Authors’ Response to the Reviewer Comments

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

Authors: Anoop Kumar Shukla, Chandra Shekhar Prasad Ojha, Ana Mijic, Wouter Buytaert, Shray Pathak, Rahul Dev Garg and Satyavati Shukla

We sincerely thanks to the reviewers for their comments on the manuscript and offering their suggestions and critical input that has helped improve the manuscript. We provide here our replies to the reviewers’ comments and highlight the changes made in the revised manuscript based on the comments. These have been incorporated in the manuscript as follows. The point wise replies of the comments of the Reviewer#3 are given below.

General Comments:

The scientific approach is valid but there is no reference to previous similar studies analysing land use-water quality index relationships (e.g. https://doi/abs/10.2989/16085914. land use-water quality index relationships (e.g. https://doi/abs/10.2989/16085914.2015.1077777, https://doi.org/10.1016/j.proenv.2012.01.140,https://www.ncbi.nlm.nih.gov/pubmed/27498508) nor any justification of the scientific relevance and novelty of the study. In relation to the writing, some parts of the text should be moved to different sections specially from results to methods. There is too much repetition of information along the paper. English is understandable but should be revised (e.g. word confusion, articles, etc.).

We sincerely thank the anonymous reviewer 3 and appreciate his/her efforts in providing very useful comments for the improvements of our contribution. As per reviewers instructions a few case studies are described in the Section 1 “Introduction” of the revised manuscript. The following paragraph has been added in addition to the extensive modifications in it. We are grateful to the reviewer for suggesting us some previous similar studies done related to our theme of work. All the research papers mentioned above and a few others are cited in the introduction section which has helped to improve our contribution.

“Demographic changes and anthropogenic activities have potential to affect the quantity and quality of available water resources on local, regional and global scale in a river basin. These drivers pose a threat to the quantity and quality of water resources directly by increased anthropogenic water demands and water pollution. Indirectly, the water resources are affected by LULC changes and associated changes in water use patterns (Yu et al. 2016). LULC changes may alter the chemical, physical and biological properties of a river system. Several studies are carried out across the world to understand this phenomenon. Hong et al. (2016) studied the effects of LULC changes on water quality of a typical inland lake of arid area in China. The study concluded that water pollution is positively correlated to agricultural land and urban areas whereas negatively correlated to water and grassland. Li et al. (2012) studied effects of LULC changes on water quality in the Liao River basin, China. In this river basin water quality of upstream was found better than downstream due to less influence from LULC changes in the region. Similarly, impact of LULC changes was studied at Likangala catchment, southern Malawi and downstream of the river was found more polluted with increase in the number of *E.Coli* and cation/anions even though the water quality remained in acceptable class (Pullanikkatil et al. 2015). The composition and distribution of benthic macroinvertebrate assemblage were studied in the Upper Mthatha River, Eastern Cape, South Africa (Niba and Mafereka 2015). Results revealed that the distribution of the benthic macroinvertebrate assemblage is affected by season, substrate and habitat heterogeneity. LULC changes may induce changes into the river water which may affect their species distribution. Water quality changes of the Ganges river at various locations in Allahabad was studied for post-monsoon season by Sharma et al. (2014) using Water Quality Index (WQI) and statistical methods. Considerable water quality deterioration was observed at various locations due to the vicinity of the river to a highly urbanized city of Allahabad. A combination of water quality indices viz. CCME-WQI, Oregon Water Quality Index, (OWQI) and NSF-WQI were used to analyse the pollution of Sapanca Lake Basin (Turkey) and a good relationship was observed between the indices and parameters. Eutrophication was identified as a major threat to Sapanca Lake and stream system (Akkoyunlu and Akiner 2012)".

Justification of the scientific relevance and novelty of the study is addressed in detail in the Response 4 of Reviewer#2. As per reviewer's suggestion, the write up has been improved wherever required and some part of the text have been moved form results to methodology section. And the redundant information is removed. Our endeavour will be that the revised paper is much better than the current version.

Specific comments:

Comment 1: Keywords - Population or demographic change should be included.

Response 1: Word **"***Demographic change*" has been incorporated in the keywords.

