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

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Response to Reviewer #1

We thank the reviewer for the valuable comments and suggestions that helped us improve the manuscript substantially.

General comments:

The manuscript describes an analysis of how important drivers may impact water quality in a section of the Ganga river by the mid of this century. It makes use of different scenarios for climate change, land use, population development and development of the urban water infrastructure. The topic is highly relevant for science and practice in order to learn how to safeguard water quality in the future. Accordingly, the theme would into the scope of HESS.

Unfortunately, the manuscript falls short of standards for articles in this journal. There are several limitations: one the one hand it is the scope of the manuscript, on the other hand it is its quality.

Scope: The manuscript reads sometimes more like a technical report (site-specific, use of acronyms etc.) for regional managers or authorities than for a general scientific audience. This also expressed in the objective section of the paper by stating that the study shall "… help decision-makers decide in the design of treatment units to ensure water quality." (L. 122 – 123). There is nothing wrong about this objective, but is not sufficient for a scientific article, which should provide insights for a general scientific audience. As listed in the detailed comments below, there are many parts of the manuscript that lack this general interest but are very site-specific.

We appreciate this comment. We will modify the writing to include a more general discussion which will be of interest to a wider scientific audience. We acknowledge that the current writing style includes discussions that are site specific, which makes it sound like a technical report. However, the problem which we focus on is more general. The individual influence of anthropogenic factors such as climate change, land use, and industrial and population growth on water quality is the main focus of the study. We answer it with the Ganga river as a case study. Explanations and objectives, however, are more generalized. The second objective will be modified as 'to assess whether the proposed treatment can cater for additional pollution load due to anthropogenic activities'. The two locations considered in the manuscript represent a pollution hotspot (downstream of high point load confluence) and a location far away from the point loads. The results concerning Kanpur are likely applicable to hotspot regions of other polluted rivers, and results relating to Shahzadpur are likely applicable to locations that are less affected in a polluted river. In the revision, discussions will be more generalized. Also, the discussion on the results of the second objective will be more generalized. These are important points for managing any polluted river, and the study also shows the importance of considering anthropogenic factors, especially climate change, for designing sewage treatment plants for the future. These points will be given more emphasis in the revised manuscript.

Quality: The narrow scope of the study is a lack of scientific quality in itself (for a scientific article). There are additional limitations regarding the content and the way the methods and results are presented. Conceptually, the study seems to only reflect an arbitrary fraction of a hydrological system that requires a more comprehensive view. This holds true first for the spatial aspect: the authors present results for only one part of the Ganga watershed neglecting the entire upstream catchment including its influence on the study area downstream.

We appreciate the comment. We agree that more clarity is required in the text. We do not consider an arbitrary fraction of a hydrological system; instead, we consider the entire hydrological system upstream to the point of interest. Also, we model the hydrological processes in the Upper Ganga basin, the entire catchment area contributing streamflow to Ankinghat in the HEC-HMS model. We have set up a hydrological model HEC-HMS to simulate the streamflow at Ankinghat (headwater boundary for water quality simulation model) considering the entire Upper Ganga basin up to Ankinghat. Simple Canopy, Simple Surface, SCS curve number method, SCS Unit Hydrograph, Constant Monthly Baseflow, and Muskingum are the methods used for modelling the canopy, surface, loss, transform, baseflow, and routing, respectively. The model is calibrated for 1977-2002 and validated for 2003-2012. The precipitation and temperature inputs corresponding to climate change scenarios for the Upper Ganga basin are given as input to the hydrological model to simulate the streamflow at Ankinghat under climate change scenarios. The modified curve number for the Upper Ganga basin is calculated with land use projections and is given as input to the hydrological model to simulate streamflow at Ankinghat corresponding to land use projections. We will state in the revised manuscript explicitly in section 2.2.1 that the analysis is carried out for the entire Upper

Ganga basin. We will add the Upper Ganga basin in the discussion sections 3.1.1, 3.1.2 and 3.2, where the results concerning the Upper Ganga basin are presented. We will modify the sentences to bring in more clarity.

