Authors' Response to the Editors Comments

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Title: Population Growth – Land Use Land Cover Transformations-Water Quality Nexus in Upper Ganga River Basin

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We sincerely thank the editor for offering critical comments and valuable suggestions that has helped to improve the manuscript. We hereby provide our responses to the editor comments and highlight the changes made in the revised manuscript based on the comments provided. These have been incorporated in the revised manuscript as follows. The point wise replies of the comments of the editor are given below:

General Comments:

The authors have made a satisfactory revision of the manuscript, addressing the main concerns of the reviewers regarding placing the research and its aim within the wider literature; correcting the imbalance in level of detail through the manuscript; re-structuring to improve the narrative flow and enhancing the methodological detail (particularly with regard to the processing of the remote sensing data).

Response: Authors are sincerely thankful to the editor for appreciating our efforts and remote sensing work. With the given suggestions, we have further tried to improve the manuscript. We are grateful to the editor for his/her efforts in providing extremely useful comments that has helped in improving our research work further. The comments provided by editor are duly complied in the revised manuscript, which we believe have significantly improved the manuscript.

Comments to the author:

Comment 1: However, the methodological description of the derivation of the OIP and IPIs (and the use of the information within Tables 1 and 2) is still insufficiently clear and needs to be improved.

Non-public comments to the author:

Comment 2: The methodological description of the derivation of the OIP and IPIs (and the use of the information within Tables 1 and 2) is still insufficiently clear and needs to be improved. The lack of clarity partly (but not completely) arises because the concentration limits in Table 1 and Table 2 are different.

Comment 3: However, the OIP is derived from the average of the IPIs, so the purpose of the Class Index / Score of the OIP in Table 1 is not clear. The definition of x and y in Table 2 are not given. Is x the calculated value of the IPI, and y the Score from Table 1 for a given concentration?

Response 1-3: Authors are sincerely thankful to the editor for pointing out this very important question. Section "4.4.3 Estimation of OIP" in the manuscript has been elaborated significantly while answering the questions/comments 1 to 3 from the editor. The methodology used to decide the concentration ranges of water quality parameters, class index score (Table 1), mathematical value function curves, their equations as well as terms (Table 2), estimation of IPIs and OIP are described in details for better understanding of the OIP. The updated, detailed methodology and text is highlighted in the manuscript as follows:

In the present study, Overall Index of Pollution (OIP) developed by Sargaonkar and Deshpande (2003) is used which is a general water quality classification scheme developed specifically for tropical Indian conditions where, in the proposed classes (C1:Excellent; C2:Acceptable; C3:Slightly Polluted; C4:Polluted; and C5:Heavily Polluted water), the concentration levels/ranges of the significant water quality indicator parameters are defined with due consideration to the Indian water quality standards (Indian Standard Specification for Drinking Water, IS-10500, 1983; Central Pollution Control Board, Government of India, classification of inland surface water, CPCB- ADSORBS/3/78-79). Wherever, the water quality criteria were not defined, international water quality standards [Water quality standards of European Community (EC); World Health Organization (WHO) guidelines; standards by WQIHSR; and Tehran Water Quality Criteria by McKee and Wolf] were used. It was observed that different agencies use different, indicator parameters, terminologies/definitions for classification scheme and criteria such as Action Level, Acceptable Level, Guide Level, and Maximum Allowable Concentration, etc. for different uses of water. Hence, a common classification scheme was required to be defined to understand the water quality status in terms of pollution effects of the water quality parameters being considered. Table 1 illustrates the OIP classification scheme and the ranges of concentrations of the parameters under consideration. The basis on which the concentration levels for each of the parameters in the given classes are selected, are described below (Sargaonkar and Deshpande 2003):

Turbidity: According to the Indian Standards for Drinking Water (IS 10500, 1983) and European Community (EC) water quality standards, 10 NTU is maximum desirable level/ maximum admissible level for turbidity. Therefore, in the OIP classification scheme this value is considered for class C2 (Acceptable) water quality. As per WQIHSR standards and WHO Guidelines, 5 NTU is considered as maximum acceptable level, hence it is considered in class C1 (Excellent). 10-250 NTU is considered as Good water quality, and >250 NTU as poor water quality by the Wolf and McKee water quality criteria. Therefore, accordingly the Turbidity was split into the following ranges: 10-100 for class C3 (Slightly Polluted), 100-250 for class C4 (polluted) and >250 as class C5 (heavily polluted) water quality.