Comment 2: Introduction - Paragraphs could be used to better organise the ideas in the text. Lines 76-86: many water quality indices are cited, but no comment about their validity, similarities (clusters), differences, etc. is made. Why the OIP index is good compared to other? From the methods section, I see that it is only the average of individual indices of different pollutants. Should all pollutants have the same weight according to their impact on health, removal costs…? Does the OIP propose more pollutants apart from those considered in the present study? If not, what would be the approach if there are other relevant pollutants in the studied region? Objectives should be better organised and explained: Not clear that it is not a continuous time analysis, but a 2-time slice analysis (2001 and 2012) with seasonal component. Should the test of OIP as a valid index be principal in the study before it is used to extract conclusions?

Response 2: As per reviewer's suggestion, the introduction section is restructured and reorganized into paragraphs in the revised manuscript.

In lines 76-86, the following water quality indices were cited viz. Composite Water Quality Identification Index (CWQII), River Pollution Index (RPI), Forestry Water Quality Index (FWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Water Quality Index (CWQI), Comprehensive water pollution index of China, Prati's implicit index of pollution, Horton's index, Nemerow and Sumitomo Pollution Index, Bhargava's index, Dinius second index, Smith's index, Aquatic toxicity index, Chesapeake Bay water quality indices, Modified Oregon WQI, Li's regional water resource quality assessment index, Stoner's index, Two-tier WQI, Canadian WQI by Canadian Council of Ministers of the Environment (CCME), Universal WQI, Overall index of pollution (OIP), Coastal WQI for

Taiwan, etc. (Abbasi and Abbasi 2012; Rai et al. 2011). These are the various water quality indices available worldwide that can be used for water quality assessment. Not much literature is currently available on comparisons between all the above mentioned water quality indices based on clusters, differences, validity, etc. However, in a study comparison was made between CCME and DELPHI water quality indices based on multivariate statistical techniques viz. coefficient of determination (R^2), root mean square error, and absolute average deviation. Results revealed that the DELPHI method had higher predictive capability than the CCME method (Sinha and Saha 2015). However, there is no worldwide accepted method for development of water quality indices. Therefore, there is no method by which 100% objectivity or accuracy can be achieved without any uncertainties. There is continuing interest across the world to develop accurate water quality indices that suit best for a local or regional area. Each water quality index has its own merits and demerits (Sutadian et al. 2016; Tyagi et al 2013).

Water quality is defined in terms of chemical, physical and biological (bacteriological) characteristics of the water. These characteristics may vary for different regions based on their topography, land use land cover (LU/LC) and climatic factors. The acceptable levels/ranges of concentrations of particular water quality parameters are defined as water quality criteria which is different for different regions/countries and water uses. Water quality management and planning in a river basin requires an understanding of the cumulative or overall pollution effect of all the water quality indicator parameters under consideration. This helps in assessing the overall water quality/pollution status of the river in a given space and time in a specific region. Overall Index of Pollution (OIP) developed by Sargaonkar and Deshpande (2003) is a general water quality classification scheme specifically for tropical Indian conditions where in the proposed classes (Excellent, Acceptable, Slightly Polluted, Polluted and Heavily Polluted water), the concentration levels/ranges of the significant water quality indicator parameters viz. Hardness $CaCO_3$, TDS, BOD, Cl, Coliform Total, Colour, DO%, pH, and Turbidity are defined based on the Indian water quality standards (Indian Standard Specification for Drinking Water, IS-10500, 1983 and Central Pollution Control Board, Government of India, classification of inland surface water, CPCB- ADSORBS/3/78-79). This classification scheme took into consideration various international water quality assessment schemes viz. European Community (EC) standards, World Health Organization (WHO) guidelines, standards by WQIHSR and Tehran Water Quality Criteria by McKee and Wolf. The concentration ranges used in the classes and the classification scheme helped to evaluate the surface water quality status with respect to particular individual parameter whereas the OIP helped to assess the overall water quality status specifically in the Indian context. It helped to identify the parameters which are affected due to pollution from urban and rural areas. OIP is immensely helpful in studying the spatial and temporal variations in the surface water quality status of both rural and urban subbasins due to the influence of demographic and LU/LC changes. The self-cleaning capacity of the river system investigated using OIP helped to comprehend the resilience capacity of the river system against the changes occurring in water quality due to anthropogenic activities. OIP has been used successfully to study the surface water quality status of the two most important and highly polluted rivers viz. Ganga and Yamuna of the tropical Indian region. It is also used for water quality assessment of comparatively smaller river like Chambal River and Sukhna lake of Chandigarh (Chardhry et al. 2013; Katyal et al. 2012; Shukla et al. 2017; Sargaonkar and Deshpande 2003; Yadav et al. 2014). Therefore, OIP is used in the present study as it is an effective tool to communicate the water quality information to concerned policy makers and planners.

