# RESPONSES TO THE COMMENTS FROM REVIEWER 2

**Manuscript ID:** hess-2018-139
**Title:** Analysis of causes of decreasing inflow to the Lake Chad due to climate variability and human activities

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**General Comments:** In this manuscript the authors investigate the climatic variability and quantify the separate and combined impacts of human activities and climate change on the streamflow of Lake Chad basin from the period 1951-2015. They applied statistical trend tests and hydrological modeling. The results showed increasing trend in mean temperature, and decreasing signals in precipitation, with a decreasing trend of streamflow to Lake Chad. Furthermore, the impacts of human activities for the reduction of streamflow is more substantial than the impacts of climate variability. In general, the topic is scientifically challenging and is relevant for proper water resource management. The differentiation between climate impact and human impact on the river discharge into Lake Chad is performed in a rather simple way. A baseline period ("normal" climate before the detected breakpoint in 1971) is defined and the hydrological model is calibrated and validated for this period. For the remaining period up to present conditions the model is rum with the calibrated parameters. The deviation between the measured and the simulated hydrographs after the breakpoint is associated to human impact. This approach is intriguing, but has to be proved in a more rigorous way. Missing points are (see also my comments in the paper (pdf)): 1. Estimation of the uncertainty of the hydrological model (sensitivity of the parameters), 2. Interpolation and associated uncertainty of the meteorological input variables, 3. Cross checking of the results by incorporating the irrigation areas into the hydrological model. The conclusion that water transfer from the Congo River is the best solution is not scientifically proven. There are many other options in the framework of Integrated Water Resources Management. The authors should skip this conclusion (It is not part of the paper) and write a second paper about it.

**General Response**: We are grateful to the reviewer for his valuable comments which will greatly increase the quality of the manuscript. The manuscript is carefully revised and the comments have been incorporated. Some text about sensitivity analysis is incorporated in the methodology and results sections (Calibration and Validation). However, if you want to see more detail such as graphs and tables related to sensitivity of parameters we can include them in the next revision, but we think these will increase just the quantity. To consider spatial variability, we divided the basin into sub-basins, each sub-basin covers 3 grids of CRU data, on an average. So we think further interpolation is not required. However, as you suggest to incorporate some text about reliability and uncertainty of input data, the text has been added. Since the information about annual irrigation consumption and irrigation areas are not enough which can be utilized to simulate streamflow based on irrigation use for this long period from 1951-2015. However, we indirectly cross check with the study by Coe and Foley (2001), they used estimated irrigation data to simulate streamflow and to find the impacts of human and climate on the streamflow for 1983-1994, and our results are quite similar to their results.
On the whole, we have responded to your comments carefully here (as bellow) and in **hess-2018-139-RC2-supplement** as well as incorporated in the manuscripts and highlighted with yellow color. If something still need to address, we will be happy to incorporate in the next revision

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Note: For an easy follow up, the revised and incorporated comments are highlighted with the yellow color in the modified manuscript, for reviewer # 2.

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## RESPONSES TO THE SPECIFIC COMMENTS FROM REVIEWER #2

**Comment** 1: On page 5, L11-L12: monthly data of 11 meteorological (six for the period of 1950–2013 and other for 1985–2013) stations and 7 hydrometric stations (four for 1997–2007, two for 1951–2007, and one for 1951–2013) were collected from the Lake Chad Basin Commission (LCBC). However, on page 14, L6-L7, only the three stations of TM and PP were compared with CRU data for validation using statistical indicators. As the study area is very large, spatial variability is expected, and hence, validation of CRU data at three stations is not enough to capture the spatial variability.

**Response:** We greatly appreciate your comment that study area is large and spatial variability is expected. One thing, we were provided very limited meteorological stations, though more stations were available in the study area. Most of them were of very short period and starting from 1990s and not of good quality (especially missing values), even some years were missing in some data series. They provided only 4-time series of temperature. Secondly, we were needed long time series data starting from 1951 or ever before 1951 because we had to point out Change point year where we can divide data into two parts baseline (naturalized) period and impacted period. That's why, we choose that stations which were good quality and of long period. Due limitation of data, we decided to use CRU data because this data sets has been used confidently in different areas though out the world and also was composed of many climate variables which were needed for the study like precipitation, max, min and mean temperature, wet-day frequency etc.

**Revision:** No revision

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**Comment** 2: On page L26-L28, the surface area of LC is decreased from 25, 0000 km 2 to 300 km2 in the 1980s. Moreover, the lake was divided into two parts in 1975 because of devastating drought over the African Sahal belt. This showed that climatic variability has a great impact on the hydrology of the Lake Chad. However, the findings of this paper is different (i.e. on the hole, an average decrease of 40% was estimated due to climate variability and human activities for the period of 1972–2013, of which 66% of total decline was due to human activities and 34% due to climate). It is hardly possible to find a justification that can prove your model result. How do you explain this contradiction?

