Interactive comment on "Reviving the "Ganges Water Machine": where and how much?" by L. Muthuwatta et al. (Anonymous Referee #3)

Q1. Model-model comparisons

1.1 The main focus of the study is modeling. The model calibration is glanced over with little reference or information. Apparently, there has been no calibration or validation of this model carried out. With that, it is impossible to say how good the model is performing. There are numerous methodological permutations for SWAT and without state how these were selected and calibrated, it is not possible to consider the validity of the results. This is a cardinal sin for a modeling study. Lack of observation data can be a common shortcoming to modeling, but there must be some contingency to address this within the analysis framework.

Answer:

The SWAT model used in this study was developed to assess the effect of external drivers such as land use and climate changes on the streamflow in the Ganges River Basin. The calibration and validation is conducted at 8 locations within the Ganges basin (Mutuwatte, et al, 2014). We agree with the reviewer's comment and following section is added to the "Data and Model setup "section.

The model was initially calibrated and validated for the monthly discharge data collated at the Harding Bridge. The calibration period was selected from 1981 to 1990 and the validation period was selected as 1991–2000. The performance indicators, (Nash-Sutcliffe efficiency) NS and coefficient of determination (R2) are 0.69 and 0.73, respectively, for the calibration period and indicate reasonable agreement between observed and simulated streamflow time series. For the validation period, NS and R2 are 0.75 and 0.81. Additionally the model simulations were compared with the observed flow data at another seven locations, for which the observed data were available. Following table presents the model performance indicators for these seven locations. The performance indicators show reasonable agreement between observed and simulated values.

Model performance indicators for seven locations in GRB.

Number	River	Latitude	Longitude	Period	R^2	NS
1	Baghmati	27.15	85.49	1981–2006	0.83	0.82
2	Karnali	28.96	81.12	1981–2006	0.79	0.61
3	Seti	29.30	80.78	1986–2006	0.76	0.54
4	Arun	26.93	87.15	1986–2006	0.63	0.64
5	Kali Gandaki	27.88	83.80	1996–2006	0.75	0.62
6	Kali Gandaki	28.00	83.61	1987–1995	0.58	0.58
7	Kali Gandaki	27.75	82.35	1984–2006	0.76	0.66

Reference:

Muthuwatta L.P., Sood A., Sharma B. (2014). Model to assess the impacts of external drivers on the hydrology of the Ganges River Basin. IAHS Publ. 364, 2014, 76-81.

1.2 In addition, there is an excessive amount of model-model comparison to add richness to the results. For example, the entirety of Figure 5 with its linear relationships among inflows and outflows is not entirely surprising given a model-model comparison. How real is this? That is the crux of the issue here. Why trust this modeling result to represent anything real? The process representation potential within SWAT opens the door for multiple types of modeling scenarios but not all of these would be valid in this region.

Answer:

We agree entirely with the reviewer's view about this issue. Other reviewer's also have commented on the same issue. Therefore, we have removed that figure from the paper and the text in the manuscript has been revised. Further, we have added new results explaining the categorization of sub-basins based on the potential increase in irrigated area, and the uncommitted surface and groundwater use in sub-basins. This was suggested by one of the other reviewers.

Q2. Potential to implement subsurface storage

2.1 The modeling results address the supply of water available within the sub-basins and information from previous work by Amarasinghe et al. (2015) regarding the subsurface storage potential (more or less). No consideration on the capacity to pump water into or the space required to actually recharge the aquifer is presented. What rates of pumping would be required and could the structure of the aquifer take that? Given that, it would be nice to see (at least a rudimentary) estimation of the cost associated with such an undertaking. If the recharge is through nature zones, how would the change in land used impact (feedback) on the modeling itself? What are the capable recharge zones to get high flows quickly into the ground?

