

## **Response to comments of Reviewers**

**Manuscript doi:**10.5194/hess-2017-189, 2017

**Title:** Spatial Extent of Future Changes in the Hydrologic Cycle Components in Ganga Basin using Ranked CORDEX RCMs

5 **Authors:** Jatin Anand, Manjula Devak, Ashvani Kumar Gosain, Rakesh Khosa and Dhanya C.T.

We would like to express our gratitude to the referees for constructive and helpful comments. We have revised the manuscript based on these comments and hope that the revised manuscript reads better and is acceptable. Our specific responses to the reviewer's comments are given below.

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### **Response to Comments of Reviewer #2**

**Comment:** For example, what are the reasons for using SWAT?

15 **Response:** As rightly mentioned by the reviewer, a wide range of hydrological models are available (e.g., SWAT, VIC, TOPMODEL etc.). However, SWAT is deployed in the present study, due to its widely-known versatility. Arnold et al. (1999) in his study used SWAT model to simulate the entire U.S.A. for river discharges at around 6000 gauging stations. Gosain et al., (2006) modeled twelve large river catchments in India with the purpose of quantifying the climate change impact on hydrology. Faramarzi et al., (2013) used the African model to study the impact of climate change in Africa. Abbaspour et al., (2015) simulated hydrology and water quality for entire Europe. Also, the larger capacity of ArcGIS now allows building finer resolution large-scale models, which could be calibrated using powerful parallel processing (Rouholahnejad et al., 2012). It includes a snow module, permitting the delimitation of up to ten elevation bands with associated precipitation and temperature lapse rates (Fontaine et al., 2002; Rahman et al., 2013). Also, SWAT allows users to define simulation of irrigation water on cropland on the basis of five alternative sources: stream reach, reservoir, shallow aquifer, deep aquifer, or a water body source external to the watershed (Gassman et al., 2007). In addition to it, SWAT provide the users Reservoir operation and inclusion of domestic water demands, which other models lack. Furthermore, SWAT allows the users to limit the size of catchment based on the gauge and reservoir sites, which the other grid based models lack and is an important factor considering the size of the basin. The wide range of SWAT applications, underscores that the model is a very flexible and robust tool that can be used to simulate a variety of watershed problems. Moreover, the process of developing SWAT model for a given watershed has also been significantly facilitated by the development of GIS-based interfaces, which provide a direct means of translating digital topographic, land use, and soil data into model inputs. Also, it is an open source code which ensures the improvement in the simulation accuracy of key processes.

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**Manuscript is revised by adding the following lines. Vide Pg. 7, lines 11-18 of the revised manuscript.**

40 *“SWAT has inbuilt snow module to capture and simulate snowmelt hydrology, permitting the delimitation of up to ten elevation bands with associated precipitation and temperature lapse rates (Fontaine et al., 2002; Rahman et al., 2013). In addition, SWAT allows users to add lapse rate for both precipitation (PLAPS) and temperature (TLAPS) which is very essential in the study region considered. In this study, sub-basin has been divided into ten*

elevation bands. Furthermore, in SWAT the date and net volume of irrigation water can be set according to the actual condition along with the irrigation water source (surface rivers, reservoirs or groundwater, etc). Also, the domestic, ecological and industrial water in the model can be added in the model as “consumptive use water”.”

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**Comment:** Why was RCP4.5 used?

10 **Response:** In the IPCC 4th Assessment Report, the emission scenarios were fabricated in view of the storylines that were gathered into an all the more financially concerned advancement or a more ecological and sustainable advancement, and into a more globalized world or an all the more regionally developing world. While, In the IPCC 5th Assessment Report, the scenarios are based on total anthropogenic radiative forcings towards the end of the 21st century. Economic models can take diverse ways to achieve distinctive radiative forcings that are  
15 equivalent to distinctive concentration paths of the greenhouse gases, the so-called Representative Concentration Pathway scenarios (RCPs). The different scenarios are marked as: RCP 8.5, RCP 4.5 and RCP 2.6, which correspond to radiative forcings of  $8.5 \text{ Wm}^{-2}$ ,  $4.5 \text{ Wm}^{-2}$ , and  $2.6 \text{ Wm}^{-2}$ , respectively. The first RCP is the most skeptical and results in a worldwide warming towards the end of the 21st century of about  $4^\circ\text{C}$ , whereas the last RCP is the most optimistic and corresponds to a global warming of about  $1^\circ\text{C}$ . Then again, RCP 4.5 can be  
20 reasoned as neither extreme (RCP 8.5), nor mild (RCP 2.5); but the moderate degree scenario, which can be helpful in capturing the average response of the catchment. The RCP 4.5 resembles around to B1 scenario in IPCC 4th Assessment Report, the radiative forcing increases almost linearly up to about the year 2060 and then slows down the increase rate until the end of the century where it stabilizes. Moreover, the forcing pathway of the RCP4.5 scenario is similar to a several climate policy situations and numerous low-emissions reference  
25 conditions, such as the SRES B1 scenario. In this work, the results are shown for RCP 4.5 scenario.