Second, it turns out (semi-)implicitly that only dry weather conditions (the non-monsoon season) is considered without providing data and a rationale why this specific analysis makes sense compared to a holistic view considering the entire annual (hydrological) cycle.

Thank you for the comment. The water quality is poorest during the low flow period due to the lower dilution water available. The design flow (30Q10) for water quality is used here for the analysis. Also, previous studies have shown that low water quality occurs during summer, which corresponds to low flow periods. The justification for using low flow will be included in section 2.2.2 in the revised manuscript. The value of 30Q10 value considered is given in Fig 3(d). Unfortunately, we are unable to provide the streamflow time series data due to restrictions applied to it. However, the 30Q10 value computed is shown in Fig 3 (d).

Third, the information regarding the urban water management and its relevant components is very limited. Because the readers for example do not get information about the structure of sewers systems, the degree of connectivity to treatment plants etc., it is difficult to judge statements on measures such as affecting mixed sewers.

The locations where the drains join the study area are shown in Figure 1 (b), and the drain data, whether mixed or domestic sewage, is carried by the drain, flow, and quality characteristics, pH, BOD, ammonia, nitrate and phosphorous are provided in Supplementary Table S1. These descriptions of urban water management are provided in the section on the Study area. The type of industries contributing to each drain is listed in Supplementary Table S2. The catchment area for each drain is given in Supplementary Table S10. All other additional information on urban water management is provided in Supplementary Text S6. These will be discussed in the sections on the study area, methodology and results & discussion in the revised manuscript.

Also the state of the art of water treatment of relevant industries such as tanneries (L. 131) is not explained. This leaves a reader wonder to which degree the current status reflects best practices such as described in pertinent documents (https://leatherpanel.org/sites/default/files/publications-attachments/common_effluent_treatment_plant_amburtec_ambur_india.pdf).

Thank you for the comment. The effluent from Tannery industries in the study area (Verma, 2014) is given secondary-level treatment. This information will be included in the manuscript (L131). The industries which are discharging beyond effluent disposal limits are getting shut down in the Ganga basin by the Central Pollution Control Board, India. Therefore, we assume that the industries discharge within effluent disposal limits. Hence, the level of treatment given in industries is not focused. Instead, the level of treatment at sewage treatment plants is considered. We do have drain data (Table S1) for modelling water quality. In the stretch considered, there are 487 grossly polluting industries discharging to the Ganga river, and the effluent data for each individual industry is not available. These discussions will be included to Supplementary.

(Verma, R. Assessment for Approaches for Eliminating Use of Fresh Water in Tanneries at Jajmau, Kanpur. M.Tech Thesis Indian Institute of Technology, Kanpur (2014).)

There are also issues with the literature used, which seems at least partially outdated with relevant papers on the topic and the Ganga river missing (e.g., Bowes et al., 2020; Khan et al., 2018; Nepal & Shrestha, 2015). Other articles are cited (e.g., Chawla & Mujumdar, 2018; Jin et al., 2015), but the respective key findings are not really considered and discussed.

Bowes et al., 2020; Khan et al., 2018; Nepal & Shrestha, 2015 will be added in the revised manuscript.

We have used the land use projections from Chawla & Mujumdar (2018), and the details of the same are discussed in the manuscript. The discussion on Jin et al. (2015) will be elaborated in the revised manuscript.

We will also cite the following studies on water quality studies in the Ganga river.

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).

Question marks exist also for some specific aspect regarding modelling and the data analysis. The model for example is only accounting for steady-state flow. This is only mentioned in the SI (Sec. S3). How are then transient conditions modelled? Or did the authors only model steady-state low flow conditions, neglecting any impact during rainfall (including non-point sources from urban and agricultural areas affecting P and coliforms, for example)? On the data analysis side, I have doubts whether the different nitrogen forms are correctly treated or whether nitrate and nitrate-N for example have been mixed up (see also the comment below):

Thank you for the comment. We have used only low flow analysis to compare the anthropogenic effects. The design low flow (30Q10) calculated for the period 2040-2060 is used to represent the future time period. The water quality is the poorest during the low flow periods, and the effect of anthropogenic factors is expected to be high during this critical period. Therefore, we are interested in assessing the individual effects of anthropogenic factors during the low flow periods. This discussion will be included in the methodology section of the revised manuscript. QUAL2K model is a steady state model, hence, has its limitation in time series simulation. However, our study uses only design low flow runs in QUAL2K. Hence, transient conditions are not modelled. The non-point source pollution is simulated for the future, corresponding to the design low flow. The non-point source pollution variation seasonally was calculated in our previous paper Santy et al. (2022).

