Comments on "Reviving the Ganges Water Machine: Why?"

Summary

This paper assesses in rough terms the extent of "unmet" demand in the Indian portion of the Ganges Basin, as a way of assessing whether the idea of the Ganges Water Machine should be revived. In simple terms, this idea says that groundwater could be pumped during times of rainfall and surface water scarcity, and that aquifers could then be recharged during the monsoon, to better smooth water supply availability to meet demands in the basin. The authors find that there is indeed significant unmet demand in the basin, and posit that this amount will only increase in the future, making more detailed investigations of the feasibility of the GWM an issue of great importance.

General comments

I have a number of general concerns with the paper, which chiefly revolve around: a) questioning its contribution; and b) the lack of consideration of issues beyond the simple balance of water demand and supply that would affect the feasibility of the GWM. The authors argue that these issues are the subject of additional research; I feel however that what is in this paper is not sufficiently novel and that those issues must therefore be addressed.

Author's response: 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.

1. The authors take a singular "water" perspective when proposing the four conditions for the success of the pump-deplete-recharge-pump" (PDRP) cycle that characterizes the GWM. The problem however also relates to energy availability and energy poverty. Large swathes of the Ganges Basin have no dependable and consistent access to energy, whether through the electrical grid or via diesel pumping. Thus, the problem cannot be viewed through this singular water lens. The energy constraint receives mention in only a few lines in Section 5.

Author's response: We are aware of this of course and agree with the review that access to energy is a major issue in the region. The component dealing with this issue assesses energy demand, supply and opportunities with alternative energy such as solar and their tradeoff. IWMI is conducting other research studies dealing with solar energy in several other projects, and the component on the GWM project addresses the issues and opportunities for the Ganges. This paper only mentioned it as a constraints for the revival of GWM, and the opportunities are assessed in another component. We simply cannot address all issues related to GWM in one paper due to the enormity of the issue.

2. I am question whether this paper constitutes a significant contribution to the GWM debate. The authors acknowledge that there is unmet demand for irrigation water and argue that their contribution is to specify "the exact locations and quantities of unmet demand in the basin" (p.6).

But this is mainly an accounting exercise that is not a substantive contribution by itself. I think the authors need to (and can) work harder to assess whether conditions 2-4 detailed on p. 6 can be met (in fact they already provide some details about annual recharge amounts). In addition, it is unclear why conditions 2 and 3 are strictly necessary, since partial satisfaction of unmet demand is sufficient to enable some useful PDRP. Condition 4 is critical, but it is unclear from the analysis whether it is likely to be satisfied. Without additional work on these issues, it is hard to know what to conclude from this paper.

Author's response: The projects has identified several important issues regarding the GWM, which were also the general concerns of the stakeholders and include: given that the Basin has undergone many changes over the last 40 years, Why GWM now? How much and where it has the potential in terms of water supply? Technical feasibility given the changes of land and water use and in the environment, and the ability for artificial recharge to capture monsoon runoff, access to energy, and the effect of this on Eflows etc. To begin with we estimated the water accounts at present. This is our contribution to the GWM concept.

Authors agree that a partial satisfaction of unmet demand can create a SSS. But, in the project, we wanted to know the potential unmet demand, and then later estimate the cost, the benefits and tradeoff. And we know the potential additional consumptive water demand by 2050 in the Basin could be over 70 Bm^3. Therefore, we thought that: Condition 1 is important because without an unmet water demand it can't deplete the resource to create a sub-surface storage (SSS); Condition 2 is important because the without adequate groundwater resources it cannot meet the unmet demand; Condition 3 is important because there should be sufficient dependable uncommitted monsoon runoff that can recharge the SSS.

However, there is hardly any published data available to assess this situation in the Ganges, especially after the changes in the basin over the last 4 decades. This paper address condition 1, 2nd paper (being reviewed in HESSD) address condition 2. Conditions 3-4 are being assessed now.

We agree with the review that the condition 4 is critical. The paper based on component is being reviewed in another journal now.

And there are other issues, as discussed earlier, for feasibility of reviving the GWM. The synthesis of all these studies form the techno-socio-economic feasibility

3. I am troubled by the fact that the analysis of water accounting only covers the Indian portion of the basin. While this area does represent the bulk of water demand, the problem is that this approach neglects the transboundary nature of the river, and the fact that the GWM may have important distributional effects on the other riparians. Data on irrigated areas and hydrology in Nepal and Bangladesh are more easily obtained than data for India, so I do not think data availability should be described as a constraint here, contrary to what the authors assert on p.7. It seems more likely that the authors did not make the effort required to obtain those data.

Authors response: The particular attention on the Indian side was because the sheer magnitude of the process consumptive water use at present in the Indian portion (91.3% of the total of 123 Bm3. The total includes 3.6 Bm3 in Nepal, 7.1 Bm3 in Bangladesh and 112.4 Bm3 in India) and the potential opportunity to have a large impacts from the sub-surface storage. The potential for surface storage is high in Nepal (regardless of the uncertainty of whether Nepal can or want to build this capacity), but the potential for SSS in Nepal is low because of its low irrigation

consumptive water use.