Yes, in the OIP the aggregation method used is additive. No, the water quality pollutants should not have same weights with respect to impact on health, removal costs, etc. However, each water pollutant or water quality parameter is important and should not be ignored. It solely depends on the objectives of the work to be done. In addition to the 7 water quality parameters used, OIP considers total 13 water quality parameters viz. pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness $CaCO_3$, total dissolved solids (TDS), total coliform and some of the toxicity indicator parameters viz. Arsenic (As) and Fluoride (F). If there are other relevant water quality parameters, the IPIs and OIP can developed for those parameters using methodology given by Sargaonkar and Deshpande (2003) which first involves, proposing a classification scheme for the particular water quality parameters based on some water use standards or pollution permissible limits. The concentration range of the parameters should be defined and a class score should be decided based on the standards. Then mathematical value function curves can be plotted to get the mathematic equations which will help to calculate IPIs. As OIP uses an additive aggregation method, the average of IPIs of all the parameters will estimate OIP.

Objectives of the work are now clearly defined in the revised manuscript. A paragraph is given below regarding the same:

Ganga River is extremely significant to its inhabitants as it supports various important services such as: (i) source of irrigation for farmers in agriculture and horticulture; (ii) provides water for domestic and industrial purposes in urban areas; (iii) source of hydro-power; (iv) serves as a drainage for waste and helps in pollution control; (v) acts as support system for terrestrial and aquatic ecosystems, (vi) provides religious and cultural services; (vii) helps in navigation; (viii) supports fisheries and other livelihood options, etc. (Amarasinghe et al. 2016; SoE report, 2012; Watershed Atlas of India, 2014). However, for the past few decades Upper Ganga River basin has experienced rapid growth in population, urbanization, industrialization, infrastructure development activities and agriculture. Due to these changes, maintaining the acceptable water quality for various uses is being challenged. Therefore, there is a need to study the causative connection (nexus) between the changing patterns of population, Land Use/Land Cover (LULC) and water quality at both river basin (small scale) and at districts level (large scale) for three different seasons. Such study is yet to be done for this large river basin. OIP developed specifically for Indian context is used in this study to assess the status of water quality across the study area. Due to unavailability of the continuous population, satellite and water quality data at desired interval, establishing the interrelationship between these factors is not trivial. Hence, in order to achieve the objectives a comprehensive set of analyses are performed in this study. Between LULC and OIP a 2-time slice analysis is done for the years 2001 and 2012 with seasonal component. A relationship is developed between LULC and OIP (Indian WQI) using correlation and multi linear regression analyses. Further, trend (Mann-Kendall method) analysis was performed on monthly water quality parameters of the monitoring stations from 2001 to 2012 to understand their temporal variations over the years. Also, it was interesting to see the effects of seasonal variations on status of water quality. Hence, finally the results were inferred from these comprehensive set of analyses to understand nexus between population-LULC-water quality of Upper Ganga River basin which is our main contribution. The test of OIP as a valid index can be done to assure the validity of the index. However, a number of studies have successfully used OIP to assess the surface water quality of various Indian rivers.

Comment 3: Case study - Justify why the 7 selected pollutants are important and not others – Not sure if the data sources should be detailed after the methods section and be, therefore, better related to each methodological stage.

Response 3: Authors have addressed the same question in detail in Response 4 of Reviewer#1. We agree with the reviewer that data sources should not be detailed after the method section. Hence after doing modifications in the methodology flow chart, the text was also updated suitably. And as suggested by the reviewer the data description is done at each methodological stage in methodology section of the manuscript.