**Manuscript is revised by adding the following lines. Vide Pg. 6, lines 8-26 of the revised manuscript.**

*In the IPCC 4th Assessment Report, the emission scenarios were fabricated in view of the storylines that were gathered into an all the more financially concerned advancement or a more ecological and sustainable  
30 advancement, and into a more globalized world or an all the more regionally developing world. While, In the IPCC 5th Assessment Report, the scenarios are based on total anthropogenic radiative forcings towards the end of the 21st century. Economic models can take diverse ways to achieve distinctive radiative forcings that are equivalent to distinctive concentration paths of the greenhouse gases, the so-called Representative Concentration Pathway scenarios (RCPs). The different scenarios are marked as: RCP 8.5, RCP 4.5 and RCP 2.6, which  
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40 IPCC 4th Assessment Report, the radiative forcing increases almost linearly up to about the year 2060 and then*

slows down the increase rate until the end of the century where it stabilizes. Apparently, RCP 4.5 is a stabilization scenario in which total radiative forcing is stabilized just after 2100, without exceeding the long-run radiative forcing target level. Moreover, the forcing pathway of the RCP4.5 scenario is similar to a several climate policy situations and numerous low-emissions reference conditions, such as the SRES B1 scenario (Wise et al., 2009).

5 Thus, in this study, RCP 4.5 scenario is adopted to study the impact of climate change on the different hydrologic components and the results are shown for the same. ^

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10 **Comment:** Why were the RCMs evaluated on the basis of streamflow and not precipitation?

**Response:** Streamflow is an important component for ensuring proper management and ensuring sustainable use of water wealth. However, just analysing precipitation and temperature does not give us the complete picture of the inherent hydrology of the basin. As, just determining the increase or decrease in the precipitation and  
15 temperature doesn't provide any information whatsoever about the streamflow being generated or for that matter how much recharge that may happen or how much evapotranspiration occurred in the watershed. While, all the stakeholders and managers and policy makers are more likely to be interested on the availability of water for that matter. Moreover, other important hydrological components such as recharge and base flow can't be figured out just by analysing the precipitation. Also, ET can be an important factor when assessing the hydrological  
20 characteristic of the basin. Hence, it was necessary to rank the RCMs based on the end product, i.e. streamflow. Here, we tried to establish which RCM performed better in mimicking the hydrology of the basin (surface runoff in this case – the only observed variable). The comparison with respect to observed runoff, however, indirectly take into account the precipitation characteristics also, since all the other parameters used in the model are same.

25 **Manuscript is revised by adding the following lines. Vide Pg. 12, lines 7-13 of the revised manuscript.**

“SWAT model developed for Ganga river basin is calibrated manually by following a systematic approach (Arnold et al., 2012). At first, upstream gauge is calibrated and the parameters corresponding to that gauge site are kept constant while the parameters of the sub-basins between upstream gauge and the next downstream gauge site is calibrated. The same approach was repeated for the next downstream stations till we reach the outlet of  
30 the catchment (Farakka). Once the model has been established competent enough to mimic the hydrology of the entire basin, then it is simulated using the outputs from different RCMs, using same set of calibrated parameters.”

**Manuscript is revised by adding the following lines. Vide Pg. 16, lines 6-9 of the revised manuscript.**

35 “The ranking of RCMs is done to establish, which RCM performed better in mimicking the hydrology of the basin (surface runoff in this case – the only observed variable). The comparison with respect to observed runoff, however, indirectly take into account the precipitation characteristics also, since all the other parameters used in the model are same.”

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**Comment:** The hydrological model has been calibrated with discharge measurements at various points on the Ganga and its tributaries. However, this river system is both highly regulated by surface water infrastructure and strongly influenced by anthropogenic activities within the basin. Clearly the assumption that such factors are stationary is false (as the authors acknowledge), which leads me to question the validity and utility of projections of surface runoff using this approach. This should be discussed in more detail.