Answer:

We thank the reviewer for raising this important point. Use of sub-surface storage (SSS) in the Ganges River Basin has been discussed in number of scientific articles (e.g. Revelle and Lakshminarayana, 1975; Sadoff et al, 2013; Khan et al, 2014). Those studies mainly focused on ground water component and has not substantially discussed the availability of the monsoon period surface runoff and the suitable sub-basins for SSS in terms of agriculture expansion potentials, unmet water demands and surface runoff potentials. Therefore, as mentioned in the introduction, the main objective of this paper is to assess the availability of runoff, by conducting a hydrological analysis of the sub-basins of the Ganges River Basin. The questions that we have addressed in this paper are:

1. Is there sufficient monsoon runoff to store as groundwater?

2. Is it possible to create additional agricultural water demand to use the additional recharge during the monsoon period?

Table 2 presents the runoff generated in sub-basins and Table 3 presents the unmet water demand based on two scenarios proposed and the percentage of surface runoff requited to cover the unmet demand. Further we have added (new section) to the manuscript uncommitted surface and groundwater in different sub-basins (Table 4) and the additional areas that can be irrigated if *water is available. Based on that we have ranked sub-basins according their potential for to develop sustainable SSS solutions.*

To answer the additional questions proposed by the reviewer on capacity of the aquifer to pump, space required to recharge the aquifer, rate of pumping and associated costs requires detail studies and we are not in a position to answer those question based on the results of the current study. Further, we feel that the cost estimation is out of the scope of this paper. We indeed recognize that identifying recharge zone and cost/mode of pumping are important components of SSS study, and they are currently being studied as separate components in the Ramganag sub-basin.

Reference:

Khan, M.R., Voss, C.I., Yu, W., Michael, H.A., 2014. Water resources management in the Ganges Basin: A comparison of three strategies for conjunctive use of groundwater and surface water. Water Resources Management 28: 1235-1250. DOI 10.1007/s11269-014-0537-y.

Sadoff, C., Harshadeep, N.R., Blackmor, D., Wu, X., O'Donnell, A., Jeuland, M., Lee, S., and Whittington, D., 2013. Ten fundamental questions for water resources development in the Ganges: Myths and realities. Water Policy 15: 147-164.

Revelle, R., Lakshminarayana, V., 1975. The Ganges water machine. Science, 188(4188): 611-616.

2.2 On top of that, little is given regarding the downstream impacts of reallocation of the upstream runoff. Taking water from the streams could have profound implications to the countries downstream. This impact could be acute (during the high flow season) and more subsequent (impacts on the low flows via diversion of recharging waters). While the emphasis on flood mitigation is important, why exclude other flow impacts since these waters are important to both upstream and downstream people?

Answer:

The reviewer has raised a valid point: the withdrawal of water upstream will impact in-stream water downstream. The goal of this paper is to answer a query – is there adequate flows that can be captured during the monsoon season (Introduction section)? The analysis in this research has focused on water availability only during the peak flow months. The impact of this on downstream river flow will be positive in terms of reduced floods. On the other hand, excess groundwater storage could augment the dry-season flow, either from direct contribution from the groundwater or from return flows from abstracted groundwater. The quantification of this impact, although relevant, is beyond the scope of this research.

To make the paper complete, we have added the following section to the paper:

Changes in flow upstream will impact the water availability in the river downstream. The flow withdrawn during wet months (monsoons) will not have adverse impact on the flow downstream. If at all, it may help mitigate the floods. On the other hand, water withdrawn in the upstream in dry months, without additional groundwater recharge during the monsoon, could adversely impact water availability downstream. For instance surface water based irrigation projects in UP annually withdraw about 28 Bm3 of river flow, at least 50% during the dry season. If this volume is not diverted, dry season flow in the Ganges at the UP-Bihar boundary would increase by 25% (Khan et al, 2014). However, this study assess where and how much it can recharge during the monsoon to be used for in the dry periods. The extra water in the aquifer, recharged during the monsoon, could in fact augment the dry-month flows in the river and provide benefits to downstream users. This would require a detailed surface water-groundwater modeling to understand capacity to recharge, flow patterns between river and aquifer during withdrawals, and how it will affect the river flow.