Comment 4: Methods - There is repetition of information. Try to avoid it by re-organising the text (section 4.1, remove details from the introduction and explain them only in this section). Move table 1 to data section or to results, but it is not part of methods. The classification for OIP that relates the obtained values with an overall water quality status should be included in the methods section, like the IPI classification. The OIP classification is currently described in the results section (5.4.2). Explanation about the link between LULC and water quality at the diverse stations is missing. I assume that the sub-catchments draining to the locations of the water quality stations are defined and this is used to relate the impact of spatial LULC change with water quality. I think it is worth including that as part of the methods section and also in Figure 2.

Response 4: In methodology section, repetition text has been removed and re-organised according to the reviewer's suggestion. In introduction section, some text has been removed and explained in the section 4.1.

Table 1 has been removed from methodology section and added in results section.

Individual parameter indices (IPIs) and overall indices of pollution (OIPs) have been removed from the results section (5.4.2) and added in methodology section.

Authors agree with the reviewer that the link between LULC and water quality at the diverse stations was missing in the earlier manuscript. Earlier the manuscript had redundant information due to which the paper size was bigger. But after review, redundant information is identified and removed. Also, restructuring of the manuscript is done in which the description is added in "results and discussion" section with special focus on the link between LULC and water quality. A new subsection is added in the manuscript for describing the relationship developed between LULC and OIP using multi linear regression. Our endeavour will be that the revised paper is much better than the current version.

Reviewer#1 in Comment 7, has suggested to estimate the district specific LULC and to relate it to water quality.

Reviewer#1 (Comment 7): *I would recommend the addition of district specific land use change maps to help support your discussion. At present, it is impossible to visually relate the pattern of land use change to the water quality and population statistics because the scale of the mapping in figure 4 is too small.*

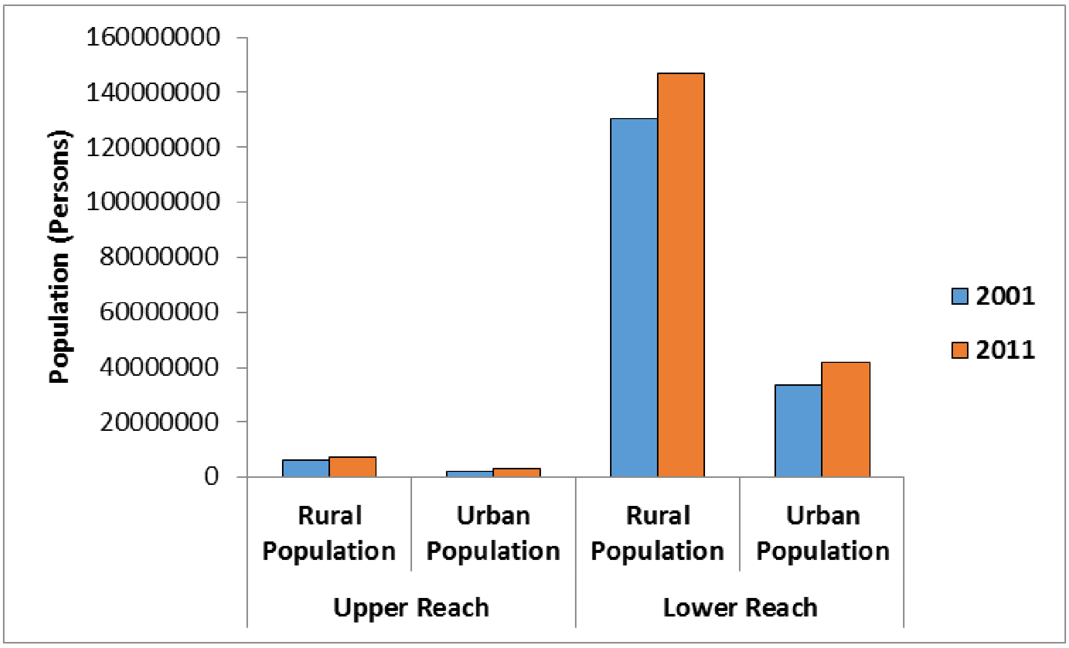
This study will help to determine the causative connection (nexus) between the changing patterns of population, Land Use/Land Cover (LULC) and water quality at both river basin (small scale) and at district level (large scale) for three different seasons. It will help to understand water quality status of Upper Ganga River basin at both complete river basin and local scale. In addition to this, population information is available for the districts hence, this analysis was done. A relationship was developed between LULC and OIP. This new work done has been updated in the work flowchart accordingly. And further it is updated and explained in the methodology as well as results section.

