Title: Influence of climate change, land use land cover, population and industries on the pollution of Ganga River

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MS No: egusphere-2022-796

MS type: Research article

Response to Reviewer#2

This paper has integrated hydrological, LULC, and water quality data with the climate change simulation models to derive projections on water quality in one of the most polluted stretches of the Ganga river around Kanpur. While the concept and idea of the paper are sound, the paper is not very coherent and organized. There are also several; issues with the language several sections need a thorough rewriting. The figures are very bad, and they need to be redrawn. My specific comments on different sections are as follows:

We thank the reviewer for the comments and suggestions on the overall presentation. In the revision, we will make the changes for a well-organized coherent presentation. We will modify the text for better clarity. Also, we will make the discussion more generalized. We will also make changes to the illustrations (Figures) so that they are visually appealing.

Abstract: The abstract starts by saying that they have analysed the 'most' polluted stretch of the Ganga River but the definition of the stretch comes much later. In any case, this definition of the 'most' polluted stretch (Kanpur) may be debatable, and it may be better to replace this with 'one of the most polluted' stretches. There are minor language issues that I have marked.

We appreciate this suggestion. We will make the suggested change in the abstract.

Introduction: The introduction sets the background and motivation well but lacks comprehensive referencing. The Ganga river has been studied quite extensively for water quality including modeling efforts by Indian workers. It is suggested to include a short review of these papers and more importantly presents a summary of water quality data to justify the pollution level of this stretch vis-à-vis global standards. Interestingly, the authors do not present the actual number of WQ parameters anywhere except in the plots with modeling results. It would be useful to let the readers know the pollution status of the river early in the paper.

Thank you for the suggestion. In the revision, we will include a short review of the studies on Ganga River water quality and cite the relevant literature in the Introduction. We will add a new figure in the Supplementary showing historical water quality plots to know the pollution status of the river. Also, a new figure of water quality profile plot of the historical period with the low flow for water quality parameters considered will be added in Supplementary. We will add a discussion on the actual observed WQ parameters in the newly added figure legends.

Following references of Ganga water quality studies will be added:

Kamboj, N. & Kamboj, V. Water quality assessment using overall index of pollution in riverbed-mining area of Ganga-River Haridwar, India. Water. Science 33(1), 65–74, https://doi.org/10.1080/11104929.2019.1626631 (2019).

Sharma, P., Prabodha Kumar Meher, P. K., Ajay Kumar, A., Gautam, Y. P. & Mishra, K. P. Changes in water quality index of Ganges river at different locations in Allahabad. Sustainability of Water Quality and Ecology 3(4), 67–76 (2014).

Bhutiani, R., Khanna, D. R., Dipali Bhaskar Kulkarni, D. B. & Ruhela, M. Assessment of Ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices. Appl Water Sci 6, 107–113 (2016).

Jain, C. K. & Singh, S. Impact of climate change on the hydrological dynamics of River Ganga, India. Journal of Water and Climate change, https://doi.org/10.2166/wcc.2018.029 (2018).

Kumar, C. et al. Seasonal dynamicity of environmental variables and water quality index in the lower stretch of the River Ganga. Environ. Res. Commun. 3 075008 (2021).DOI 10.1088/2515-7620/ac10fd.

Ali, S. Y., Sunar, S., Saha, P., Mukherjee, P., Saha, S., Dutta, S. Drinking water quality assessment of river Ganga in West Bengal, India through integrated statistical and GIS techniques. Water Sci Technol 84 (10-11): 2997–3017 (2021).

Dwivedi, S., Mishra,S. and Tripathi, R. D. Ganga water pollution: A potential health threat to inhabitants of Ganga basin. Environment International 117: 327-338 (2018).

Study area and Methodology: This section is generally okay but again the authors use subjective assessment of WQ parameters such as BOD, Chemical oxygen demand (COD), solids, TN, chromium, sulphate, sulphide and chloride without providing any data.

Thank you for the comment. Lines 131-132 are general information on industrial effluent pollutants. The data are obtained from IIT Consortium reports and Kharayat, 2012. The discussion on effluent constituents was provided in the manuscript for general understanding.

We use the drain data as the point load input (Table S1) for water quality simulation. We understand that the sentence creates unnecessary confusion. Hence, the remark on water quality parameters will be deleted. The following reference will be added to the revised manuscript.

(Kharayat, Y. Distillery wastewater: bioremediation approaches. Journal of Integrative Environmental Sciences 9(2): 69–91(2012).)

Figure 1 is very badly drawn and does not reflect the rigour expected for a manuscript. The Ganga basin map is directly taken from the website, and the subbasin maps lack details of the site, drainage network, major locations etc. The schematic diagram is very poorly drawn and various symbols have not been explained. It is also not clear how this diagram was prepared and the data source for this figure should be cited.

We appreciate the suggestions for improving the quality of Figure 1. In the revision, we will make the suggested improvements and provide the data sources for this figure.

Similarly, Figure 2 is poorly formatted and it seems to be a part of some report rather than a manuscript figure. This needs to be simplified and made legible – the idea of this figure should be to provide an overall view of the methodology and details of different kinds of models and specific parameters can be minimised.

In the revision, we will make the suggested changes and provide a simplified overall view of the methodology and avoid too many details.

Also, this can be shortened a bit by improving Tables 1 and 2 and avoiding duplication of information between text and tables.