Since GWM try to capture only the uncommitted monsoon flows, it will not affect the downstream riparian regions including Bangladesh. Rather it will have positive impacts for Bangladesh in terms of mitigation of floods in the monsoon, and potentially more flows in the river in non-monsoon months in the long-run.

We have some data of Nepal and Bangladesh parts now and we will add these estimates and include sentences to the effect of the present analysis in the discussion section.

4. The TRWR numbers in Table 1 are surface water runoff, right? This needs to be clarified, since "green (rainfall) + blue water" in the basin is much greater than these amounts. This also relates to my next comment.
   Author's response: TRWR includes both surface runoff and groundwater as shown in the GOI estimates and also in AQUASTAT. We have clarified this in the text referring to the table.

5. It is not clear how the authors calculate the PUWR amounts on p. 10 and in Figure 2. This needs to be explained. In particular, I am worried about how the authors handle green vs. blue water use. The crux of the problem is that surface water irrigated area (as specified by the GOI) is unlikely to reflect all surface water use, if some of that water ends up in groundwater aquifers where it can be pumped out by other farmers not connected to the surface water irrigation network. Or conversely, some of the water use in surface water irrigated areas may be from groundwater pumping that comes from green (not blue) water. These two facts will lead to complicated water balance problems, which also underlines the significance of assessing conditions 2 and 3 on p.6, and not stopping at condition 1 and a partial water account.

   Author's response: We have not estimated the PUWR. These were taken from the official estimates by GOI. We agree with the return-flows and reuse issue. But there is no way of handling this without a detailed surface water and groundwater modelling. And it is not feasible to do this for the whole of Ganga basin. We use only a sub-basin Ramganga in assessing conditions 4

   In our work, we estimated the process consumptive water use (CWU) from surface and groundwater irrigated areas to assess the magnitude of the process ET, and have ignored the overlap. What is important for the analysis of this paper is the additional CWU that can be depleted through irrigation and from groundwater, and whether there is adequate monsoon surface runoff to recharge the depleted aquifer.

6. EFs: I don't see much value in annual numbers for EFs, since the EF issue is mostly a critical one during the dry season. This is acknowledged on p.14, but there is no analysis of the issue.

   Authors response: EF is important for both monsoon and non-monsoon months, and we agree that it is critical in the latter. Assessment of monthly EF's is a separate component in the project. However, we have used the total annual EF requirement in this paper to illustrate that there is still some uncommitted monsoon flow after meeting the EF that are potentially available for recharging the aquifers in the GWM. We woulld like to stress again that we have produced / producing several papers that deal with various components of the GWM concept. Some are done at the scale of the entire Basin, others – at drill down to smaller scales to get to the core of the problem locally. This paper looks at the problem at macro level

7. Section 5 is useful in identifying a number of limitations of the analysis, and many are highlighted above in my comments. I think the authors need to do more than list these to create a strong and significant contribution to the literature.

   Authors estimate: It is unclear what the reviewer meant by do more. As mentioned before we are addressing these limitations component by component.

Specific comments

1. It would be easy to take issue with the initial statement in the abstract and introduction, namely that "The Ganges River Basin may have a major pending water crisis." In particular, it would seem more accurate to say that the Ganges River Basin already faces severe water-related challenges related to a mismatch between supply and demand, and that these challenges seem likely to increase as demands increase in the future.

   Agreed. Have changed the text accordingly.
   Line 1-2: The Ganges River Basin faces severe water related challenges related to a mismatch in demand and supply.
   .
   Lines 5-8: Addressing this mismatch requires substantial additional storage for both flood reduction and improvements in water supply

2. Abstract, line 15: these estimates of 59 and 119 bcm/yr are on average, correct? If so, please specify that, since the numbers will vary from year to year depending on surface water availability as well as the contribution of rainfall.

   Author's response: They are the potential values under the two scenarios. Actual depletion vary from year to year and depends on the surface runoff. Have clarified this in the text.
   Lines 14-15: This paper shows that the potential unmet water demand ranging from 59 to 119 Bm^3 exists under two different irrigation water use scenarios:

3. Abstract: I would suggest the authors be more specific about the role and effect of enhanced SSS across years, since variability is a critical concern for riparians in this basin.

   Author's response: The role and the effect of SSS especially the benefits to downstream riparian regions are highlighted in lines 15-20.

4. Introduction, p.4, line 10: I am unclear what the authors want the reader to conclude from the statement that water scarcity "barely allows cropping to only about 1.3 times the net sown area." This suggests that the water is not fully used since net sown area is lower than what water resources would allow. So why is water scarcity binding?

   Authors response: Water scarcity (both physical and economic) in the non-monsoon periods is the main reason for low cropping intensity. Additional GW irrigation can increase land use intensity to as much as 300% and also create SSS to mitigate floods.

We have modified the text in L 10: "Water scarcity, both physical and economic in the non-monsoon period due to inadequate water supply and inadequate development respectively barely allows cropping to only about 1.3 times the net sown area.