Q3) Results put forward

In general, the results presented are basic and not considering the full potential of the modeling. There are numerous flow metrics that could have been considered in addition to the 75% dependable flows. Why not present a better cross section of the potential flows that are considered in the generation of excess runoff. Also, why focus only on the flows themselves? One central advantage of a modeling approach to these issues would be to compare the amounts of water (or at relative changes) in storages within the subsurface. Taking that one step further, what not show the impacts of subsurface storage on the hydrological response of the system? It would be a reasonable thing to account for the potential feedback of recharging the groundwater on the hydrological response of the catchments. Also, it is interesting that the only results presented are maps of absolute volumes of water. One would anticipate relative percentages of water contribution.

Also, why not show hydrographs for the basins? At the very least for the key sub-basins be considered for repurposing of flows. Finally, it seems appropriate to demonstrate more the implications on flows via the implementation of subsurface storage scenarios. What impacts on the timing of flows would be created and how would this further feedbac onto upstream and downstream resources? One imagines that there are various manners by which to implement the recharge needed to increase subsurface storage. It is surprising that these various scenarios of recharge practice are not explicitly considered since this is the true strength of a modeling approach. This is especially relevant in the face of land use and climatic changes (although care is needed in extrapolating a model beyond calibrated ranges).

Answer:

We thank the reviewer for raising this important point. We have described four conditions in the introduction to develop sustainable SSS solutions and this paper we are addressing the second condition which is "Existence of adequate flows for capture during the monsoon season". We fully agree with the reviewer on importance of investigate the impacts of subsurface storage on the hydrological response of the system and the impacts of various recharge scenarios. It is not possible with the model we have used in this study. It certainly need a coupled system of surface and groundwater models that currently we are working over Ramganga sub-basin. In the

"Results" section of the manuscript, we do have the percentage contribution of each of the sub-basins to the river flows in Ganges. We have also added the following text in our manuscript:

Chinnasamy (forthcoming) analyzed if there is sufficient aquifer storage available to hold the excess runoff require detailed study on the groundwater aquifers in different sub-basins. The study found that the groundwater depletion rate over Ramganga sub-basin located in the North western part of the Ganges basin as 1.6 km3/year and concluded that, the depleted aquifer volume can be used to store 76% of the rainfall in the sub-basin.

Q4) Structure

The results section contains much text that is not truly results. These are either methods text or findings from previous studies. These are not the results of this work. More significantly, the manuscript provides no discussion of the results and findings. How does this work relate to management or understanding of the region? This is a large oversight that prevents this study from being considered as a standalone contribution to the scientific literature.

Answer:

We feel that this comment may not exactly reflect of what the paper is trying to contribute to the scientific literature of the Ganges Basin hydrology. This paper assess the dependable runoff generated in different sub-basins which is not comprehensively described in other studies. However, as mentioned in previous answers, to make it more scientifically stimulating, we have added a new section explaining the categorizing of of sub-basins based on the potential increase in irrigated area, and the uncommitted surface and groundwater use the sub-basins. Therefore, the results section is rewritten by adding new results.

Minor/Editorial Comments

P9742L6: Should be 'increasing' and 'mitigating'

This has been corrected in the manuscript.

P9742L8: 'sub-basin-wise' is awkward. Just use 'sub-basin'

This has been corrected in the manuscript.

P9744L1: What about the potentials for remobilization of chemicals and/or increase interactions with pollutants? Are these possible issues that limit the feasibility of increase subsurface storage as a viable choice?

We think this is out of the scope of this paper.

P9744L2: 'Popular belief' may not be the same as the views of the scientific community that reads HESS. How appropriate is this line of logic to a scientific paper? Cover a review of the relevant science on these management issues.

Popular belief is that having large dams is the only option to meet the basin's water storage needs (Onta, 2001).

P9745L17: The main issue here is knowing the actual processes that take place in the real-world system. How sure are you that your SWAT model setup actually captures the processes and true hydrological responses within the sub-basins?

Answer:

SWAT is a watershed-based model developed by the US Department of Agriculture's Agriculture Research Service. The model has been previously used for number of studies for different watershed scales (e.g. Muttiah &Wurbs, 2002; Ringler, Caib, Wang, Ahmed, & Xue, 2010; Singh & Gosain, 2011, Sood et al, 2013). The hydrological ability of the model to capture real world situations are extensively discussed in these articles. Additionally, Ganges SWAT model was calibrated using the observed data at number of locations for which observed data is available. Further, simulated water balance components seems to be comparable to the results of the other similar studies (e.g. Gosain and Sirinivasan, 2011).