In the revision, we will make the suggested changes to Tables 1 and 2 and avoid duplication of information between text and tables.

Results and discussion: The results section is generally well-written and the interpretations are clear. However, the figures need a lot of improvement to make these publishable and to bring clarity. In Figure 4, the plots are too small to see the different classes and there is too much blank space. You can also combine the legend. Parts e and f might be better represented as column graphs.

Many thanks for this comment. In the revision, we will improve the readability of Figure 4 as per the suggestions.

Some specific comments are as follows:

Line 373 says that the effect of landuse changes on stream flow is more pronounced at sub-basin level but there is no analysis done at this scale. Therefore, I am not sure why this statement is required here. Also, I am not convinced about the statement itself. River basins are completely hierarchical and impacts should be visible at all scales. In fact, you are analyzing at sub-basin scale only. You must explain why the impacts of LULC changes on stream flow are not visible at this scale. This is rather contrary to the previous work done in several basins (see e.g. Ocgoa-Tocachi et al., 2016, Hydrological Processes; Buytaert et al., 2004, HESS) including the Ganga basin.

Thank you for the comment. We agree that the sentence is unnecessary. We simulate the streamflow at Ankinghat by considering the entire Upper Ganga basin as the catchment area. The simulated streamflow from the hydrology model at Ankinghat drives the water quality model. This important simplification in our work will be made clear in the revised manuscript. The analysis is not performed at subbasin scale. The prescribed land use land cover projections are small. Hence, the simulated changes in low flows due to land cover change are too small. Line 373 will be deleted in the revision because it leads to confusion.

Ocgoa-Tocachi et al. (2016) show that cultivation, afforestation and grazing have effects on streamflow variability. Buytaert et al. (2004) use the linear reservoir concept to quantify the impact of changes in land use on the hydrology of catchments and observed that water release in a disturbed catchment is faster than in an undisturbed catchment. We use future land use projections and simulate the consequent changes in streamflow. However, our simulation results don't show a notable change in low flow with land use change. The curve number comparison of the baseline with land use projection (Figure S5) shows only a small change. The change detected is very small; hence the streamflow is not much affected.

Line 410-412 again says that LULC alone does not lead to higher pollution but together with climate change it can aggravate it. I really do not understand this and this finding is also quite different from the earlier work done in the same area by Shukla et al. (2018). It is very surprising that the authors have not even cited this paper even though this work is exactly in the same area and on a similar theme. You may or may not agree with the results but omitting such directly relevant papers is not a good practice.

We appreciate these comments. In the revision, we will cite Shukla et al. (2018). which uses statistical methods to assess the correlation between land use types and water quality using 2001 and 2012 for the Upper Ganga basin. In our study, the land use projections have resulted in an increase of 10% in non-point source load. However, the effect of non-point source pollution is found to be small in comparison with the point loads on water quality. The effect of point load is largely affected by the dilution factor, which changes due to changes in river flow with climate change. This discussion will be added to the revised manuscript.

(Shukla, A. K., Ojha, C. S. P., Mijic, A., Buytaert, W., Pathak, S., Garg, R. D., and Shukla, S.: Population growth, land use and land cover transformations, and water quality nexus in the Upper Ganga River basin, Hydrol. Earth Syst. Sci., 22, 4745–4770, https://doi.org/10.5194/hess-22-4745-2018, 2018.)

In general, none of these findings are new in terms of science. The impacts of LULC, population, and industry on water quality are well established. The impact of climate change on some of the specific WQ parameters such as N and P on the Ganga river has also been modelled (e.g. Whitehead et al., 2015, 2018; Jin et al., 2015). So, the authors should clearly highlight what is different in this paper and what new information has been provided. In a broader sense, the findings do not seem to be different from the previous works although the quantum of change etc. might be different. However, this needs to be highlighted clearly in this manuscript.

In Whitehead et al., 2015, 2018; Jin et al., 2015, the overall change in water quality for the future is assessed. However, in this study, we investigate the individual effects of anthropogenic factors such as climate change, land use, population and industrial growth on water quality and identify the factor that contributes the most to water quality deterioration. This assessment is important, especially for highly polluted rivers, to design adaptation and mitigation measures to improve water quality in the future. This novelty of our approach will be highlighted in the manuscript.

Another weakness of the paper is that it lacks any serious discussion on the trends and results obtained from the modeling. All it has presented is different trends and numbers but the process understanding of these projected changes attributed to climate change is missing.

We appreciate these comments. In the revision, we will provide deeper insights into the reasons for the projected changes that are attributable to climate change. Climate change would result in increased air temperature and stream temperature. Increased stream temperature would result in increased reaction kinetics. Also, climate change can lead to a reduction in low flow due to a reduction in precipitation in the pre-monsoon period. This would lead to lower dilution volume for pollutants and deterioration of water quality with climate change. This discussion will be added to the revised manuscript.

The conclusions section brings out some good points, particularly about the STPs and segregation of wastes which was demonstrated by the model. However, I think that this section can be sharpened and made more precise. Since most of these points have already been discussed in the main text, this section should be short and crisp.

We appreciate this comment. In the revision, the conclusion section will be made short and crisp.

Overall, this manuscript presents some good ideas, but it needs significant reorganization and restructuring. The writing as well as the figures need to be improved significantly before it becomes publishable.

Thank you for these positive comments. We will improve the text and illustrations in our revision as per your suggestion.