Nitrate-N is nitrate concentration expressed in mg/L of Nitrogen. We will use the same notation in the revised manuscript.

Apart from the content-related issues, the manuscript is hard to follow because the text is often poorly structured, figures and figure captions are not always very clear (see also below for details) or even showing contradicting results (e.g., Fig. S13 and Tab. S9). The water quality model calibration for example, which is an essential part, is poorly described. The fundamental information is only provided in the SI (Section S3). The description is hard to follow. It is not very transparent which data has been used and where and from when data is available (only 3 grab samples during low flow conditions)? This makes it hard to get a complete and consistent understanding (e.g., how to reconcile Fig. 5 with Fig. S10?).

Thank you for the comment. We will improve the manuscript by bringing out more clarity in text, figures and figure captions. Figure legends will have more details in the revised manuscript. The model is already set up in our previous papers, Santy et al. (2022 & 2020); hence details are provided in Supplementary. An explanation of the data used will be added in the model description section. More explanation will be added wherever required, as mentioned in detailed responses. Fig S13 shows calibration results, and Table S9 shows validation results. Figure and Table legends will be modified for better understanding.

Detailed comments

20: what are mixed sewers in this context?

Mixed sewers are sewers that carry domestic as well as industrial sewage. This explanation will be added in the revised manuscript.

23: Kanpur is not mentioned before. Why is this relevant? Is it relevant for the general scientific audience or the regional authorities?

Yes, we agree. We will indicate that the study is conducted on river stretch passing through Kanpur in Abstract. Kanpur is the most polluted city discharging into the Ganga river. It can be considered as the representative of pollution hotspots of any polluted river. The hotspot considered in our paper receives industrial and domestic sewage along with non-point source pollution from agriculture. The individual contribution of anthropogenic factors to water quality change at the hotspot reveals which all anthropogenic factors should be considered before taking any mitigative measures to control the pollution of the river. It is relevant for the scientific audience as it brings in the importance of considering anthropogenic influence for designing a treatment unit. Also, it is helpful for regional authorities so that they can take appropriate actions to contain future pollution. An explanation of its relevance to the general audience will be added in the revised manuscript.

23 – 24, 28 – 30: These statements are contradictory: If proper STP development leads to good water quality, this seems to offset the climate change effect. This implies that management has a stronger effect that climate change.

Thank you for the comment. We agree that proper clarity is lacking in the manuscript. STPs are built to contain pollution. They are designed for future populations and based on funds available. Climate change can lead to poor water quality if no mitigation measures are taken. In our manuscript, we propose the mitigation measures that are feasible for the study area considered under climate change. Proper management strategies such as STP development are required to offset the deterioration of water quality due to climate change. The sentence will be restructured in the revised manuscript for better clarity.

31: Keywords shouldn't repeat words already used in the title.

Keywords will be modified to "water quality, Ganga action plan, anthropogenic influence, and sewage treatment plant" in the revised manuscript.

36: As I read the cited article, there is not much information on how such a proper management looks like.

The following references will be added to substantiate the statement.

Anawar, H., M., and Chowdhury, R. Remediation of Polluted River Water by Biological, Chemical, Ecological and Engineering Processes. Sustainability 12: 7017 (2020). doi:10.3390/su12177017

Yibo Wang, Y., Liu, Y., Huang, J., Wu, T. and Huang, J. Analysis and Prevention of Urban River Pollution. J. Phys.: Conf. Ser. 1549 022056 (2020).