Comment 5: Results - No need to explain how to calculate a % change (lines 27-31). If you decide to include it anyway, it should be placed under the methods section. Figure 3 would be more useful if showing the results for the upper and lower reaches separately, instead of aggregated for the whole basin. It would support the statement in lines 20-21 which is not proved based on results. Table 4 and Figure 5 present the same results. Only one of them should be included in the paper to avoid repetition of information. Lines 95-99 should be moved to the methods section, including a description and reference about the Kappa statistics. The meaning of user's and producer's accuracy is not clear. Lines 124-158 could be moved to methods section as they describe the Mann-Kendal test. Best scenario to select representative months based on what? In figures 6 and 7 it would be useful to depict the OIP thresholds as horizontal lines instead of as a legend. Some discussion about the conclusions and comparison with the current study should be included.

Response 5: Authors are sincerely thankful to reviewer 3 for suggestions on improving the write up. We agree that, the formula to calculate % change is generic and it is not required. Therefore it is removed and the text was edited suitably.

As per suggestions of reviewer, the Figure 3 is modified. Total population as well as PGR is estimated and presented for upper and lower reaches of the Upper Ganga River basin. We are grateful to the reviewer for this comment, it helped us to support the statement in lines 20-21 which was not proved based on results. The necessary modifications are done in the paragraphs and it improved the revised manuscript.

(a)



(b)

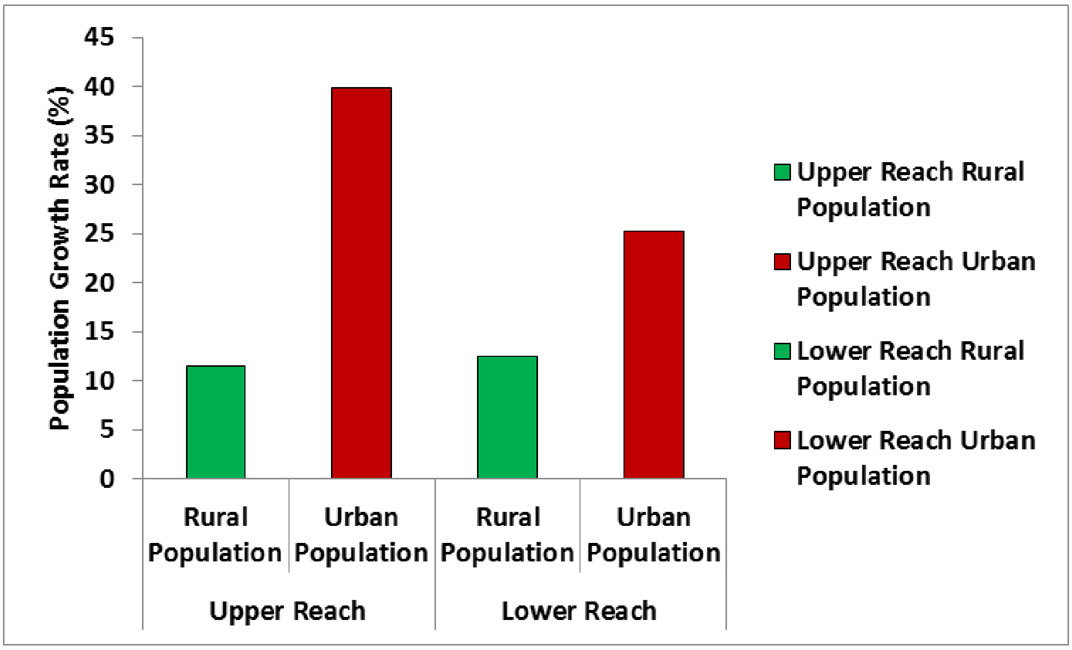


Figure 3: Growth in the rural and urban population of upper and lower reaches of Upper Ganga River basin between 2001-2011 (a) Total population, and (b) Population Growth Rate (PGR)

As suggested by Reviewer#1 in Comment 9, Table 4 was removed and a cross tabulation table of the 2001 and 2012 LULC classes is presented. It will help reader to see what has changed to what and then the gross and net changes are shown in Figure 5. The table is presented in Response 9 of Reviewer#1.