BOD: For BOD, the classification given by Prati et al. (1971) is used which conforms with the CPCB water quality standards i.e. for class “A” water (drinking water) , BOD values should be 2 mg/L and for class “B” water (outdoor bathing), BOD values should be 3 mg/L. According to EC water quality standards, for freshwater fish water quality or recreational use the guide level and maximum admissible level should be 3 and 6 mg/L respectively. And according to McKee and Wolf water quality scheme, the BOD of >2.5 indicates poor water quality. Hence, in OIP classification scheme, for classes C3 (Slightly Polluted), C4 (Polluted) and C5 (Heavily Polluted) water quality, the higher concentration values are assigned in geometric progression.

DO%: The maximum DO at a given space and time is the function of water temperature. It is highly variable and specific to a location. The average tropical temperature of India is 27°C and 8 mg/L is the corresponding average DO saturation concentration reported from studies, which represents 100% DO concentration and applies to class C1. During day time, in eutrophic water bodies with high organic loading very high DO concentration is observed which is undesirable situation. Therefore, in the OIP classification scheme for DO% in a particular class, the concentration ranges on both lower and higher sides of the average DO% level are considered. The ranges of %DO concentration defined are illustrated in Table 1.

F: As Fluoride is a toxic element, the classification criteria for it is more stringent. According to Indian standards for drinking water (IS 10500, 1983), the desirable limit for Fluoride is 0.6-1.2 mg/L which is considered under class C1 in OIP classification scheme. According to EC standards for surface water (potable abstraction) and action level in WHO Guidelines, the mandatory limit for F is 1.5 mg/L which is considered the maximum level in class C2. 1.5-3.0 mg/L of F is considered as good water quality but the concentration >3.0 mg/L indicates poor water quality according to McKee and Wolf water quality standards. Hence, for class C3 (slightly polluted) water quality, the concentration value of 2.5 mg/L is used. The F concentration >1.5 mg/L is bad for human health as it can result in tooth decay and further higher levels can cause bone damage through Fluorosis. Therefore, concentration values of 6.0 and >6.0 mg/L is used for classes C4 and C5 respectively.

Hardness $CaCO_3$: As per Indian standards for drinking water, the desirable limit (maximum) for hardness is 300 mg/L whereas the concentration value of 500 mg/L is indicated as action level according to WHO Guidelines. Hence, accordingly the ranges of Hardness were taken as: class C1 as 0-75 mg/L, class C2 as 75-150 mg/L, class C3 as 150-300 mg/L, class C4 as 300-500 mg/L and >500 mg/L in class C5.

pH: According to CPCB, ADSORBS/3/78-79, pH range of 6.5 to 8.5 is considered for classes A (drinking water), B (outdoor bathing) and D (Propagation wild life, fisheries, recreation and aesthetic). EC standards guide limit for surface waters (potable abstractions) is 5.5-9.0. Hence, based on these the concentration level of pH in the OIP classification scheme is defined for classes C1-C5, as given in Table 1.

Total Coliform: In the given OIP scheme, for class C1, C2 and C3 the Coliform bacteria count of 50, 500 and 5000 MPN/100 mL respectively as specified in CPCB classification of inland surface water is considered. Coliform count range of 50-100, 100-5000 and >5000 is considered as excellent, good and poor water quality respectively by McKee and Wolf water quality criteria. EC bathing water standards consider count of 10000 MPN/100 mL as the maximum admissible level, therefore, the concentration range 5000-10000 is assigned to class C4 which indicates polluted water quality and makes the criteria more stringent. The count of >10000 indicates heavily polluted water and therefore, it was assigned to class C5.

After the concentration level/ranges were assigned to each parameter in the given classes, the information on water quality data was transformed in discrete terms. Different water quality parameters are measured in different units. Therefore, in order to bring the different water quality parameters into a commensurate unit so that the integrated index can be obtained to be used for decision making, an integer value 1, 2, 4, 8 and 16 (also known as Class Index Score as given in Table 1) was assigned to each class i.e. C1, C2, C3, C4 and C5 respectively in geometric progression. The number termed as class index indicated the pollution level of water in numeric terms and it formed the basis for comparing water quality from Excellent to Heavily Polluted (Table 1). For each of the parameter concentration levels, the mathematical expressions were fitted to obtain this numerical value called an index (P_i) or (IPI) which indicated the level of pollution for that particular parameter. Table 2 illustrates these mathematical equations. The value function curves, wherein, on the Y-axis the concentration of the parameter is taken and on the X-axis index value is plotted for each parameter. The figures of value function curves for important water quality parameters used in OIP scheme can be referred from Sargaonkar and Deshpande (2003). The value function curves provide the pollution index (P_i) or (IPI) for individual pollutants. For any particular given concentration, the corresponding index can be read directly from these curves or can be estimated using mathematical equations given for the value function curves as illustrated in Table 2. Hence, IPIs were calculated for each parameter at a given time interval. Finally, the Overall Index of Pollution (OIP) is calculated as the mean of (P_i) or IPIs of all the seven water quality parameters considered in the study and mathematically it is given by expression (1):