L: 48: Does the problem only exist in that area?

No, the problem exists in other areas, also. As per CPCB (2013), out of 764 grossly polluting industries discharging to Ganga, 487 are from Kanpur. Agricultural land is the prominent land use type in the study area which can lead to increased non-point source pollution. The high industrial and domestic sewage, along with agricultural runoff, makes Kanpur a highly polluted spot in the Ganga river. This discussion will be added to the revised manuscript.

48 – 57: This is very site-specific. What are the general scientific issues to be shared in HESS?

We agree that the details are site-specific. The general scientific issue that we discuss in this manuscript is the individual effects of anthropogenic factors such as climate change, land use, population and industry on river water quality and the importance of considering these factors for design purposes. Different management practices are available in other polluted rivers. But the analysis of individual effects of drivers helps understand the major factor and aids in taking proper mitigation strategies to control future pollution. These explanations for general scientific interest will be added in the revised manuscript.

66: What's this scenario?

Thank you for the comment. The scenario referred to is the SRES A1B climate change scenario. We will add 'climate change' along with the scenario in the revised manuscript.

77 – 78: Which limits?

The limits we are referring to here are the effluent disposal limits. We will add 'effluent disposal' in the revised manuscript.

L: 89 – 95: What are the findings of these studies? What questions emerge?

Santy et al. (2020) show that climate change can affect all water quality parameters considered, and land use can affect nutrient pollution. Santy et al. (2022) show an increased risk of low water quality, fish kill and eutrophication for future climate change scenarios. Previous studies show that climate change affects water quality. However, land use projections and industrial and population growth are factors that can affect water quality as well. The individual effects of these factors on an industrial stretch have not been quantified. Also, whether the effect of anthropogenic factors is so high that the proposed treatment won't be sufficient to offset it is not known. These discussions will be added to the revised manuscript.

96: What were the scenarios accounting for?

The scenarios considered are RCP 4.5 and 8.5. It is indicated in the previous sentence.

100 – 103: This are very site-specific statements.

We agree that more clarity is required for the statement. The statement (100-203) is not relevant to only the site discussed in this work. The capacity of a treatment plant is typically designed considering only population growth. This is true for most river basins including the Ganga basin. There is always a chance that anthropogenic factors could reduce water quality, and the treatment given is not sufficient. The following references will be added to substantiate the statement.

Puspalatha and Kalpana, P. Design Approach for Sewage Treatment Plant: A Case Study of Srikakulam Greater Municipality, India. Environ Sci Ind J. 12(9):112. (2016).

Teklehaimanot, G. Z., Kamika, I., Coetzee, M. A., Momba, M. N. Population Growth and Its Impact on the Design Capacity and Performance of the Wastewater Treatment Plants in Sedibeng and Soshanguve, South Africa. Environ Manage. 56(4):984-97 (2015). doi: 10.1007/s00267-015-0564-3.

Sunaina, K., Lubna, C. H. Design of Primary Sewage Treatment Plant for Cherpulassery Municipality. International Research Journal of Engineering and Technology 8 (5) (2021).

106 – 108: Why is this of general interest to the scientific community?

2nd objective will be modified in the revised manuscript: 'to assess whether the proposed treatment can offset the deterioration of water quality due to anthropogenic activities'. There are other polluted rivers like Ganga for which action plans are made to improve water quality in the future. A similar analysis of assessing individual effects of anthropogenic factors helps us understand the important factor which shouldn't be excluded from sewage treatment design.

L: 113 – 117: What is the relevance of the two data sets? They haven't been introduced? The structure of the paragraph is not very logical.

CMIP6 is already in place, and our analysis is based on CMIP5 models. In the manuscript, we provide (L 113-117) our justification for using CMIP5 datasets for the analysis.

L: 122 – 123: Is a meaningful objective, but very site-specific with relevance for the respective authorities. A HESS paper however should provide general insights.

