Reviewer #1

General comments: This is a well-presented and interesting paper that makes a useful contribution to the projection of water resource availability in the Ganges basin and elsewhere. The use of a range of outputs from models of climate, water demands and land use is novel and allows for particularly valuable exploration of relative impacts and uncertainties. However, while the climatic projections come from well-developed models, the land use and water demands are fairly crude, not very well justified, and may be internally inconsistent. Revisions focusing on improvements in this area could improve the paper substantially and make it an excellent exemplar of a widely-applicable methodological approach. In the absence of such improvements the conclusions of the study are not fully supported and would have to be significantly qualified.

Specific comments:

Introduction: The first (long) paragraph doesn't really need so many population statistics; they would be better grouped and trimmed.

This paragraph has been edited and trimmed down in response to both reviewers' comments.

Research hypothesis, lines 112-114: This hypothesis is not fully tested as currently worded, because the land use impacts are not assessed individually. Doing so, especially if more advanced/diverse land use 'scenarios' were used, would be very useful.

We have now tested this hypothesis by assessing the land-use change impacts individually. To do this we held the meteorology constant to historical levels, and run the model with the 15 different land-use scenarios. In addition to examine some more diverse / extreme land use scenarios, we implemented a sensitivity test in which the model climatology was held constant and we assumed 100% coverage by each of the 8 land cover types. Extra figures and text has been added throughout the manuscript to reflect these additions.

When only land-use change is taken into account, different land-use pathways project different types of change for Q5: one of the pathways (08-10) is projecting an increase of 1.3%, other pathways are projecting decreases of up to 0.5%. For low flows, exceeded 95% of time (Q95), all pathways are projecting a decrease, ranging from 11.8% to 19.5%. In terms of evapotranspiration, when the model was run with the 15 different land-use pathways and the outputs compared against the 2010 land cover map model outputs, the changes are of the order of ±1.9 %. For soil moisture tha changes relative to the 2010 land cover map model outputs range from -1.8% to +6.8%, depending on the land-use pathway.

Land use 'scenarios', Section 2.4: These 15 projections of land use change are not wholly convincing, and certainly not as useful as they could be, for a number of reasons. 1) 2000-2010 is a very short time-period, during which highly specific factors may have driven land use transitions. Is there any reason to think this particular period will be representative of future change?

The Markov chains method is based on the assumption that the driving forces that produced changes in the past will continue to do so in the future. This assumption is not always true, especially over long timescales, which is why we chose to apply the method only for the period from 2000 to 2010, a period with high frequency of available land-cover maps (one map every two years).

Another reason we decided to apply the method only for the 2000-2010 period is because we assume that the more recent trends are likely to continue in the nearby future. For example, in the initial stages of the green revolution (1960s-1970s), the agricultural area expansion was achieved through deforestation (Singh 2000). But since the early 1990s, India has pursued a policy of afforestation and reforestation in an attempt to protect its existing resources (FAO, 2011). We therefore assume that more recent trends such as forest growth but also urbanisation & crop expansion are likely to continue. But even over that more recent period (2000-2010), the trends in different matrices vary, generating diverse pathways of future change.

2) They are not really 'scenarios', in the sense that they don't represent coherent and alternative futures, but simply extrapolations of arbitrary (and overlapping) time periods.

The reviewer's point is fair, in that the "scenarios" do not represent coherent futures. However, they do represent alternative pathways of future change. The Markov chain analysis used to develop these scenarios is a simple method for projection of trends and, regardless of its limitations, it can serve as an indicator of the direction and scale of future changes (Bell 1974). We have replaced the word "scenarios" with the word "pathways".

3) There's an inconsistency in assuming, on the one hand, that future change will follow the same trends as observed in the past but acknowledging that, on the other hand, past trends depend on the time period you consider. Why should these 15 projections differ, and what does that mean for future change? And why use all 15 possible combinations?

Before developing future projections of land use, we tested the method in a previous study, over the same area, to examine its accuracy (Tsarouchi et al., 2014). As a validation measure of the ability to generate future land-cover scenarios under Markov chain analysis, we used transition matrices of years previous to 2010 and generated maps for the year 2010. These maps were then compared to the historic land-cover map of 2010. The results showed that the generated maps for 2010 were not very different compared to the historic map of 2010. Highest overall uncertainties were observed for the forest and shrubs land use types. For example, the proportion of forest in the historic 2010 map was 17.12%, while the two most extreme values of forest coverage that we obtained through Markov chain analysis were 19.98 and 15.20%. This gave us confidence to apply the same method for developing other near-future scenarios.

