Interactive comment on “Reviving the “Ganges Water Machine”: where and how much?” by L. Muthuwatta et al

We thank the editor for providing very useful comments. We have tried our best to address all comments/concerns to the extent possible in this manuscript.

Q1: "There are still serious problems with the additional analysis, and problems with the hydrological definitions and interpretations. The simulation of the impact of the two scenarios to meet unmet demand (Figure 5) don't seem to actually meet that demand by increasing ET, and therefore underestimate (or rather don't even account for) the impact of meeting unmet demand on streamflow; rather, they only account for the impact of reallocating direct runoff to GW and baseflow. Specifically, either the methods or the simulation results in figure 5 are incomplete. Results in figure 5 are said to represent scenarios 1 and 2, but according to the description in the text (l 308-316), they only include the effect of increasing recharge, not the impact of increasing ET by meeting unmet agricultural demand. If the results include the impact of meeting unmet demand and having that go to ET, that needs to be stated clearly on l 308-316—and I would argue that’s not an appropriate and even misleading simulation, since it presumes increased subsurface storage with no increased ET by irrigation expansion. Figure 5 makes it look like there's no impact of the scenarios in annual flow, which I find hard to believe if you're increasing ET significantly to meet unmet demand. As presented, figure 5 presents an overly optimistic scenario of the impact of meeting unmet demand since only the partitioning of flow from infiltration excess overland flow to gw recharge is simulated, not the impact of increasing ET by meeting unmet demand. The authors say they’d need to do a complicated sw-gw flow model with pumping to simulate the impact, but they could simply remove the unmet demand from the GW store in SWAT, no? otherwise, I think Figure 5 is not publishable"

I agree with the above comment, and I don't see it addressed adequately in the responses. The scenarios show increase in baseflow beyond the base case, but groundwater extraction would lead to a decrease in baseflow in the irrigation months. So Figure 5 is incorrect, especially in the months that irrigation is occurring.

Answer:

We agree with the editor’s view on this section. We have conducted a detailed analysis of the effect of groundwater pumping on the base flow and added a new table (Table 5) instead of the Figure 5. First we have estimated monthly water requirements for additional irrigation areas based on FAO 56 (Allen et al, 1999). Then in the SWAT model, these volumes removed from the groundwater storage to implement the pumping scenarios. Results of these simulations are presented in Table 5. Following is the additional analysis added to the manuscript.

Effect of enhanced groundwater recharge and increased pumping on the hydrology

Although runoff is available to store in sub-surface storage (as presented in Table 3 and 4), it is pertinent to scrutinize the effect of enhanced groundwater recharge and increased pumping on dry season and peak flows in the stream and on downstream water availability. This is demonstrated for the Ramganga sub-basin by simulating hydrology for the baseline scenario and two alternative scenarios: 35% increase of groundwater recharge compared to the baseline – S-35; and 65% increase of groundwater recharge compared to the baseline – S-65. Increase of groundwater recharge was implemented in the calibrated SWAT model by changing the curve number (CN). Groundwater pumping was implemented in the SWAT model by removing water from the groundwater storage. The groundwater pumped is assumed to be consumptive use for ET and hence lost from the system. In Amarasinghe et al (2016), scenario 2 of unmet agriculture water demand indicated that the agricultural areas in Ramganga sub-basin could be increase by another 160,000 hectares. Thus for this analysis we only consider scenario 2 of the unmet agriculture water demand. In this analysis we assume that the additional agriculture area will be wheat as this crop is predominantly grown during the period of November to March. To estimate water requirements for additional wheat areas from November to March, Crop coefficients (k_c) for wheat, as obtained from FAO56 (Allen et al, 1998) for similar climatic conditions and crop development stages were used. The Penman-Monteith method served to estimate the daily reference evapotranspiration (ET_0) as required for the crop water requirement estimations. Estimated water requirement for wheat was calculated as 520 mm, which is within the range of recommended water requirements (450–650 mm) for regions with similar settings (see Doorenbos and Kassam 1979).

Table 5 shows the effect of enhanced groundwater recharge and increased pumping on the base flow and total stream flow at the main outlet of Ramganga (Bm^3) . Columns 1-3 (c1 to c3) presents the total stream flow at the main outlet of Ramganga sub-basin under baseline (BL), S-35 and S-65 scenarios respectively. Columns 4 to 6 show the simulated monthly base flow under the three scenarios. Additional water required to expand irrigated wheat area of 160,000 hectares during the period November to March (as discussed in Scenario 2 of the unmet agriculture water demand) is presented in column 7. Effect of additional pumping under S-35 and S-36 is presented in columns 8 to 13. Column 8 shows the monthly base flow if 100% of the additional area is irrigated by groundwater under S1 scenario while values in columns 9 and 10 estimated by assuming 50% and 60% of the 160,000 hectares are irrigated.