The objective will be made more general in the revised manuscript. The objective will be changed to isolating the effects of the major drivers: climate change, land use land cover, population and industrial growth on water quality in terms of nine water quality parameters and identifying the most crucial driver for *future water quality*. The problem is general across highly polluted river stretches around the world, and it is very important to assess the same before taking management practices to control future pollution of any river.

125, Sec. 21: Essential information is missing: climate, land use, hydrological data etc. Not sufficient for a scientific paper.

The following lines will be added in the revised manuscript in Sec 2.1. Ganga basin has an average temperature varying from a maximum of 30.3°C in the summer to a minimum of 6.4°C in winter months (Central Water Commission and National Remote Sensing Centre, 2014). The basin receives the bulk of rainfall in the summer monsoon, and low flows are experienced during dry periods from November to May (Whitehead et al., 2015b; Santy et al., 2020). The average annual rainfall in the Ganga basin is 300–2,000mm. The basin has a varied topology with elevation ranging from 29 to 7,796m up to Shahzadpur. Agricultural land is the most predominant land use for the Ganga basin. The predominant soil type in the basin's lower part is Eutric Cambisols, which is suitable for cultivation.

(*Reference: Central Water Commission and National Remote Sensing Centre (2014). Ganga Basin. New Delhi: Government of India Ministry of Water Resources.*)

These details will be discussed in the revised manuscript

134 – 136: Fig. 1 is not very helpful in this form. The relationships between the three maps is not clear (panel a). Panel b is not clear either.

Fig 1 will be modified in the revised manuscript for improved clarity.

140, Table S1: Locations not clear; data not clear (in the SI). Insufficient to properly understand the data.

A small schematic diagram of the river will be added in the supplemental material file.

L: 144 – 152: This paragraph can be skipped.

This paragraph gives an idea of drain loadings to the river, even without looking at Supplementary Table S1. Even if a reader doesnt want to read Supplementary, the brief on loading in the manuscript will give them better clarity on loadings and hence the results. Therfore we think it would be ideal if we retain it in manuscript.

161 – 163: Sentence not clear. Have the findings by these authors (Chawla & Mujumdar, 2018) also be considered for the hydrological analysis (e.g., their result about the substantial uncertainty and the non-stationarity)? Are these findings taken into consideration and if yes, how and where?

No, we haven't used their results on uncertainty and non-stationarity. We have used the land use projections for 2040 from Chawla & Mujumdar (2018). We will modify the sentence for clarity.

165: Which city?

The cities mentioned are Kanpur Dehat, Kanpur Nagar, and Unnao. This information is provided in Table S10. This will be added to the revised manuscript, and the table will be cited.

184: One cannot see that well in the SI.

R^2 plot will be added in SI.

187: What's this?

The sentence will be revised in the revised manuscript for better clarity. From the streamflow time series, a 30-day low flow with a return period of 10 years is calculated, and the QUAL2K model is run for a 30Q10 flow.

194 – 195: How important are the headwater fluxes (water, nutrients etc.) for the final results? Where have one to set priorities (up-stream or in the section itself)? -> This could be a relevant question for a general scientific audience!

Headwater fluxes are very important factors determining downstream water quality. It depends on the location where the water quality is of concern. For the location nearby the headwater, the influence of the headwater will be stronger, whereas the location further downstream of the reach will be affected by the point loads in the section. The priorities can be set depending on the streamflow, point and non-point loadings at the location of interest. The individual effects of anthropogenic factors at two locations are compared in the manuscript; we can see that climate change has a higher effect on the Kanpur location, which is nearer to headwater. The effect diminishes as the distance from headwater increases. The climate change effect has reduced headwater flow, and this effect will be more pronounced in locations near the headwater. In the locations away from headwater (Shahzadpur), other drivers, such as population and industrial growth, are found to be predominant, indicating that point loadings in these sections have more influence. For such locations, priorities are to be set in the section itself. This discussion will be added to the revised manuscript.

293 – 294: What happens upstream?

The results of upstream are mentioned in this line. Ankinghat catchment is the Upper Ganga basin which is upstream of Ankinghat. The sentence will be modified in the revised manuscript for clarity.

305 – 306: How is that calculated?