**Response:** You are right during 1980s, there was a devastating drought in the region and climate viability must have greater impact. Our results also showed that during 1982–1991 (Table 6), climate variability was the major factor causing decrease in flow. In Table 6, it is clearly described that during 1982–1991, climate variability has major impact (59%) in decreasing inflow to the lake.

However, on the whole, 66% of total decrease in flow was due to human activities for the period 1972–2013because after 1980s precipitation started increasing and human activities also started increasing.

**Revision:** No revision

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**Comment** 3. The potential impacts of irrigation projects are usually carried out during feasibility studies and detailed design of the irrigation fields. Please cite the outcome of these (governmental) studies and explain why the impact of the irrigation on discharge is higher than estimated.

**Response:** Thanks for your great suggestion. The focus of this study was to estimate general trends and to identify and quantify which factor (Climate or Human) causing more impacts on decreasing streamflow to the lake. The results of this study showed that after 1990, human activities played major role in decrease of streamflow. In the next study, we will consider comprehensively that which human activities such irrigation, dams, drinking, livestock contributing more impacts on the decreasing streamflow. The potential impacts of these human activities (especially, irrigation projects) will be carried out more comprehensively, in the next steps of this feasibility project.

**Revision:** No revision

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**Comment** 4: Deficit and constant loss method that you used for your HEC-HMS model is referred to as event model in the HEC-HMS technical reference manual on page 40. This event model simulates behavior of the hydrologic system during a precipitation event while soil moisture accounting loss model is a continuous model that simulates both wet and dry weather behavior. So, base flow simulation during the dry weather might be questionable in your model?

**Response:** The initial and constant (IC) loss method is the event based but Deficit and constant (DC) is a continuous loss method, this is extension of IC. It recovers moisture during the dry period between two precipitation events. Page 13 and 37 from Technical Reference Manual (2000) are attached below for your reference (http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Technical%20Reference%20Manual_(CPD-74B).pdf).

*Table 4. Runoff-volume models.*

| Model | Categorization |
|---|---|
| Initial and constant-rate | event, lumped, empirical, fitted parameter |
| SCS curve number (CN) | event, lumped, empirical, fitted parameter |
| Gridded SCS CN | event, distributed, empirical, fitted parameter |
| Green and Ampt | event, distributed, empirical, fitted parameter |
| Deficit and constant rate | continuous, lumped, empirical, fitted parameter |
| Soil moisture accounting (SMA) | continuous, lumped, empirical, fitted parameter |
| Gridded SMA | continuous, distributed, empirical, fitted parameter |

*Table 5. Direct-runoff models.*

| Model | Categorization |
|---|---|
| User-specified unit hydrograph (UH) | event, lumped, empirical, fitted parameter |
| Clark's UH | event, lumped, empirical, fitted parameter |
| Snyder's UH | event, lumped, empirical, fitted parameter |
| SCS UH | event, lumped, empirical, fitted parameter |
| ModClark | event, distributed, empirical, fitted parameter |
| Kinematic wave | event, lumped, conceptual, measured parameter |
| User-specified unit hydrograph (UH) | event, lumped, empirical, fitted parameter |

*Table 6. Baseflow models.*

| Model | Categorization |
|---|---|
| Constant monthly | event, lumped, empirical, fitted parameter |
| Exponential recession | event, lumped, empirical, fitted parameter |
| Linear reservoir | event, lumped, empirical, fitted parameter |

The choices for modeling channel flow with HEC-HMS are listed in Table 7. These so-called routing models simulate one-dimensional open channel flow.

*Table 7. Routing models.*

| Model | Categorization |
|---|---|
| Kinematic wave | event, lumped, conceptual, measured parameter |
| Lag | event, lumped, empirical, fitted parameter |
| Modified Puls | event, lumped, empirical, fitted parameter |
| Muskingum | event, lumped, empirical, fitted parameter |
| Muskingum-Cunge Standard Section | event, lumped, quasi-conceptual, measured parameter |
| Muskingum-Cunge 8-point Section | event, lumped, quasi-conceptual, measured parameter |
| Confluence | continuous, conceptual, measured parameter |
| Bifurcation | continuous, conceptual, measured |

*Table 11.* *SCS soil groups and infiltration (loss) rates* (SCS, 1986; Skaggs and Khaleel, 1982)

| Soil Group | Description | Range of Loss Rates (in/hr) |
|---|---|---|
| A | Deep sand, deep loess, aggregated silts | 0.30-0.45 |
| B | Shallow loess, sandy loam | 0.15-0.30 |
| C | Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay | 0.05-0.15 |
| D | Soils that swell significantly when wet, heavy plastic clays, and certain saline soils | 0.00-0.05 |

## Deficit and Constant Loss Model

The program also includes a quasi-continuous variation on the initial and constant model of precipitation losses; this is known as the deficit and constant loss model. This model is different from the initial and constant loss model in that the initial loss can "recover" after a prolonged period of no rainfall. [This model is similar to the loss model included in computer program HEC-IFH (HEC, 1992).]