Table 5: Mean monthly distribution of river flow and base flow in Ramganga sub-basin under different groundwater recharge and abstraction scenarios (BL –Baseline scenario, S1 – 35% increase of groundwater recharge, S2 – 65% increase of groundwater recharge)

month	Flow			Base Flow (Groundwater Recharge scenarios)			Additional water requirement	Base Flow Additional Irrigation Scenarios S-35			Base Flow Additional Irrigation Scenarios S-65		
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
	BL	S-35	S-65	BL	S-35	S-65		100%	60%	50%	100%	70%	60%
Jan	0.217	0.237	0.303	0.164	0.228	0.292	0.132	0.089	0.148	0.178	0.111	0.159	0.186
Feb	0.229	0.259	0.314	0.143	0.175	0.210	0.126	0.089	0.149	0.179	0.104	0.149	0.174
Mar	0.204	0.220	0.256	0.202	0.243	0.286	0.104	0.123	0.205	0.246	0.142	0.203	0.237
Apr	0.152	0.180	0.206	0.17	0.200	0.230	-	0.087	0.145	0.174	0.099	0.142	0.166
May	0.09	0.105	0.119	0.096	0.113	0.129	-	0.046	0.077	0.092	0.052	0.074	0.086
Jun	0.817	0.661	0.508	0.053	0.070	0.088	-	0.035	0.058	0.069	0.043	0.062	0.072
Jul	4.566	3.877	3.320	0.428	0.623	0.796	-	0.623	0.623	0.623	0.623	0.623	0.623
Aug	6.381	5.890	5.492	1.557	2.065	2.566	-	2.065	2.065	2.065	2.065	2.065	2.065
Sep	5.745	5.796	5.844	2.335	3.069	3.767	-	3.069	3.069	3.069	3.069	3.069	3.069
Oct	2.304	2.857	3.452	2.1	2.668	3.252	-	2.668	2.668	2.668	2.668	2.668	2.668
Nov	1.114	1.497	1.823	1.005	1.387	1.689	0.097	1.384	1.384	1.384	1.384	1.384	1.384
Dec	0.493	0.683	0.840	0.448	0.623	0.770	0.093	0.277	0.462	0.554	0.351	0.501	0.585

Although 85% of the recharge in Ramganga occurs between July and October, about 80% of the groundwater contribution (base flow) occurs during the period August to November (Table 5). The analysis shows reduction of river flow during the high flow months of July, August and, September, for both scenarios as compared to the BL scenario. Under the BL scenario, the stream flow volume at the sub-basin outlet during this three-month period is 16.7 Bm^3. It reduces to 15.6 Bm^3 and 14.7 Bm^3 respectively when groundwater recharge is increased by 35% and 65% respectively (as compared to the baseline scenario). The overall reduction of high flows during this period is 6.8% and 12.2% for scenarios S-35 and S-65 respectively.

As presented in Table 5, the higher base flow occurs during the four-month period from August to November. The BL scenario indicates about 7.0 Bm^3 of base flow during these four months and it increases to 9.2 Bm^3 and 11.3 Bm^3 when groundwater recharge is increased by 35% and 65% respectively. During the Rabi season (November to March) the increase of base flow under S-35 and S-65 is 0.694 and 1.285 respectively.

Under both S-35 and S-65 scenarios, irrigating 100% of the additional area would result in reduction of base flow below the BL scenario during November to March. However, as presented in Table 5, for scenario S-35, additional irrigation to cover 50% of the new wheat area would still maintain the base flow little above the BL level while irrigating 60% of additional irrigated wheat areas would reduce the base flow volumes below the BL levels. Results, further, indicate that under S-65 scenario it will be possible to supply irrigation to 70% of the additional irrigated area without reducing the volumes of base flow simulated in BL scenario.

References

Allen, R.G., Pereira L.S., Raes D., Smith M., 1999 Crop evapotranspiration: guidelines for computing crop water requirements. FAO irrigation and drainage paper, 56. FAO, 300 pp

Doorenbos, J., Kassam, A.H., 1979. Yield response to water. Irrigation and drainage paper 33. FAO Rome, Italy

Q2: The definition of the seasons is confusing. The terms hot season, dry season, rabi, monsoon, are used without definition. For the scenarios, is the hot season the kharif season, or a third cropping season? The seasons need to be defined, with months of each in parentheses.

Answer: Definitions of the seasons were added to the manuscript.

Q3:The hydrological terms are confusing and inconsistently used. "Surface runoff" is defined by the authors as what's left after ET and infiltration on the hillslope, before the water reaches the stream (L 209), but I think they a really defining it as the direct runoff produced by the SCS curve number (also known as quickflow, which is equal to infiltration excess overland flow if there's no saturation overland flow or subsurface stormflow). Direct runoff computed using SCS is not what's left after evaporation and infiltration—it's what's left after infiltration. Water that's left after ET is recharge, which can eventually become baseflow. Usually, surface runoff is defined as the total flow in a stream, including baseflow and direct runoff. In the abstract and L 330 they refer to "net gw recharge", but I didn't understand the term, since all GW eventually becomes streamflow or is used for ET by pumping (which I don't think is included *in their model). The authors need to very carefully define their hydrological terms and make sure they are consistent with the hydrological literature"*

Answer: We agree with the editors comment and the used terminology is clearly described in the manuscript. Following clarification is added to the manuscript.

The spatial and temporal distribution of the annual runoff is analyzed to determine the water availability in different sub-basins. River flow includes direct runoff, lateral flow and base flow from groundwater, which can be captured by diversion or from dams. Direct runoff is calculated in SWAT using SCS curve number method (SCS, 1972). In standard hydrological definitions, it is infiltration excess overland flow, which is part of precipitation that is left after infiltration. It can be captured for MAR before it reaches the stream (in this paper runoff is referred to the direct runoff calculated by SWAT). Therefore, only the runoff portion was considered for augmenting SSS. Figure 2 shows the simulated catchment-scale mean annual runoff.