$$Overall\ Index\ of\ Pollution\ (OIP) = \frac{\Sigma_i P_i}{n} \quad (1)$$

Where, P_i is the pollution index for the i^{th} parameter, i=1, 2,…., n and n denotes the number of parameters. Finally, OIP was estimated for each water quality monitoring station across the UGRB over a period of 2001 to 2012. It gave the cumulative pollution effect of all the water quality parameters on the water quality status of a particular monitoring station in a given time. For each water quality monitoring station of UGRB, the OIP was estimated for three primary seasons i.e. pre-monsoon, monsoon and post-monsoon seasons. The interpretation of IPI values for individual parameter index or OIP values to determine the overall pollution status is done as follows: The index value of 0-1 (class C1) indicates Excellent water quality, 1-2 (class C2) indicates Acceptable, 2-4 (class C3) indicates Slightly Polluted, 4-8 (class C4) indicates Polluted and 8-16 (class C5) indicates Heavily Polluted water. The upper limit of the range is to be included in that particular class. In case some additional relevant water quality parameters are required to be considered, an updated OIP can be developed using methodology given by Sargaonkar and Deshpande (2003). The mathematical value function curves can be plotted for the new parameters to get the mathematical equations which will help to calculate IPIs. As OIP uses an additive aggregation method, the average of IPIs of all the parameters will estimate updated OIP.

"The lack of clarity partly (but not completely) arises because the concentration limits in Table 1 and Table 2 are different".

Table 1 represents the classes considered in the OIP classification scheme, respective class index score in geometric progression and the concentration limits/ranges of water quality parameters defined based on various water quality classification schemes by national and international agencies for different water uses. In Table 2 mathematical equations are given for value function curves. For each of the parameter concentration levels, the mathematical expressions were fitted to obtain the numerical value called an index (P_i) or (IPI) which indicated the level of pollution for that particular parameter. For any particular given concentration (including the concentration limit/range of parameters in various classes in Table 1), the corresponding index can be read directly from these curves or can be estimated using mathematical equations of value function curves illustrated in Table 2.