To use this model, the initial loss and constant rate plus the recovery rate must be specified. The moisture deficit is tracked continuously, computed as the initial abstraction volume less precipitation volume plus recovery volume during precipitation-free periods. The recovery rate could be estimated as the sum of the evaporation rate and percolation rate, or some fraction thereof.

## SCS Curve Number Loss Model

### Basic Concepts and Equations

The Soil Conservation Service (SCS) Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \qquad (15)$$

where $P_e$ = accumulated precipitation excess at time $t$; $P$ = accumulated rainfall depth at time $t$; $I_a$ = the initial abstraction (initial loss); and $S$ = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation. Until the accumulated rainfall exceeds the initial abstraction, the precipitation excess, and hence the runoff, will be zero.

From analysis of results from many small experimental watersheds, the SCS developed an empirical relationship of $I_a$ and $S$:

$$I_a = 0.2\,S \qquad (16)$$

Therefore, the cumulative excess at time $t$ is:

Fig. 1. Page 13 and 37 of Techinical Reference manual, showing that this method is continuous moisture counting.

**Revision:** No revision

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**Comment** 5: HEC-HMS model is a lumped model in which spatial variations are averaged or ignored. Hence, the application of HEC-HMS for such large area (967,000 km2) considering the same landcover, soil type and other catchment characteristics might have an effect on the result.

**Response:** I greatly welcome your comment. HEC-HMS can be used as lumped model, semi-distributed or fully distributed model. In the present study, we have used semi-distributed form of this model, where we divided the large area into small sub-basins, as shown in Figure 2, to consider the spatial variability of Land use land cover in the basin. However, these land use land cover were kept constant through the simulation period, as a limitation for land use data availability throughout the period.

**Revision:** No revision

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**Comment** 6: Why human impact becoming dominant for the decreasing of the streamflow? How much water is extracted for irrigation will help to understand the implication of separate human activities as recommended by this manuscript. The role of evapotranspiration combination of both human and climate variability is also missing.

**Response:** I greatly appreciate your comment. Human becoming dominant because after 1960s–1970s, population in the basin increased extensively (1960 ($13 \times 10^6$) to 1990 ($26 \times 10^6$), as mention in the manuscript (ms), which causes increase in irrigation water consumption in the basin, consumption for drinking and livestock too. Different dams were constructed in the basins for rice irrigation along the Chari-Logone River basin (Maga, $625\times 10^6$ $m^3$, Mokolo $5\times 10^6$ $m^3$, Tourour $8\times 10^5$ $m^3$, Oumbeda $1.44\times 10^5$ $m^3$), all these constructed after 1970s (Komble et al. 2016). Unfortunately, in-situ annual consumption for irrigation are not available in the Chari-Logone basin and even in whole basin, or might not be documented completely in English version. Moreover, not much information is available on FAO AQUASTAT for the countries located in the Chad basin. However, Coe and Foley (2001) used estimations for two periods in their study, they used estimation of irrigation water consumption for Chari-Logone basin as 2.5 $km^3$ for 1965-1977 and 10 $km^3$ for 1990–1991. The later estimation (10 $km^3$) was also used in Gao et al. (2011) in their studies. We can consider irrigation as major factor in reduction in streamflow because irrigation requirements have increased as estimated by Coe and Foley (2001) in two different periods. Since a complete and accurate water uses not fully documented for the basin that is why we used a subjective term, human activities. However, further study can be done exploring major human activities separately like irrigation, dam construction, evapotranspiring, local farming, small ponding along the river which can cause reduction in stream flow.

**Revision:** No revision

## Responses to the Minor comments

a) Description of study area is too much and there is a redundancy in different section of the manuscript which sometimes confused to understand.

**Response:** Description of study area is modified carefully described and redundancy is remove from the introduction part.

b) On page 2, L21....only in the last century (906-2015).. what is 906??

**Response:** Typo error is corrected as 1906-2005

c) On page 2, L30...1973-105... "105" may be error

**Response:** Typo error is corrected as 1973-1975

d) In the manuscript the word "streamflow"; " flow" and "runoff" used interchangeably. So, better to used one word consistently

**Response:** We decided to use streamflow

e) time period for analysis is not consistent for instance, 1951-2015, 1951-2016, 1951-2013....

**Response:** 1951–2015 was used for precipitation and temperature, and 1951–2013 period was used for flow data because the flow data was provided for this period.

f) On page 6, L16 911000 km2 is mentioned which is different from 967000km2

**Response:** 967000 km2 is the whole conventional basin while 911,000km2 is the study area as shown in Fig. 1. More clarification is provided in the study area

g) On page 6, L26-L27, for each subbasin, meteorological variables were obtained by taking the average of all CRU grids covering that basin. How do you deal about the spatial variability of the climate? why not used some interpolation techniques?

**Response:** To deal with the spatial variability, we divided the whole basin into small sub-basins. Each sub-basin on average contains 3 (1–5) grids of CRU data and we take average of these grids (3 grids on average). The variation of climate variables within each sub-basins is not so much.

h) Figure 3 is not clear, needs improvement

**Response:** Figure 3 has been improved

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