Interactive comment on "Reviving the "Ganges Water Machine": where and how much?" by L. Muthuwatta et al. (Anonymous Referee #1)

This article uses a hydrological model to determine surface runoff and unmet irrigation demand in the Ganges river basin. The premise is that surface water outflow from a subbasin could be used to recharge aquifers for use during post monsoon seasons. The model is publicly available, which is a great public service. The model seems to be well implemented and validated.

Q1. The overall results are useful for pointing to management possibilities, but the analysis has limitations that the authors are aware of but should be highlighted earlier in the text. In the conclusion the authors acknowledge that they have not determined whether there is sufficient aquifer storage available to hold the proposed "excess" surface water, or opportunities and locations for recharging the water. I think this should also be stated in the methods section.

Answer:

We agree with the reviewer and added the following text to the manuscript.

This study examines the availability of monsoon flow in different sub-basins. To determine whether there is sufficient aquifer storage available to hold the excess runoff require detailed study on the groundwater aquifers in different sub-basins. There are no comprehensive assessments of the groundwater system in the Ganges. However, studies based on the data from the Gravity Recovery and Climate Experiment (GRACE) satellite given an indication of this potential in the Ganges Basin. (Swenson and Wahar, 2006; Morrow et al, 2012, Rodell et al, 2009). Rodell et al, 2009, using GRACE satellite data, estimated that the mean rate of groundwater depletion over the Indian states of Rajasthan, Panjab and Haryana as 17.7 ± 4.5 km3/year. Chinnasamy (forthcoming, submitted to Hydrology Research) estimated that groundwater depletion rate over Ramganga sub-basin located in the North western part of the Ganges basin as 1.6 km3/year. He further concluded that, the depleted aquifer volume can be used to store 76% of the rainfall in the sub-basin. Khan et al (2014) showed that the subsurface storage create in Uttar Pradesh by pumping groundwater during dry period can accommodate up to 37% of the yearly average monsoon flow.

References:

Swenson, S., and Wahr, J., 2006. Post-processing removal of correlated errors in GRACE data. Geophysical Research Letters 33 L08402 1-4

Morrow, E., Mitrovica, J., and Fotopoulos, G., 2011. Water storage, net precipitation, and evapotranspiration in the Mackenzie River Basin from october 2002 to september 2009 inferred from GRACE satellite gravity data. Journal of hydrometeorology 12 467–473.

Rodell, M., Velicogna, I., and Famiglietti, J.S., 2009. Satellite-based estimates of groundwater depletion in India. Nature 460 999–1002

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.

Chinnasamy, P (forthcoming, Hydrology Research). Depleting groundwater – an opportunity for flood storage? A case study from part of the Ganges river basin, India

Q2. The authors suggest that flooding in Bihar could be alleviated by recharge, but I don't think that's well substantiated. They correlate runoff from upstream with inflow into Bihar, but the relationship between groundwater pumping, recharge, and surface water use is not sufficiently developed or modelled to make strong conclusions about the impacts of different management actions. This limitation should also be acknowledged in the methods and discussion.

Answer:

We agree with the reviewer and revised the text in the manuscript and removed figure 5.

Q3. The authors could also make a clearer link with recent research on groundwater in India, which suggests severe depletion in the western sub basins, e.g. (Rodell, Velicogna, & Famiglietti, 2009). However, there may be much less depletion in the eastern basin, where much of the surface water is available. The authors suggest that pumping could create extra storage space, which may or may not be the case in the basins with "excess" surface water. Finally, the authors do not acknowledge that wide-spread pumping could have other hydrological impacts, including dry season streamflow depletion, depending on how the newly recharged water is pumped and released. I don't know in detail about Ganges flow availability, but I think low flow in the dry season is already a problem. Whether recharge could compensate for increased pumping is an unanswered question. So overall, I think the paper needs some more qualifiers about its recommendation for pumping and recharge, with acknowledgement of uncertainty in basin response and potential for unintended consequences.