The design low flow used for water quality problem is 30 day low flow with a return period of 10 years (30Q10). 30 day low flow corresponding to each year is calculated, sorted in order and corresponding probabilities are calculated; 30Q10 value is the flow corresponding to 10% cumulative probability. These details are provided in Supplementary Section S4. We will add this reference in the revised manuscript wherever 30Q10 is used.

307, Sec. 3.1.2: This not really a result, but describes the scenarios used as boundary conditions.

Thank you for the comment. We will modify the sentence for clarity. We extracted the land use projections for the study area and calculated the non-point source pollution using the export coefficient method which is discussed in Sec 3.1.2. Hence, they can be considered as results. We will add that non-point source pollution is quantified from land use projections using the export coefficient method in Sec 3.1.2 of the revised manuscript.

318, Sec. 3.1.3: This are not results, but reasons for the scenarios.

Thank you for the comment. We will modify the sentence for clarity. We have calculated the point loads corresponding to population growth and industrial growth, and the results are discussed in Sec 3.1.3.

345 – 347: Adding loads of different water constituents does not make sense. They have to be treated separately. Which non-point sources have been considered? Are urban areas also delivering non-point source inputs?

The non-point source pollution is calculated from all land use classes- agricultural, builtup, forest, waste land and water body for nitrate, ammonia, BOD, phosphorous and faecal coliform. Non-point source pollution from urban areas are also considered. All these water quality parameters affect DO of the river. This explanation will be added to the Figure legend in the revised manuscript.

348, Fig. 5: Partially poor scales: one cannot see actual values of many data points (e.g., for nitrate or P).

Fig 5 will be modified in the revised manuscript.

356 – 357: What about the upstream basin?

Streamflow is simulated with Ankighat as an outlet point considering the entire Upper Ganga basin. We will mention that streamflow results are for Ankinghat in the revised manuscript.

372 – 374: why should that be a general result for which this reference makes sense? I assume this very much depends on the spatial distribution of land use within a watershed.

The line will be deleted as it creates confusion. It was added as a justification for not seeing a difference in low flows.

395 – 397: Does this hold true also for nitrate? Is groundwater no nitrate source? Distinguishing between non-point and point sources seems needed.

Groundwater can be a source of nitrate. This contribution is modelled as non-point source pollution in our study. The nitrate concentration in the river is very high in comparison with the point and non-point nitrate loads joining. Hence, the resulting nitrate concentration at the drain confluence is not much affected. This explanation will be added to the revised manuscript.

415: Why should municipal sewage not contain P? Human excreta contain a lot of P!

The drain data obtained from Central Pollution Control Board of India is given in Table S1. It shows the presence of P only from Jajmau drains (low concentration) which carry domestic and industrial sewage. However, the drains which carry only domestic sewage do not have significant P concentration (e.g. Ranighat drain, Permiya drain). P concentration might have been removed from the treatment plant with the existing treatment. The drain includes domestic sewage with partial treatment and treated industrial effluent. This is likely the reason for little P concentration in most of the drains. This explanation will be added to the revised manuscript.

418 – 422: Very specific results related to scenario assumptions.

Agreed. These are results specific to the characteristics of point load. The contribution of domestic sewage to the Pandu river drains is high. Therefore, the effect of the population dominates industrial growth. This can be generalized as the locations downstream of high domestic sewage confluence will be predominantly influenced by population growth, whereas industrial growth would exert a dominant influence at locations downstream of high industrial load and the locations where streamflow is too low during low flow periods, climate change would be the dominant factor. This generalized discussion will be added to the revised manuscript.

460: This basically reflects the assumed changes in sources and the assumed climate effect on low flow.

The streamflow is simulated with realistic climate change projections of RCP 4.5 & RCP 8.5; hence a realistic low flow for the future is considered. The reduced dilution volume is a result of reduced low flow simulated for the climate change scenarios considering the entire upper Ganga basin. This explanation will be added to the revised manuscript. However, we understand there are uncertainties associated with the results which are mentioned in the conclusion section.

470 – 475: This results are relevant for regional decision makers but not for a general scientific audience.

