Review of "Reviving the Ganges Water Machine: why?", submitted to HESS by Amarasinghe et al.

October 2015

General comments

The authors present a study exploring the potential of increasing subsurface storage before the monsoon season to increase water availability in the Ganges basin on an annual scale. Since the Ganges basin is prone to water stress that is likely to increase in the future when water demands continue to increase, this is an important topic. Exploring the effects of possible measures to increase the water availability are thus of scientific and societal interest. The paper is in general quite well written, and conveys its message. However, some changes should be implemented.

1. The Introduction section could use some reformatting as indicated in the specific comments below. Besides, my suggestion would be to rename the Results section to Results and Discussion. The section discussing the regional differences of the findings should be elaborated, as indicated in the specific comments below.

   Authors response: Introduction section is reformatted. The first paragraph (L1-L12) is moved to L27. Results section is renamed to Results and Discussion. Regional differences are elaborated more. See below for details.

2. The authors make the general assumption that climate change will cause problems in the future in the Ganges basin. Although this is likely true for climatic extremes (floods, droughts), climate change may also provide opportunities in terms of total water availability. For example, Sharmila et al. (2015) and Krishna Kumar et al. (2011) show that the monsoon's precipitation amounts are likely to increase and that the monsoon season is likely to become longer. On the other hand they show that precipitation events are likely to be more extreme and that the number of dry days during the monsoon increases. Lutz et al. (2014) showed that increases in water availability from the upstream parts of the basin are likely and that low flows outside the monsoon season may increase. The general point here is that the paper would benefit from a short paragraph discussing the projected climatic changes in the Ganges basin, for example in the Introduction section, to place the present study in the context of future changes.

   Authors response: We thank the reviewer for showing these recent references. We have replaced the P8730 L8-11 with the following para.

Climate change may exacerbate the water related issues due to extreme variability of rainfall and associated streamflow, although the projections are widely divergent. Hosterman et al., 2012; Immerzeel et al., 2010 projected a decrease in annual rainfall, while Sharmila et al 2015 and Kumar et al. 2011 show an increase in monsoon rainfall and longer monsoon seasons. The latter also projected an increase in dry spells during the monsoon, implying that the intensity of precipitation in the rainfall events will increase. However, according to Lutz et al (2014) water availability in the upstream and also in the low flow periods will increase. While any increase in rainfall, especially in the non-monsoon period, is a good opportunity, any increase in variability of rainfall could be a challenge for water management in the Basin. Unless there is adequate storage to buffer the variability, most

climate change scenario projections could increase the impacts of floods and droughts substantially on the rapidly expanding population in the Basin.

3. I do not understand why the analysis stops here, at their first out of four conditions for successful implementation of a PDRP scheme. Wouldn't it be a better option to include findings on the other three conditions as well? That would certainly have more scientific value. Now the analysis seems incomplete.

   Author's response: The answer to this question (see below) that we can give at present is same as that was given to the one of the other review.

   This paper is the first of a series of papers of a research project dealing with feasibility of reviving the Ganges water machine. Two papers are submitted to HESSD at present and they shall be seen together. The other paper assess water supply of sub-river basins (using SWAT). The other papers deal with technical feasibility of recharge (using MODFLOW and SWAT), availability and access to energy for GWM, water quality issues for GWM, and environmental flows and socio-economic issues. These issues are treated as standalone components, and possibly, will lead to journal articles. We are trying to publish the results of these components as and when they are completed. This paper is the first among them, and we believe that it addresses issues beyond simple water balance, which though is imperative for assessing the feasibility of reviving the GWM. The final synthesis paper-techno-socio-economic feasibility of the project will address all these issues.