As suggested, lines (95-99) have been moved to the methodology section, including a description and reference about the Kappa statistics.

Lines 124-158 have been moved to methods section as they describe the Mann-Kendal test in the revised manuscript.

After accuracy assessment of the satellite images an error matrix (confusion matrix) is generated which gives the ratio of number of correctly classified samples to the total number of samples in the reference data. Overall accuracy depicts the accuracy of the whole classification. To determine the accuracy of individual classes two coefficients are used: (a) producer’s accuracy, and (b) user’s accuracy.

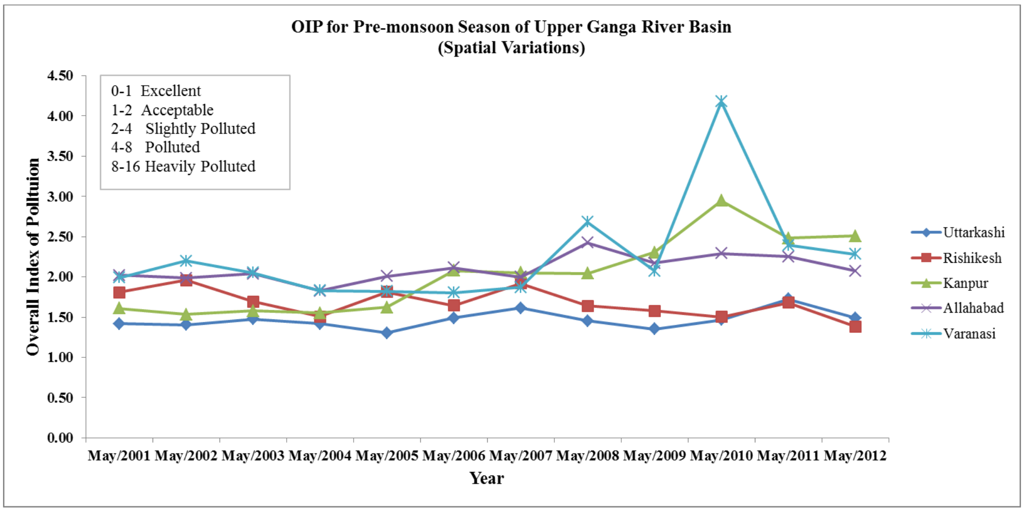
In producer’s accuracy, the interest of the image producer is in how well the samples from the reference data can be mapped using remotely sensed data. That is why it is called producer’s accuracy. It measures errors of omission, which is a measure of how well a real-world LULC types can be classified. On Contrary, the user’s accuracy indicates the probability that a sample from the classified image would actually represent that particular class on the reference data. User’s accuracy measures errors of commission, which represents the likelihood of a classified pixel matching the land cover type of its corresponding real-world location. Producer’s accuracy is estimated by dividing the number of correctly classified samples of a class by the column total. Whereas the user's accuracy can be estimated by dividing the number of correctly classified samples of a class by the row total (Campbell 2007; Congalton 1991; Jensen 2005). A description on accuracy assessment and Kappa coefficient is given in Comment 7 of Reviewer 2. Confusion matrix is also presented to support the description.

It is interesting to see in which season the water quality of the river is affected more by LULC changes with respect to climatic variables. Best scenario/representative month means the season in which the water quality of the river is mainly affected by LULC changes not by climatic conditions such as rainfall during monsoon. It is observed based on the OIP values at a monitoring station during different seasons.