Answer:

The reference (Rodell et al, 2009) is added to the manuscript. Two examples were added to the manuscript to describe the possibility of creating additional sub surface storage by pumping groundwater. (Khan et al, 2014, Chinnasamy forthcoming- Hydrology Research). The following paragraph has been added to explain the effects of pumping groundwater on the dry season stream flow.

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.

Other comments:

The difference between figures 3 and 4 need clarification. For example, sub basin 19 has low runoff in figure 3 but high total outflow. I think the differences that figure 3 (and. Tables 3 and 4) are surface runoff generated within the sub basin while figure 4 is total outflow which includes contributions from upstream sub basins.

Answer:

We agree with the reviewer and the following text has been added to the manuscript

In this, estimated out flow at the sub-basin outlets include the contributions from upstream sub-basins. Therefore, the values presented in Figure 4 are significantly higher compared to the surface runoff values presented in Figure 3.

Minor Comments

3-1. Downstream of

This has been corrected in the manuscript

4-1. But 30-50 is smaller than 130-145. How much greater?

The following description has been added to the manuscript to indicate the relative magnitude of the volumes.

For instance, the mean annual replenish able groundwater in the Ganges basin is about 202.5 Bm3/ year (Ministry of water resources, 2014). Further, the estimated storage available in the shallow alluvial aquifers of eastern Uttar Pradesh and Bihar, which could be utilized in the dry season and naturally recharged in the wet season, is 30-50 Bm3 (SMEC, 2009).

References:

Ministry of water resources, 2014. Ganges Basin Report (version 2)

SMEC (Snow Mountain Engineering Corporation International Pty Ltd), 2009. Preparation of Ghanga Gomti Basin plans and development of decision support systems. Final Report prepared for the State Water Resources Agency, Uttar Pradesh.

4-2. Into?

We think that the text presented in the manuscript gives the correct meaning as we are trying to describe the "Existence of adequate un-met demand (e.g., for agriculture and other uses) to deplete the water pumped from the aquifers in a basin/sub-basin".

5-1. Wonderful! This is a great service!

We thank the reviewer for this encouraging comment.

8-1. these scenarios seem identical. 2 includes non-irrigable crop land? Why include those if they can't be irrigated? Or does irrigable mean currently irrigated in at least on season? Or in irrigated command areas?

We agree with the reviewer and the following scenarios were re-phrased:

Scenario 1: Provide irrigation to the total irrigable area, i.e., increase irrigated area in the Rabi season from 26 Mha (current irrigated area in this season) to 30 Mha (irrigable area), and in the hot-weather season from 3 Mha (current irrigated area in this season) to 30 Mha (irrigable area), respectively

Scenario 2: Provide irrigation to the total cropped area. At present, not all cropped area is equipped for irrigation. i.e., irrigable area (30 Mha) is less than the cropped area (35 Mha). Therefore, the Scenario B is to increase irrigable area in order to increase irrigated area from 26 to 35 Mha in the Rabi season and from 3 to 35 Mha in the hot-weather season respectively

10-1. higher volumes of

This has been corrected in the manuscript

10-2. wouldn't a percent contribution be more useful?

We agree with the reviewer and necessary changes were added to the manuscript.

10-3. Major assumption. Can the aquifers store it?

Additional description with references has been added to the manuscript to support this assumption (see answer to Q1).

11-1. previous page says 30%

This has been corrected in the manuscript

11-2. Why just that sub basin?

This has been corrected in the manuscript

17-1. I think it would be useful to have runoff expressed in mm, which normalizes for sub basin area.

This paper has two other companion papers and in all three papers water volumes are expressed in Bm3.

17-2. Include the number, then could remove table 2

This has been corrected in the manuscript

18-1. Include the number

This has been corrected in the manuscript

23-1. Useful?

We agree with the reviewer. This figure has been removed from the manuscript and the text has been revised.