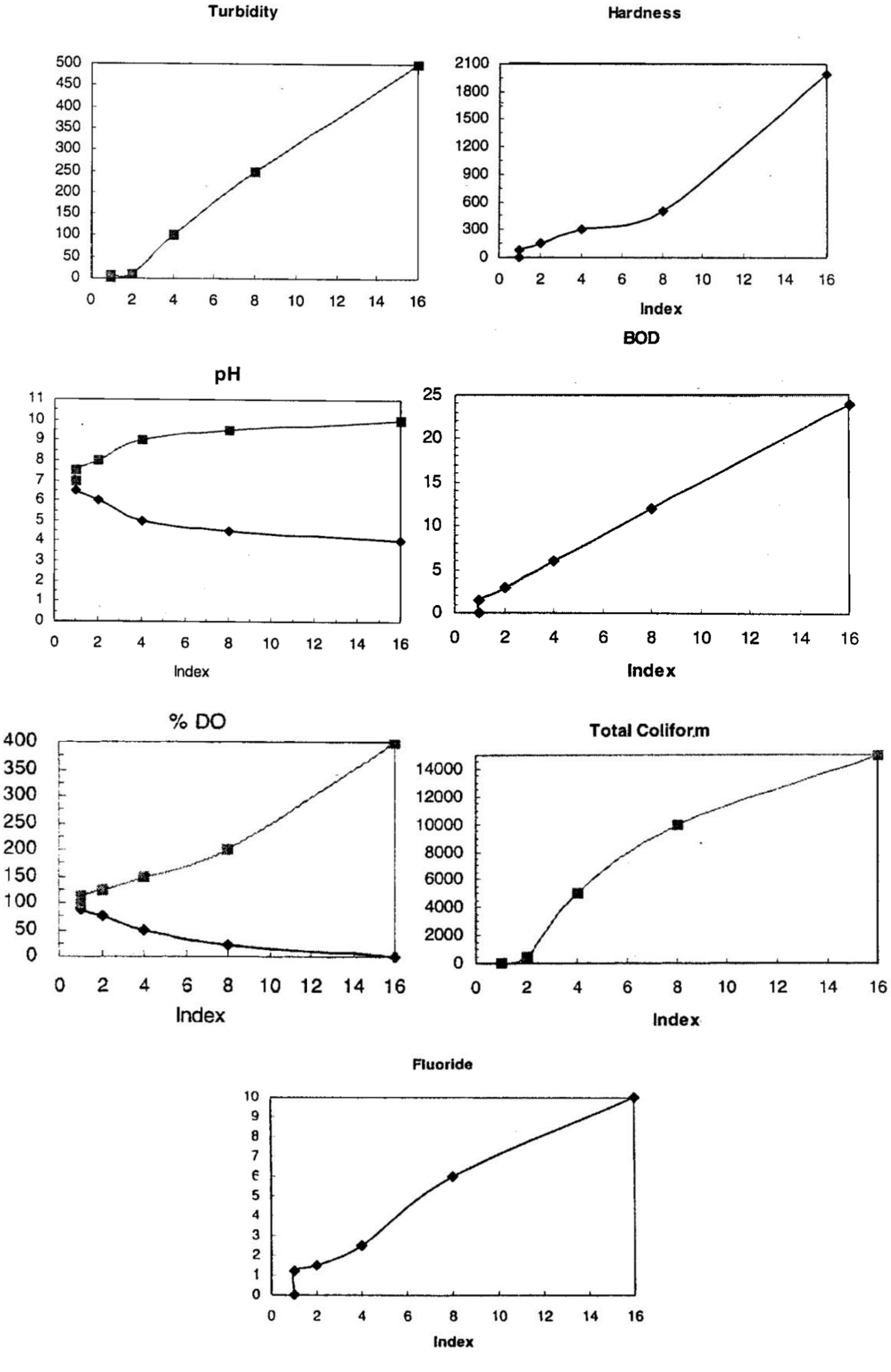

Figure 1. Value function curves for important water quality parameters in the given scheme. (Source: Sargaonkar and Deshpande 2003)

Comments to the author:

Comment 4: A few additional minor text edits are also required. Also please ensure that all figures are of appropriate resolution /dpi e.g. Figure 5.

Response 4: Authors are sincerely thankful to the editor for pointing it out. Editor suggestions regarding the additional minor text edits, proofreading of the manuscript has been conducted and typos are corrected in the revised manuscript. Authors have corrected the missing words and grammar, improved the phraseology and checked the English in whole manuscript. Authors have improved the quality of all the Figures 1 to 6 in the manuscript as suggested by the editor. The modified figures are of appropriate resolution i.e. 1000 dpi. The improved Figure 1 to Figure 6 have been updated in the revised manuscript. Our endeavour will be that the revised paper is much better than the current version.

Non-public comments to the author:

Comment 5: L479 states that population increased in all 77 districts but L483 and Table 3 states that PGR only increased in 74 districts. Correct this inconsistency.

Response 5: Authors are sincerely thankful to the reviewer for pointing it out. We checked the results obtained from demographic analysis and as suggested by Editor, in section "5.1 Population dynamics" the sentence L479 is modified and the paragraph is updated accordingly in the manuscript. L478-491 is modified as follows:

"Analysis of the population dataset of the years 2001 and 2011 acquired from Census of India, GoI reveals that in the UGRB, out of the 77 districts that fall in four different states, viz. Uttar Pradesh, Uttarakhand, Bihar and Himanchal Pradesh, total population and PGR has increased in 74 districts. With majority of the districts showing population increase, the total population of UGRB has increased consequently (Table 3). The population growth rate (PGR) of 20.45% is observed in the total population of UGRB from 2001 to 2011. Table 3 illustrates that the PGR is ≥20% in the districts having bigger urban agglomerations or cities e.g. Agra, Allahabad, Bahraich, Ghaziabad, Lucknow, Kanpur (Dehat+Nagar), Varanasi, Patna, etc. However, Almora, Pauri Garhwal and Shravasti are showing decreasing PGR. It is to be observed that these are either hilly or very small towns with poor employment opportunities. People migrate from these locations to nearby cities, therefore, decreasing the PGR. It was noticed from Census of India reports that the population density of Dehradun (Rishikesh), Kanpur, Allahabad and Varanasi districts are much higher against the average population density of Ganga River basin, i.e. 520 per square km. Varanasi is one of the most populated districts in the country".

Comment 6: L620-627 includes significant repetition - please condense.

Response 6: Authors are sincerely grateful to the reviewer for pointing it out.

As suggested by Editor, the authors have modified section "5.4 Trend analysis on monthly water quality data" and L618-630 are as updated follows: "From the results of trend analysis (Mann Kendall rank test) it is observed that each water quality parameter varies with time and location, hence the changes in the water quality parameters are observed in all the months (Table 7). No regular trends are observed in the water quality data, therefore, they are very site-specific. Results from statistical analyses reflect that comparatively high SD and significant changes are observed in water quality of the monsoon month (July), which is followed by pre-monsoon and post-monsoon months in decreasing order. Effect of different seasons on water quality is reported from various studies (Islam et al. 2017; Sharma and Kansal 2011; Singh and Chandna 2011). In this study, three significant seasons are identified and hence the water quality data is organized into three groups: pre-monsoon season (February-May), monsoon season (June-September) and post-monsoon season (October-January). From each group, one representative month i.e. May, July, November month is chosen, which represents that particular season the best".