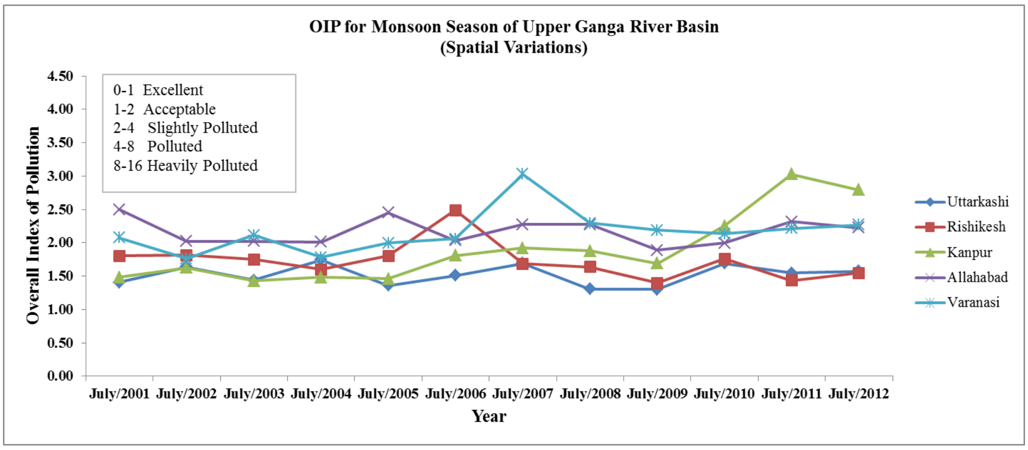
As suggested by the reviewer, in Figures 6 and 7 the OIP thresholds are now given as horizontal lines not as a legend. All the sub-figures of Figure 6 and 7 are modified suitably.

As the modifications in the structure of the manuscript were suggested by all the reviewers, hence, the manuscript is thoroughly edited and modified in all the sections of the manuscript wherever it was required. Descriptions are duly added in the results and discussion; and conclusion section of the manuscript.

(a)



(b)



(c)

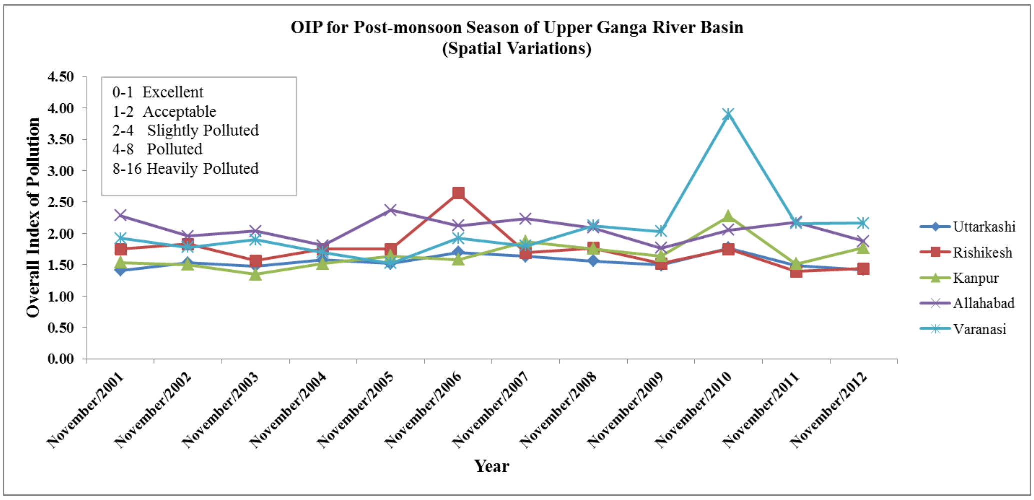
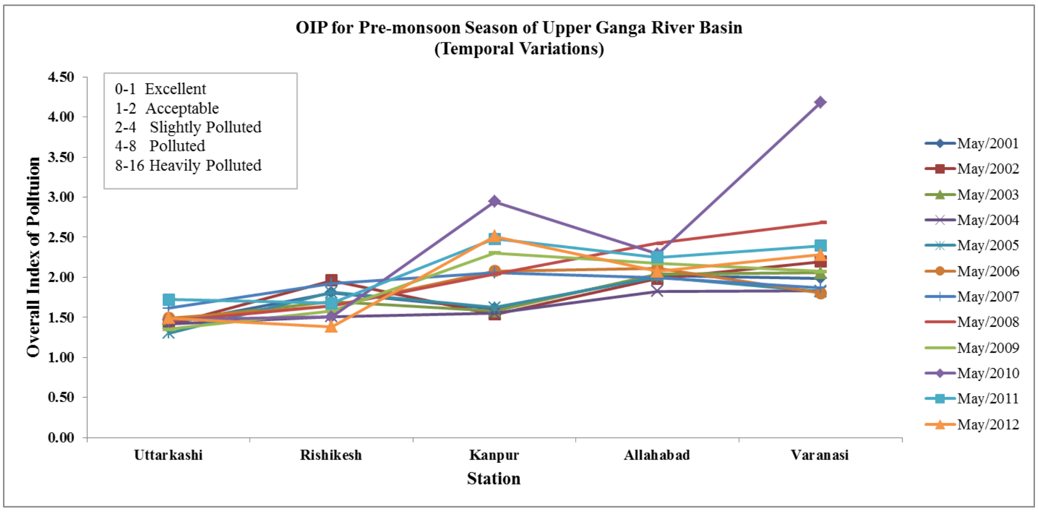
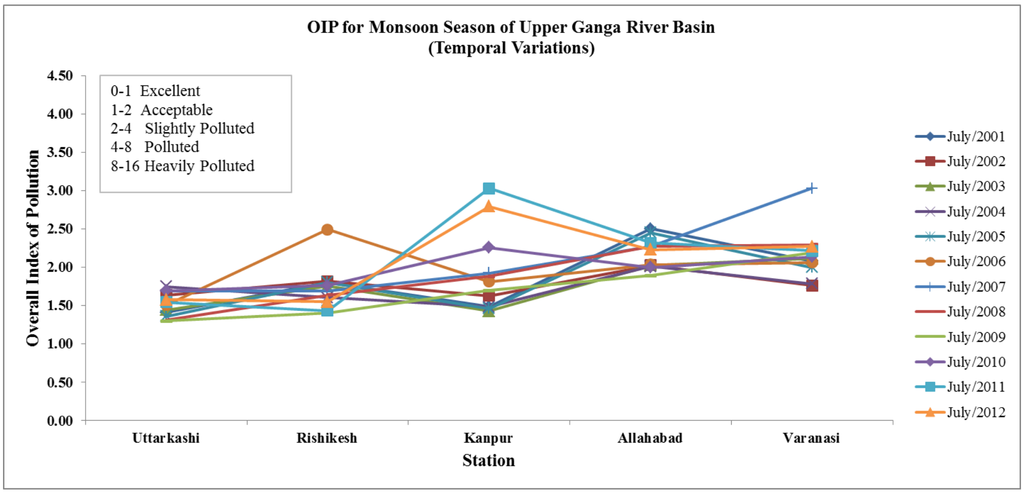