We acknowledge that there are more sophisticated models that can generate future scenarios of land-use change. However, the data requirements of such dynamic-based models do not allow for their implementation in a data-scarce region such us our study area.

We decided to use all 15 possible combinations because there was no straightforward way to select a single or a few of the projections, as more representative of future change. We feel that by keeping all 15 scenarios, we obtain a good indication of the uncertainties associated with developing scenarios of future change and their often contrasting impacts on hydrological variables. Besides, as shown in Figure 3, the variations between the different pathways are not large and some trends of change are clearly identified in most (and some cases all) of the scenarios, such as forest growth, urbanisation, loss of bare soil, grasslands and shrubs.

We have now added some text justifying the above choice in Section 3.2 of the manuscript.

4) There's also a risk of inconsistency with the other (climatic and water demand) model inputs, though this is obviously lessened by the fact that the study only runs until 2035. Still, are the same land use changes really consistent with both (contrasting) climate scenarios, and with a single water demand scenario? This issue seems to require substantially more thought and explanation, preferably with respect to the underlying processes of land use change, to develop and justify scenarios that account for past change in a coherent way and that are consistent with other assumptions about the future.

As mentioned above, the land use change projections are consistent with recent trends of change. We make the assumption that some of the changes that took place from the 1960s until the 1990s such as deforestation can't continue indefinitely. The combination of different land use and climate scenarios enables an exploration of the hydrological impacts of different drivers of change, and assessment of the interactions between these drivers.

Land-use projections across RCP 4.5 and 8.5 vary substantially. In RCP8.5, developing countries experience net increases in agricultural land, and urbanisation, while forest cover declines. In RCP4.5, due to afforestation & reforestation policies the extent of crop and grass land declines and the forested area increases[1].

The reviewer's point is correct and we've added some text to discuss potential inconsistencies between the different model inputs in the Discussion Section of the paper. Although it's difficult to point to exact scenarios that match with each other, we do believe that there is some consistency in amongst particular land use pathways and RCP scenarios. For example, the forest growth and grass decline of RCP4.5 is reflected in most of the land use pathways. Also, crop loss occurs in both RCP4.5 and scenarios 00-02,00-10,04-10,06-08,06-10,08-10. With regards to RCP8.5, urbanisation occurs in all land-use pathways, in agreement with this RCP.

Water demand data: As above, the use of this data is not really consistent with the other (RCP and land use) scenarios, since water demand is so strongly dependent on both land use and climate, and so should vary depending on those scenarios. At the very least, the extrapolation of past land use is unlikely to be fully consistent with either climate scenario, and the extrapolation of past water demand cannot be consistent with all 15 land use scenarios. I'm not sure that fully consistent water demands can be derived here, but some clear acknowledgement of these issues is certainly needed, especially when it comes to interpreting the results.

We acknowledge the points the reviewer is making. The projected water demand data assume a business as usual (BAU) scenario and are mainly based on recent trends of water and food demand drivers. According to the Amarasinghe (2007) study, these projections are consistent with further urbanisation (assuming a population growth of 1.3% over the period up to 2025 and 0.52% growth between 2025 and 2050). Further, the BAU scenario assumes continuous irrigation expansion. Given that these water demand projections are mainly based on the extrapolations of recent-year trends, we do identify some consistency with RCP8.5 (which is considered to be a BAU scenario) and also with some of the land-use change trends in the 15 scenarios used in our study (e.g. urbanisation, agricultural expansion). We have added some text in the Discussion Section of the paper to acknowledge these issues.

[1] https://www.sei-international.org/mediamanager/documents/A-guide-to-RCPs.pdf

Figure 4: This type of plot is not very suitable here as the scenario-based changes are not measurements of the same things. It would be better to simply plot all the values. Also, could an explanation for the projected increase in snow cover be provided? This seems to contradict the climate scenario results.

We replaced the figure with a new one that plots all the values. As it shown now, the snow cover is projected to increase in 5 out of 15 scenarios, whereas in the other 10 it is projected to decrease. In any case, the change in snow coverage is very small.

