erosion because soil erosion is a function of surface run-off, which further increases the productivity, improve the livelihoods and regional water resource use cooperation. However, this study might have limitations due to the uncertainties of Landsat image classification and 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. 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 might improve the results. 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

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 will add more discussion on this regard. Please see our responses above. We hypothesized that the decreasing of (Qb/Qt) might be due to the increasing of forest coverage and decreasing of cultivated land. 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 means surface runoff generated will be increased while base flow is decreasing. 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, especially 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 labor 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 to be corrected as follows in the revised manuscript. Please see the modified Figure 1.

Figure 2: Years with commas.

Reply from authors: accepted and will be corrected in the revised manuscript. Please see the modified Figure 2. Figure 4: See main shortcomings.

Reply from authors: accepted. We tried to explain the sources of errors. 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 will be corrected in the revised manuscript. Please see the modified Figure 6.

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Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2017-685/hess-2017-685-AC3-supplement.pdf

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