Specific comments

P8728L5-6: Be specific which months (June-September monsoon season) and also for the other months outside the monsoon season mentioned.
Done

P8728L13: Remove 'necessary'

Done

L16,17: Include the months in parentheses behind Rabi in the abstract as well for readers who are not familiar with Rabi/Kharif
Done

P8728L22: Change 'Importantly' to 'In

conclusion'

Done

L21: Change 'in the same year' to 'within the

year'

Done

P8729L1-12: Consider moving this part and integrating it with P8730L27-P8731L8. Then the introduction will have a better structure:

1) Importance of Ganga river for society,
2) Problems affecting Ganga water supply,
3) Limitations of increasing surface storage capacity to cope with problems,
4) Introduction to GWM and SSS as possible solution,
5) Conditions for SSS
6) Aim of paper to quantify unmet demand (being first condition for SSS)

Done: Added the following para before lines P8730 L27.

The "Ganges Water Machine" (GWM) may be the most opportune solution to the severe water challenges in the Ganges River Basin. Revelle and Lakshminarayana (1975) proposed GWM as an elaborate network of pumping and recharge wells in the rivers and tributaries to irrigate about 38million hectares (Mha) of potential cropland, and to also capture about 115 billion cubic meters (Bm^3) of monsoon runo for subsurface storage (SSS). Over the last 40 years, their estimate of gross irrigated area has already been realized, but without the elaborate "water machine" capturing the monsoon runoff. As a result, some areas are experiencing falling groundwater tables. Recurrent floods and droughts batter the basin with increasing frequency. There is already a mismatch between supply demand, and the water challenges are likely to increase with increasing demand. This paper examines the conditions under which the original GWM should be revived as a potential solution to the emerging water problem in the Ganges River Basin.

P8729L7-9: Provide a reference for this statement

Added: Amarasinghe et al 2007 (in the reference list)

L9-L10: Also for this statement add a reference.

Added: Gleeson et al 2012
(Gleeson, T., Wada, Y., Bierkens, M. F., and van Beek, L. P. 2012. Water, balance of global aquifers revealed by groundwater footprint. *Nature*, *488*(7410), 197-200)

L12: Change 'woes' to 'problems'

Done

L25: Change 'is' to 'are'

Done

P8730L1: Remove 'other'

Done

L5-6: Provide a reference for this statement
Added: Douglas 2009.
Douglas, I. Climate change, flooding and food security in south Asia. Food Security, 1(2), 127-136 (2009)

L7: Remove "'after dollars

Done

L11-13: Consider citing the more recent paper by (Lutz et al. 2014)

Done.
Lutz, A. F., Immerzeel, W. W., Shrestha, A. B., and Bierkens, M. F. P.: Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nature Climate Change, 4(7), 587-592, 2014

L17-18: Provide a reference for this statement.

Done: added CWC 2013. (in the reference list)

L20: Provide a reference for this statement.

Added FAO 2014. (in the reference list)

P8731L1: Change 'SSS is increasingly important now more than ever before' to 'SSS is now more important than ever before'

Done

L2: What is meant here with 'outcomes'? That needs clarification.

Replaced outcomes with livelihood benefits.

L2-L4: This sentence is not 'flowing' very well. Consider splitting in two sentences.

Split it into two sentences:

It provides a buffer for rainfall variability. And SSS also provides water for irrigation to increase cropped area and improve agricultural productivity, and water for use in the domestic and industrial sectors.

L26: Change 'for guaranteeing' to 'to guarantee'

Done

L29: Remove 'resources'

Done

P8732L1: Rephrase: 'There must be an adequate volume of groundwater available for pumping before the monsoon season.'

Done

L15: Change 'from' to 'for'

Done

L17-19: At what time scale is this increase necessary (decades? Centuries?)

Done. Inserted .."next 3-4 decades".