Discussion: Depending on the revisions made to the scenarios, the discussion section needs to do more to explain and interpret the effects of those scenarios. The results are clearly highly conditional on scenario definitions, and with such a limited range as there are at present it's hard to draw any strong or general conclusions. A couple of additional specific points below:

Lines 363-369: This is an almost verbatim repetition of section 2.5. Since it's in the Discussion, perhaps add some justification of assuming that water demand in contrasting futures will follow the trend from one period of the past? And some discussion of what this means for interpretation of the results?

This has been deleted and the next paragraph rephrased. We have added some justification for the water demand assumption and what this means for results and their interpretation.

Line 383: 'the main driver of future change ... is not land use change' is far too general a statement, given the highly limited nature of the 'scenarios' used. In fact I would suggest deleting this and going straight into the next sentence. Further, the point here (repeated in the conclusion) that land management is more important than land use is not derived from this work, and should be referenced.

This sentence has now been modified, referenced and moved to the next paragraph.

Figures and Tables: These could be trimmed, with some moving to the supporting information. Specifically, Figures 2 and 3 could be combined, and Table 1, Table 2, Figure 5, Figure 7 and Figure 8 removed from main text without losing any essential information.

Figures 2 and 3 were combined. Figure 5 was removed from the text. Table 1 and Figures 7 & 8 were moved to Appendix A. We decided to keep Table 2 in the main text as it provides clarity in relation to the sets of model experiments we did.

Technical comments:

General: There are too many abbreviations, which make the paper hard to read in places. Those that seem particularly unnecessary include 'UG' for Upper Ganges, 'DJF' etc. for seasons (e.g. December-February / dry period), 'ET' for evapotranspiration, 'SM' for soil moisture.

We have removed the abbreviations for ET, SM and UG but we believe that for seasons it makes sense to keep abbreviations that are widely used (DJF, MAM, JJA).

Abstract, line 7: Future projections aren't themselves affecting the hydrological response – better as 'might affect'?

Done

Abstract, line 16 and elsewhere: Calling the land use projections 'scenarios' is not really accurate, as mentioned above.

The word "scenarios" has been replaced by the word "pathways"

Line 41: 'expects' rather than 'eyes'?

Done

Lines 88-89: comma needed after 'concentrations'

Done

Line 117: Please reference (some of) these 'few studies'

We have now added some references (lines 69-70 in the updated manuscript)

Line 182: comma after '5 & 6' isn't necessary.

Removed

Table 1: The 'Country' column doesn't seem particularly relevant?

This table is moved now to the Appendix (as per the reviewer's suggestion) and we decided to keep the Country column in place.

Line 329: Clearer if 'results are presented' is deleted?

Done

Line 335: 'calculated' rather than 'presented'?

Done

Line 346: 'compared to historic values' seems unnecessary

Removed

Reviewer #2

The topic and approach of the paper is interesting and relevant for the journal scope. The combined analysis of climate change and land use change impacts is rarely addressed despite its relevance for future water resource assessment. English is correct, but the narrative is sometimes messy making the paper to lose the flow of ideas (i.e. in the introduction and methods sections). The results section is well explained and supported by (relevant) figures and tables. The discussion lacks depth and linkages with other comparable studies.

Detailed comments can be found in the attached document.

We have replied to all Reviewer #2 comments in the attached document. Please find our responses as replies to each comment on the commenting tab.

References

Rasquinha & Sankaran (2016). Modelling biome shifts in the Indian subcontinent under scenarios of future climate change. Current Science, Vol. 1 11 , No. 1, 10 July 2016

Andreassian V (2004) Waters and forests: from historical controversy to scientific debate. J Hydrol 291:1–27

Calder IR (1993) Hydrologic effects of land-use change. In: Maidment DR (ed) Handbook of hydrology. McGraw-Hill, New York, pp 13.28–13.29

Solin, Feranec and Novacek (2010). Land cover changes in small catchments in Slovakia during 1990–2006 and their effects on frequency of flood events. Nat Hazards (2011) 56:195–214. DOI 10.1007/s11069-010-9562-1

FAO (2011). Global Forest Resources Assessment 2010

Singh, R. B. (2000). Environmental Consequences of Agricultural Development: A Case Study from the Green Revolution State of Haryana, India. Agriculture, Ecosystems & Environment 82: 97–103. doi:10.1016/S0167-8809(00)00219-X.

Bell (1974). Markov Analysis of Land Use Change-An Application of Stochastic Processes to Remotely Sensed Data. Socio-Economic Planning Sciences 8 (6): 311–316. doi:10.1016/0038-0121(74)90034-2.