**Response:** The authors agree with the reviewer comment that the river system is highly regulated by surface water infrastructure and strongly influenced by anthropogenic activities. Also, the authors agree that the stationarity is not going to be there in terms of how the available water is going to be utilized in the basin. However, the authors would like to add that to determine the way the available water is going to be utilised in the basin is beyond the scope of the study. For example, the irrigation efficiency at present in India hovers around 0.35-0.45, but that can't be said to be keep on continuing as farmers are getting things automated and adopting the new and advanced practices that are currently available. Moreover, the cropping pattern in this region is quite unpredictable where few decades back there was no paddy crops grown in the Punjab and Haryana (western region of the basin) part, but has become a dominant grown crop by leap and bounds and requires huge amount of water. Also, the basin has seen the farmers moving from food crops to cash crops that have considerable impact on the seasonal availability of water. Then again, there is a continuous increase in industrial demand which cannot be pre-determined as the numbers as well as source keeps on changing.

Thus, it can be safely said that the results obtained is the most optimistic one and suffice the main objective of the study i.e. to determine the available water in the wake of changing climate and remind the policy makers and stakeholders to make the management policy for sustainable management of water before the things change for the worse.

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**Comment:** Further, the authors do not really justify their choice of SWAT. Why not a process-based, distributed model such as VIC, which has previously been used to assess hydrological change in the Ganga basin (e.g. Chawla and Mujumdar (2015), who also consider land use change)?

**Response:** As rightly mentioned by the reviewer, a wide range of hydrological models are available (e.g., SWAT, VIC, TOPMODEL etc.). However, SWAT is deployed in the present study, due to its widely-known versatility. Arnold et al. (1999) in his study used SWAT model to simulate the entire U.S.A. for river discharges at around 6000 gauging stations. Gosain et al., (2006) modeled twelve large river catchments in India with the purpose of quantifying the climate change impact on hydrology. Faramarzi et al., (2013) used the African model to study the impact of climate change in Africa. Abbaspour et al., (2015) simulated hydrology and water quality for entire Europe. Also. the larger capacity of ArcGIS now allows building finer resolution large-scale models, which could be calibrated using powerful parallel processing (Rouholahnejad et al., 2012). It includes a snow module, permitting the delimitation of up to ten elevation bands with associated precipitation and temperature lapse rates (Fontaine et al., 2002; Rahman et al., 2013). Also, SWAT allows users to define simulation of irrigation water on cropland on the basis of five alternative sources: stream reach, reservoir, shallow aquifer, deep aquifer, or a water

body source external to the watershed (Gassman et al., 2007) which is not possible in the other models. In addition to it, SWAT provide the users Reservoir operation and inclusion of domestic water demands, which other models lack. Furthermore, SWAT allows the users to limit the size of catchment based on the gauge and reservoir sites, which the other grid based models lack and is an important factor considering the size of the basin. The wide range of SWAT applications, underscores that the model is a very flexible and robust tool that can be used to simulate a variety of watershed problems. Moreover, the process of developing SWAT model for a given watershed has also been significantly facilitated by the development of GIS-based interfaces, which provide a direct means of translating digital topographic, land use, and soil data into model inputs. Also, it is an open source code which ensures the improvement in the simulation accuracy of key processes.

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**Comment:** What is the reason for choosing to rank RCMs according to surface runoff? In my opinion the performance of RCMs should be evaluated using precipitation. Do the same three models perform best if you use precipitation, not surface runoff, for evaluation purposes?

15

**Response:** Once the model has been established competent enough to mimic the hydrology of the entire basin, then it is simulated using the outputs from different RCMs, using same set of calibrated parameters. Here, we tried to establish which RCM performed better in mimicking the hydrology of the basin (surface runoff in this case – the only observed variable). The comparison with respect to observed runoff, however, indirectly take into account the precipitation characteristics also, since all the other parameters used in the model are same.

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25

*“SWAT model developed for Ganga river basin is calibrated manually by following a systematic approach (Arnold et al., 2012). At first, upstream gauge is calibrated and the parameters corresponding to that gauge site are kept constant while the parameters of the sub-basins between upstream gauge and the next downstream gauge site is calibrated. The same approach was repeated for the next downstream stations till we reach the outlet of the catchment (Farakka). Once the model has been established competent enough to mimic the hydrology of the entire basin, then it is simulated using the outputs from different RCMs, using same set of calibrated parameters.”*

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**Comment:** Throughout the manuscript the authors attribute some of the change in surface runoff to changes in snowmelt. While snowmelt is undoubtedly an important factor in the Himalayas, I cannot imagine the relative contribution in, say, Farakka is very high. Maybe I'm wrong, but in any case the authors must first quantify the contribution of snowmelt to surface runoff and place any discussion of the impact of changes in snowmelt in this context.