Figure 6. Spatial variations in the overall indices of pollution of upper Ganga River basin for **(a)** Pre-monsoon period **(b)** Monsoon period, **(c)** Post-monsoon period

(a)



(b)



(c)

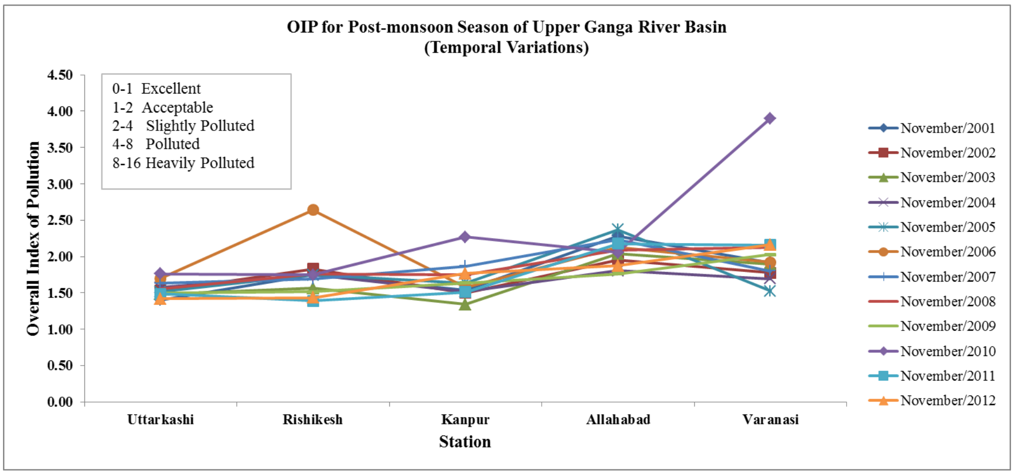


Figure 7. Temporal variations in the overall indices of pollution of upper Ganga River basin for **(a)** Pre-monsoon period **(b)** Monsoon period, **(c)** Post-monsoon period

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