References:

Muttiah, R. S., & Wurbs, R. A. (2002). Modeling the impacts of climate change on water supply reliabilities. Water International, 27, 407–419.

Ringler, C., Caib, X., Wang, J., Ahmed, A., & Xue, Y., Xu, Z., You, L. (2010). Yellow River basin: Living with scarcity. Water International, 35, 681–701.

Singh, A., & Gosain, A. K. (2011). Climate-change impact assessment using GIS-based hydrological modelling. Water International, 36(3), 386–397.

Aditya Sood, Lal Muthuwatta & Matthew McCartney (2013): A SWAT evaluation of the effect of climate change on the hydrology of the Volta River basin, Water International, DOI:10.1080/02508060.2013.792404.

Gosain, A.K, Sirinivasan, R. (2011). Water system modeling for Ganges basin. World bank.

P9745L21: Verb tense shift.
This has been corrected in the manuscript.

L9745L24: It is more correct that HRUs allow for a modeling efficiency whereby hydrological similarity of responses can be leveraged.
This is corrected in the manuscript

P9745L25: How are things routed? Are HRUs allowed to interact and flow into each other or is everything dumped to a stream and the routed out of the system? How sure are you that the dynamics of the stream systems are being represented? Even more so, once you start changing flow conditions via artificial recharge, how does this feedback into the flow routing?

In SWAT, a river watershed is divided into sub-basins, which is further divided into HRUs based on similar landuse, soil and slopes. Although, sub-basins maintain their spatial integrity, HRUs are lumped together. The HRUs do not interact with each other and their outputs are aggregated at sub-basin level. SWAT has a robust channel routing routine to link all the sub-basins and flow through the system. Since sub-basins have spatial integrated, we have delineated Ganges into finer resolution sub-basins (1684 sub-catchments).

Eq1: In my printout, the summation sign is dropped. Double check PDF formatting.
Also, the double f's are printed strange everywhere.
It is correctly printed in the original document.

P9746L2: Why this threshold?
This is described in the manuscript as follows:

The Ganges River Basin has been delineated using 3,000 ha as minimum area threshold and has resulted in 1,684 sub-catchments. The area threshold was selected by trial and error in an attempt to match the SWAT sub-basins as closely as possible to capture the all tributaries of the GRB.

P9746L21: Was the impact of treating the entire of Nepal as one region explored?
Does it influence the timing of the modeled flows?

As presented in figure 1, in the original SWAT model setup, the Nepal region was divided into number of small sub-catchment based on the topography. The hydrology was simulated for all these units. However, in this study our concern is to identify the potential sub-basins in the Indian part of The Ganges basin. If we consider daily flows, it would have influenced the timing of the modeled flow. In our study we have used the monthly simulations as our focus is on the runoff during monsoon months.

P9746L25: Not an adequate amount of information regarding calibration, choices of model setup and validation procedures given here. More information is needed since this is a standalone study. Further, it would be good to demonstrate clearly how this work pushes beyond previous work.

Description is added to the manuscript on calibration and validation.

P9747L9: Seems like there should be a reference for the statement regarding the adequacy of the dependable flow metric.

Reference is added to the manuscript.

Wang, Z, Lee, J.H.W, Melching, C.S., 2014. River Dynamics and Integrated River Management. Springer, ISBN 978-3-642-25651-6.

P9749L15: Why not compare the MODIS product with you modeled results? That sounds more interesting.

The section on the relationships between upstream flows and the inflow to Bihar has been revised.

P9750L5: Why are we surprised by this linear relationship given a model-model comparison? It seems to follow naturally based on the limited model setup insight provided. Did the authors anticipate non-linearity here? My guess is that the scatter around the line actually derives from uncertainty in parameter and process representation of the SWAT setup. That alone could provide a more fruitful exploration

Figure 5 is removed from text.

P9751L14: This study as it is presented does not discuss this or any other implications.

We have add a paragraph describing the downstream impacts of the reallocation of the upstream runoff.

Figure 2: Consider a black-white relevant color scale.

This has been corrected in the manuscript