**Response:** The quantification of snowmelt to snowmelt to surface runoff has been done and also impact of changes in snowmelt has been quantified (Figure S1 in supplementary material). The authors agree that the relative contribution at Farakka is very small but in the context of snow dominant and areas downstream to it is very essential.

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**Comment:** Since the aim of the paper is to assess the spatial extent of future changes in hydrology it should quantify the relative contribution of various hydrological processes to streamflow at different points in the basin. This would be an interesting study. Presently, however, readers are left with little understanding about the reason for the spatial variability in surface runoff apart from the precipitation pattern.

**Response:** Thanks for bringing this into the notice of the authors. Requisite changes are made during the manuscript revision. Results pertaining to the quantitative assessment of the different hydrologic components for different tributaries of Ganga basin has been added in Section 6.4 (Pg. 26)

**Manuscript is revised by adding the following lines. Vide Pg. 26, lines 4-11 of the revised manuscript.**

*“Apparently, in the order to tackle the water management issues proficiently, it is important to quantify and analyze the different hydrologic components within the basin for different system. Water balance is an important component in SWAT model as it involves all the processes happening within the watershed area (Fletcher et al., 2013; Shawul et al., 2013). The analysis of the results projected by RCA4 (CNRM-CERFACS) for the different systems of Ganga river basin show that the water yield and evapotranspiration has the major share in the water balance (Figure 13). Further examination of results reveal that the Upper Ganga River System (Upstream of Allahabad) have made the largest contribution to the water yield in the catchment while Chambal and Sindh river systems have the lowest contribution in the total water yield (Figure 13).”*



Figure 13. Annual water balance components for major tributaries of the Ganga river basin projected by RCA4 (CNRM-CERFACS)

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**Comment:** Page 2, line 18: “The imbalance between the water demands and water supply has been increasing of late due to change in climate”

**Response:**

10 **Sentence is modified in the revised manuscript, as follows. Vide Pg. 2, lines 18-20 of the revised manuscript.**  
*“Moreover, the imbalance between the water demands and water supply has been increasing of late due to change in climate and rapid urbanization (Alsharhan and Wood, 2003; Guo et al., 2002; Kahya and Kalaycı, 2004).”*

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15 **Comment:** Page 2, line 34: This is the first mention of objectives. Perhaps they could be stated explicitly beforehand.

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20 **Comment:** Page 4, line 1: “Furthermore, the Ganga river basin is highly governed by snowfall accumulation and snowmelt processes within the catchment” – This

**Response:**

**Sentence is modified in the revised manuscript, as follows. Vide Pg. 4, lines 2-3 of the revised manuscript.**

25 *“Furthermore, the Northern part of the basin is highly governed by snowfall accumulation and snowmelt processes within the catchment.”*

-----X-----X-----

**Comment:** The following claim, that “snowmelt processes provide most of the surface water during non-monsoon season” is at best misleading and should be explained further.

5 **Response:**

**Sentence is modified in the revised manuscript, as follows. Vide Pg. 4, lines 3-5 of the revised manuscript.**

*“Since snowmelt processes is one of the major contributor to the surface water during non-monsoon season in this region of the basin, its monitoring is important in hydrologic simulations.”*

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**Comment:** Page 4, line 25: “The primary sources of water in the river are precipitation, base flow, and snowmelt water from the Himalayas” - again, this statement fails to recognise that the relative importance of these sources changes as the river moves downstream. Meltwater may well be an important component of discharge in Rishikesh or Haridwar, but in Patna or Farukka, say, I would imagine it’s contribution would be very small. In any case the contribution of the various hydrological processes should be quantified.

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**Response:** Thanks for bringing this into the notice of the authors. Requisite changes are made during the manuscript revision. Results pertaining to the quantitative assessment of the different hydrologic components for different tributaries of Ganga basin has been added in Section 6.4 (Pg. 26)

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Figure 13. Annual water balance components for major tributaries of the Ganga river basin projected by RCA4 (CNRM-CERFACS)

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**Comment:** Page 4, line 19: This section essentially repeats what you have said in the final paragraph of the Introduction, and could be removed.

**Response:** Suggested change has been made in the revised manuscript.

10 -----X-----X-----

**Comment:** Page 6, Table 1: Use consistent units for spatial resolution (e.g. SRTM @ 3 arc second, soil @ 5 arc minute, etc.)