This paragraph discusses how individual effects of anthropogenic factors change with location. It can be seen that the percentage contribution is highly influenced by point & non-point loadings and the river flow. For locations where streamflow is reduced by a larger amount by climate change, the dominant factor for such locations will be climate change. And for locations which have little change in low flow amounts, the dominant factor would be population growth, industrial growth or land use projections depending on the point and non-point loadings at that location. Kanpur is a representative of a pollution hotspot region, and Shahzadpur represents a location far away from point loads. Hence the results obtained for these locations can be generalized for polluted rivers. This generalized explanation will be added in the revised manuscript.

L: 501: Which treatment units?

The treatment units mentioned here are sewage treatment plants. It will be added to the revised manuscript.

544: Units missing.

The unit is MPN/100mL. It will be added to the revised manuscript.

551: This will happen anyway during rain periods?! But does it happen under dry weather conditions? Basic explanations of the existing sewage system are missing.

Yes, it happens in dry weather conditions also due to insufficient capacity of the existing sewage treatment plant. This will be discussed in the revised manuscript. An explanation of the existing sewage system and the gap is given in Supplementary Section S6. This will be cited in this line in the revised manuscript.

564: From the figures, it seems that the 7 mg /L refer to nitrate-N, not nitrate. This implied a nitrate value of around 28 mg nitrate /L. Please check the entire data for consistency.

We understand confusion is created by using nitrate and nitrate-N in the manuscript. Nitrate-N is nitrate concentration expressed in N mg/L. The nitrate concentration mentioned throughout the manuscript is in mg/L of N. Consistency will be checked in the revised manuscript.

579 – 581: Such technical issues haven't been mentioned so far: the system description regarding the urban water management system is not presented in sufficient details.

Thank you for the comment. We acknowledge lack of clarity in explanation. These are discussed in Sec 3.4, but the explanations are based on bathing class, and the objective of GAP is to achieve bathing class standards which were not mentioned in that section and in lines 579-581. We will mention it clearly in Sec 3.4 of the revised manuscript. Details on urban water management systems are provided in Supplementary Section S6. This will be cited.

619 – 621: There are major uncertainties! These should be treated much more explicitly and quantitatively.

We agree. We have mentioned it as a limitation of our study and can be the future scope of this paper.

Table S1: What do the data represent? Mean values of measured data? How many data, what type of samples, period of sampling etc.? Please clarify.

The drain data was collected for the dry weather period of the year 2016. That was the only data available for the drain loadings. The data is obtained from the Central Pollution Control

Board of India, and the results correspond to a single sample. These details will be added to the Table S1 legend.

Fig. S2: No seasonal patterns? What are upstream conditions?

Fig S2 shows the inputs given for the 30Q10 run for QUAL2K water quality simulation. Stream temperature is simulated from air temperature at Ankinghat using a linear regression model already set up for the area. We are interested in stream temperature for Ankinghat- Shahzadpur stretch as water quality simulations are carried out in this stretch. These details will be added to Fig S2 legend.

Fig. S3: How have these data be derived?

The minimum value for each year has been identified, and a box plot is plotted for this annual minima series corresponding to the runs from HEC-HMS. These details will be added in the Fig S3 legend.

Fig. S4: For which gauging station?

Fig S4 is for gauging station Ankinghat. This will be discussed in Fig. legend.

Fig. S9: Where are measured data to compare with?

Fig. S9 shows the results of simulations for socio-environmental scenarios. The location where the results are shown in Fig 9 and 10 of the manuscript from Fig S9 and S10 is taken will be marked.

Tab. S9: The data contradict the results in Fig. S13. That's confusing.

We acknowledge that the figure legends were short and hence lacked clarity. Fig S13 shows calibration results, and Table S9 shows validation results. Both show different results, not the same. The Fig S13 and Table S9 legends will be expanded.

Fig. S13: Units are missing. What does CWC stand for?

Thank you for pointing this out. Units will be mentioned in legends. CWC stands for Central Water Commission. The full form will be used in the figure legend.