P8733L2: Change 'Ganges' to 'Ganges basin'

Done

P8733L14: Change 'unmet demand for water' to 'unmet water demand'

Done

P8736L1: change 'varies' to 'vary'

Done

P8737L6: change ‘is’ to ‘are’
Done

L14: change to: ‘…meeting the ESS and requirements for socioeconomic activities’
Done

L24: change to: ‘…be considered additionally in WA…’
Done
P8738L1: Change Bm^3 to Bm^3yr^{-1}, and indicate the location of Hardinge Bridge in Fig. 1
Done

L4-9: See previous comment
Done

L15-16: Change to ‘environmental flows’ or ‘EFs’ P8739L22: Change ‘is’ to ‘are’
Done
L23: GOI should be GoI
Done

P8740L5-6: The figure legend mentions ET and the text mentions CWU. Be consistent and use one of them in both the text and the figure
Done
L7: Change ‘is’ to ‘are’
Done
L8. Change to: ‘…out of 4 years. The river is…’
Done

P8741L1: Additional pumping and depletion of GW is argued here to be the only feasible way to increase SSS here. However other ways to increase SSS are not discussed. The claim that it is the only feasible way needs to be more substantiated.
To create SSS, it needs to pump water out and deplete as ET. This is what was mentioned there

L4: ‘in the’ is doubled

Deleted

L25: It is not clear to me how Table 3 is linked to Figure 8. How do you get from the numbers in Table 3 to potential unmet water demand? This needs more elaboration.

Inserted these sentences at L25.

The potential unmet demand in the Rabi and hot-weather seasons are given in columns C15 and C16 under scenario 1, and in columns C17 and C18 under scenario 2. The spatial variation of the total potential unmet demand under Scenario 1 (sum of columns C15 and C16) and Scenario 2 (sum of columns C17 and C18) are shown in Figure 6 upper and lower panels respectively.

P8741L24-P8742L18: The spatial differences are your main findings and therefore deserve some more discussion in the paper. I suggest that this section be elaborated, highlighting regional differences and their causes and consequences
Inserted these two paras at line 25.

Sub-basins located in the eastern Ganges generally have the highest unmet water demand. They include Bhagirathi, Damodar, Gandak and Son and the Ghagra. Given that these basins have economic water scarcity, i.e., inadequate water development, especially groundwater, they may have the highest potential for increasing CWU and creating the SSS.

The upper Campbell, Ramganga, and lower, middle and upper and Yamuna in the middle to western of the Ganges also have high unmet CWU demand. But, these areas already have high groundwater depletion that in some locations exceeding the recharge (CGWB 2013). The locations with high groundwater depletion have low potential for increasing groundwater irrigation CWU without recharging the aquifers first.

P8742L26-P8743L14: I think one very important aspect that could be a limiting factor is the time required to recharge the groundwater after pumping. This has to be completed within one monsoon- season, otherwise the situation will be unsustainable. Consider emphasizing this in this section.

Done

P8743L20: Change 'basin' to 'Ganges basin'
Done

P8744L4: Change the wording as the statement is based on future projections with uncertainties: change 'will' to 'could' or 'is likely to'
Done

P8745L9: Change 'in the same year' to 'within the year'
Done

Table A1: Include EF as acronym

Done

Table 1: Consider referring to Table A1 in the table caption for meaning of

acronyms.

Done

Figure 1: Indicate the location of Hardinge Bridge.

Done

Figure 3: In the caption text about effective rainfall estimates is written, but there is nothing about that in the figure. Panel B is shown here, but not referred to in the text. Either remove the panel or use it in the text to substantiate your findings.
Done

Figure 4: The caption says that the source of trends are author's estimates. This is not necessary to mention in the caption, because it is based on the study described in this paper. Besides change in caption: 'The projections for 2025 and 2050 are from…'

Done

Figure 8: Units are missing and the map needs a legend for the color scale.

Made changes to the figure 6

References

Krishna Kumar, K. et al., 2011. Simulated projections for summer monsoon climate over India by a

high-resolution regional climate model (PRECIS). *Current Science*, 101(3), pp.312–326.

Lutz, A.F. et al., 2014. Consistent increase in High Asia ' s runoff due to increasing glacier melt and precipitation. *Nature Climate Change*, (June), pp.1–6.

Sharmila, S. et al., 2015. Future projection of Indian summer monsoon variability under climate change scenario: An assessment from CMIP5 climate models. *Global and Planetary Change*, 124, pp.62–78.