**Response:** Suggested change has been made in the revised manuscript.

15 -----X-----X-----

**Comment:** Page 6, line 5: Explain why RCP 4.5 was chosen.

**Response:** In the IPCC 4th Assessment Report, the emission scenarios were fabricated in view of the storylines that were gathered into an all the more financially concerned advancement or a more ecological and sustainable advancement, and into a more globalized world or an all the more regionally developing world. While, In the IPCC 5th Assessment Report, the scenarios are based on total anthropogenic radiative forcings towards the end of the 21st century. Economic models can take diverse ways to achieve distinctive radiative forcings that are equivalent to distinctive concentration paths of the greenhouse gases, the so-called Representative Concentration Pathway scenarios (RCPs). The different scenarios are marked as: RCP 8.5, RCP 4.5 and RCP 2.6, which correspond to radiative forcings of  $8.5 \text{ Wm}^{-2}$ ,  $4.5 \text{ Wm}^{-2}$ , and  $2.6 \text{ Wm}^{-2}$ , respectively. The first RCP is the most skeptical and results in a worldwide warming towards the end of the 21st century of about  $4^\circ\text{C}$ , whereas the last

RCP is the most optimistic and corresponds to a global warming of about 1°C. Then again, RCP 4.5 can be reasoned as neither extreme (RCP 8.5), nor mild (RCP 2.5); but the moderate degree scenario, which can be helpful in capturing the average response of the catchment. The RCP 4.5 resembles around to B1 scenario in IPCC 4th Assessment Report, the radiative forcing increases almost linearly up to about the year 2060 and then slows down the increase rate until the end of the century where it stabilizes. Moreover, the forcing pathway of the RCP4.5 scenario is similar to a several climate policy situations and numerous low-emissions reference conditions, such as the SRES B1 scenario. In this work, the results are shown for RCP 4.5 scenario.

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“In the IPCC 4th Assessment Report, the emission scenarios were fabricated in view of the storylines that were gathered into an all the more financially concerned advancement or a more ecological and sustainable advancement, and into a more globalized world or an all the more regionally developing world. While, In the IPCC 5th Assessment Report, the scenarios are based on total anthropogenic radiative forcings towards the end of the 21st century. Economic models can take diverse ways to achieve distinctive radiative forcings that are equivalent to distinctive concentration paths of the greenhouse gases, the so-called Representative Concentration Pathway scenarios (RCPs). The different scenarios are marked as: RCP 8.5, RCP 4.5 and RCP 2.6, which correspond to radiative forcings of  $8.5 \text{ Wm}^{-2}$ ,  $4.5 \text{ Wm}^{-2}$ , and  $2.6 \text{ Wm}^{-2}$ , respectively. The first RCP is the most skeptical and results in a worldwide warming towards the end of the 21st century of about 4°C, whereas the last RCP is the most optimistic and corresponds to a global warming of about 1°C. Then again, RCP 4.5 can be reasoned as neither extreme (RCP 8.5), nor mild (RCP 2.5); but the moderate degree scenario, which can be helpful in capturing the average response of the catchment. The RCP 4.5 resembles around to B1 scenario in IPCC 4th Assessment Report, the radiative forcing increases almost linearly up to about the year 2060 and then slows down the increase rate until the end of the century where it stabilizes. Apparently, RCP 4.5 is a stabilization scenario in which total radiative forcing is stabilized just after 2100, without exceeding the long-run radiative forcing target level. Moreover, the forcing pathway of the RCP4.5 scenario is similar to a several climate policy situations and numerous low-emissions reference conditions, such as the SRES B1 scenario (Wise et al., 2009). Thus, in this study, RCP 4.5 scenario is adopted to study the impact of climate change on the different hydrologic components and the results are shown for the same.”

-----X-----X-----

**Comment:** Page 7, Model description: Explain why SWAT was chosen.

**Response:** As rightly mentioned by the reviewer, a wide range of hydrological models are available (e.g., SWAT, VIC, TOPMODEL etc.). However, SWAT is deployed in the present study, due to its widely-known versatility. Arnold et al. (1999) in his study used SWAT model to simulate the entire U.S.A. for river discharges at around 6000 gauging stations. Gosain et al., (2006) modeled twelve large river catchments in India with the purpose of quantifying the climate change impact on hydrology. Faramarzi et al., (2013) used the African model to study the impact of climate change in Africa. Abbaspour et al., (2015) simulated hydrology and water quality for entire Europe. Also. the larger capacity of ArcGIS now allows building finer resolution large-scale models, which could