5. Introduction, p.4, lines 11-13: The authors should note that climate projections are widely divergent, and that the change in water scarcity is thus uncertain, even though variability appears likely to increase.

   Authors: Increasing variability with climate change is mentioned in lines 12-13 in p 8730. We have added a separate paragraph on climate change impacts on the Ganges.

"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 in the Basin. While any increase in rainfall, especially in the non-monsoon period, is 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, some of the climate change scenarios could substantially increase the impacts of floods and droughts on the rapidly expanding population in the Basin.

6. The methodology and data sources for the water accounting exercise are not well explained. With the information in the manuscript, it would be impossible to replicate the authors' analysis.

   Authors response: We have clarified this with more information on methodology and data in the manuscript.

   Following sentences are included at Page 8736 Line 7.

   > The average monthly ETP and rainfall (RF) estimates for the districts are obtained from the University of East Anglia, Climatic Research Unit and Indian Meteorological Department respectively (. The district level cropped and irrigated areas are collected from the data published at the website of the Directorate of Economic and Statistics website, Department of Agriculture and Corporation, Ministry of Agriculture (http://lus.dacnet.nic.in/). The crop coefficients, crop growth stages, and cropping calendar are obtained from FAO AQUASTAT data base (http://www.fao.org/nr/water/ aquastat/water_use_agr/Annex1.pdf), FAO irrigation and Drainage paper 56 (Allen et al 1998), and from the Agricultural Statistics at a Glance publications by the Directorate of Economic and Statistics, Department of Agriculture India (http://eands.dacnet.nic.in/PDF/Agricultural-Statistics-At-Glance2014.pdf/).
   >
   > The estimates of the total cropped and irrigated area and the CWU of the sub-river basins are the aggregate of the estimates obtained for districts. When a district cuts across more than one basin, the estimates of the district are divided according to the geographical area of intersections with sub-basins.

7. Results: I do not understand the authors' point about the potential for reuse. Are they trying to say that additional reuse of degraded quality water is possible? Clearly, the fact that water returns to the river and nonetheless remains inadequate to meet downstream objectives (in Bangladesh)

suggests that very little reuse water remains by the time the flows reach Farakka during the dry season.

Authors response: What we meant here is that the degraded water coming from the upstream, when mixed with freshwater in the in the downstream (provided they are available) can still be depleted as process ET. Agree with the reviewers issue at Farakka during the dry season and this is already mentioned in text. Changed the sentence to clarify this.

It is also possible that some of the water with degraded quality (included in flows to sinks) from one location can become a supply source for downstream locations after mixing with freshwater, provided that freshwater are available for mixing.

8. Discussion/conclusion: This section basically repeats the abstract and introduction. I would urge the authors to provide a more critical summary.

Authors response: We have modified the conclusion section as appropriate.

Technical corrections

In general, there are many typos or grammatical phrases that could use work. I suggest the authors get their manuscript copy-edited prior to revision. I only note a few issues below.

1. Introduction, p.3 line 25: should be "megawatts". Also this sentence is awkwardly phrased, since it seems to imply that the major financial benefits are navigation and hydropower. Much of the navigation benefit is not financial

Done. Rephrased the sentence.

River water is an important source for fisheries and other riverine habitats (Payne and Temple, 1996), and for navigation extending a stretch of 1500 km. Hydropower generation with an installed capacity over 2000 megawatts is a major financial benefits of the river (GoI, 2014).

2. Introduction, p.3, lines 26-28: I don't think the religious and cultural value of the Ganges is just for tourists, but this sentence implies it is. Local inhabitants also revere the river.

Agree. Rephrased the sentence.
The river Ganga is also considered sacred and revered by its riparian population. Moreover its water is used for many religious and cultural activities, with more than 290 sites set up for tourists to access water along the major rivers and tributaries.

3. Introduction, p.4, lines 1-2: Can you be more specific about the ecosystem services that are provided?

Changed the sentence in lines p4. 1-2 to:
Many ecologically sensitive sites, including lakes and wetlands, provide numerous ecosystem services (ESS) including maintenance of aquatic organisms for food and medicine, and a space for flood control and nutrient recycling and maintaining water quality.

4. Introduction, p.4, lines 5-7: Please rephrase this awkward sentence.

Repharsed the sentence:
Recurrent floods and droughts affect the vulnerable population (the poor, and the women and children) the most.

5. Introduction, p.4 lines 24-26 seems overstated: "...could change the despair to joy for many millions of inhabitants."

   Authors response: Basin has about 600 million population and with the majority living in rural areas and few hundred million depend on agriculture, mitigating the impacts of floods and droughts can help tens of millions. We believe that it certainly is not over stated.

6. Methods, p.7, line 21: Should read "which contains…"

   Done

7. Methods, p.10, line 5: "Maintaining EFs" cannot be "more prominent". Please rephrase as this is unclear.

   Changed to: will become even more prominent …

8. Results, p.13, line 15: Delete "another" which is redundant.

   Done.

9. Section 5, p.15 lines 4-5: There are typographical errors here.

   Done