be calibrated using powerful parallel processing (Rouholahnejad et al., 2012). It includes a snow module, permitting the delimitation of up to ten elevation bands with associated precipitation and temperature lapse rates (Fontaine et al., 2002; Rahman et al., 2013). Also, SWAT allows users to define simulation of irrigation water on cropland on the basis of five alternative sources: stream reach, reservoir, shallow aquifer, deep aquifer, or a water body source external to the watershed (Gassman et al., 2007). In addition to it, SWAT provide the users Reservoir operation and inclusion of domestic water demands, which other models lack. Furthermore, SWAT allows the users to limit the size of catchment based on the gauge and reservoir sites, which the other grid based models lack and is an important factor considering the size of the basin. The wide range of SWAT applications, underscores that the model is a very flexible and robust tool that can be used to simulate a variety of watershed problems. Moreover, the process of developing SWAT model for a given watershed has also been significantly facilitated by the development of GIS-based interfaces, which provide a direct means of translating digital topographic, land use, and soil data into model inputs. Also, it is an open source code which ensures the improvement in the simulation accuracy of key processes.

15 **Manuscript is revised by adding the following lines. Vide Pg. 7, lines 11-18 of the revised manuscript.**

“SWAT has inbuilt snow module to capture and simulate snowmelt hydrology, permitting the delimitation of up to ten elevation bands with associated precipitation and temperature lapse rates (Fontaine et al., 2002; Rahman et al., 2013). In addition, SWAT allows users to add lapse rate for both precipitation (PLAPS) and temperature (TLAPS) which is very essential in the study region considered. In this study, sub-basin has been divided into ten elevation bands. Furthermore, in SWAT the date and net volume of irrigation water can be set according to the actual condition along with the irrigation water source (surface rivers, reservoirs or groundwater, etc). Also, the domestic, ecological and industrial water in the model can be added in the model as “consumptive use water”.”

25 -----X-----X-----

**Comment:** Page 7, line 3: Why is it relevant that the model is computationally efficient? In fact these first two sentences does not fit very well and the paragraph would make more sense if it started with the third sentence.

**Response:** Suggested change has been made in the revised manuscript.

30 -----X-----X-----

**Comment:** Page 7, line 10: Not sure what is meant by ‘vivid methods’ - perhaps ‘various methods’ would be more appropriate.

35 **Response:** Suggested change has been made in the revised manuscript.

**Sentence is modified in the revised manuscript, as follows. Vide Pg. 7, lines 8-10 of the revised manuscript.**

“Model offers various methods such as, Hargreaves, Priestley-Taylor or Penman-Monteith methods for the quantification of evapotranspiration.”

40 -----X-----X-----

**Comment:** Page 7, line 13: ‘The SWAT model is used to assess the impact of land use changes...’ would be more clear. Moreover it would help readers if you provide some references to back up this assertion.

**Response:** Suggested change has been made in the revised manuscript.

**Sentence is modified in the revised manuscript, as follows. Vide Pg. 7, lines 18-19 of the revised manuscript.**

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*“The SWAT model is used to assess the impact of land use changes on water supplies and erosion in large-scale catchments (Li et al., 2016; Marhaento et al., 2017).”*

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**Comment:** Page 11, line 23: See previous comments about the relative contribution of snowmelt to baseflow. Why is baseflow attributed to snowmelt? What is the relative importance of groundwater?

**Response:** Suggested change has been made in the revised manuscript.

**Sentence is modified in the revised manuscript, as follows. Vide Pg. 12, lines 20-22 of the revised manuscript.**

15

*“High values of NSE and  $R^2$  indicate that the model has been able to capture high flows, while the low values of PBias show that the low flows attributed mostly from the baseflow and snowmelt has also been captured quiet well by the model (Fig. 3).”*

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The authors would like to add that the stress has been given on the snowmelt part as the various calibration sites like Rishikesh, Uttarkashi and Joshipath are highly influenced by snow hydrology. And, rigorous calibration and validation was required to calibrate these sites, especially low flows, which was snowmelt in this case.

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**Comment:** Page 11, line 24: It’s not clear what is meant by ‘intrinsic nature’ - consider rewording.

**Sentence is modified in the revised manuscript, as follows. Vide Pg. 12, lines 22-23 of the revised manuscript.**

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*“In general, SWAT model is able to capture the inherent nature of catchment in terms of surface runoff very precisely.”*

35

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## References

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