Authors' Response to the Reviewer#1 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 reviewers for offering their critical comments and valuable suggestions that has helped to improve the manuscript. We hereby provide our responses to the reviewer's 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 Reviewer#1 are given below:

General Comments:

The paper sets out to investigate the relationships between land use/cover, population growth and water quality for a large river basin. Remotely sensed data is used in combination with population census and water quality measurements to analyse correlations between the data available. The authors have attempted to identify causal links between the patterns of change seen between 2001 and 2012. The datasets used are appropriate but there are some technical issues to be addressed as highlighted below. General observations are made with regard to the potential sources of pollutants which given the scale of investigation is probably appropriate although it would have been better if some clear cut examples could be presented that show how a specific change in land use/cover has changed the level of pollutants measured. The OIP classification is helpful in the categorisation of water quality at this scale of analysis and matches the scales of the available population and land cover/use data.

We sincerely thank the anonymous reviewer 1 and appreciate his/her efforts in providing very useful comments for the improvements of our contribution. Present study attempts to analyse the causative connection (nexus) between the changing patterns of population, Land Use/Land Cover (LULC) and water quality of water stressed Upper Ganga River basin. We agree with the reviewer that in the previous manuscript due to the given scale of investigation and data constraints the general observations were made with regard to the potential sources of pollutants. But some clear cut examples showing how a specific change in LULC has changed the level of pollutants measured can further improve the work. We thank reviewer 1 for pointing it out as it is extremely important to bring out in this study. Therefore, as suggested further in the specific comments (Comment 8), authors have further related the changes in the LULC classes with the level of pollutants at a finer scale i.e. at district level. It is explained in Response#8 of this draft. In this study a comprehensive set of analyses are presented to assess and comprehend the current status of the population-LULC-water quality nexus in the study region, with respect to their changing patterns from 2001 to 2011. The present study is conducted at two different spatial scales i.e. (a) at river basin level (small scale), and (b) at district level (large scale) for three different seasons viz. pre-monsoon, monsoon and monsoon seasons. Such study is not done before for Upper Ganga River basin. Various methodologies are developed to study effects of LULC changes on water quality. But these methods cannot be applied directly to a region because of the differences in the data availability, climatic, topographic and LULC variations which may introduce errors. Hence, necessary modifications are made in the existing evaluation methodology as per the requirement. And a relationship is developed between LULC and Overall Index of Pollution (OIP) using multi linear regression. This work helped to improve our contribution. OIP used in this study is a water quality index developed specifically for Indian conditions to categorize the water quality which helped to relate it with available population and LULC data. All the responses given are suitably added and necessary modifications are made throughout the revised manuscript.

Specific comments:

Comment 1: Better clarity is required in the description of the remote sensing methodology. Section 3.2 starts by describing the validation points used for the accuracy assessment. The sampling design used to identify these points is not described here; this information appears much later in section 5.3 and is only described as a simple random survey. The sample design must be described in section 3.2 and the selection of the sampling methodology applied justified. In particular, the use of a simple random sample must be clearly justified as this approach potentially raises a number of issues not least the potential to have a poor spatial distribution of sample points.

Response 1: We agree with the reviewer that description of the remote sensing methodology needs better clarity. Therefore, significant changes are made in Section 4 “Methodology” of the revised manuscript and it is further improved by addressing the responses for comments 1 to 6. Description of sampling design as just simple random survey is removed from section 5.3. As suggested by reviewer, description and justification of sampling design used to identify the validation points for accuracy assessment is explained and updated in section 3.2 which is given below:

To produce refined LULC maps in addition to expert judgement, ground truth (reference) data is required. In this study, a total 2014 Ground Control Points (GCPs) were collected from Global Positioning System (GPS) during the field visit and Google Earth. Out of which, 1365 were used for supervised classification of the satellite images and the remaining 649 points were used for accuracy assessment. Selection of sampling design differs in their suitability to achieve different objectives. During sampling of GCPs, selection of appropriate sampling method, sample size and measures of accuracy are very significant. Accuracy assessment using any of the probability sampling designs viz. simple random sampling, stratified random sampling, systematic sampling, and cluster sampling provides acceptable level of accuracy with not much statistical difference (Stehman and Czaplewski 1998). However, the selection of the appropriate method should be done with care considering the following elements: size as well as type of the study region; unbiased estimation of the uncertainty or variance; and characteristics of the objects being studied (Gu et al. 2012; Hashemian et al. 2004; Stephen 2009). Sample size must be enough to provide meaningful and representative basis for sampling. A good sample would sufficiently draw the properties of the objects from which it is selected. In stratified random sampling the population is divided into non-overlapping strata’s or sub-populations. But this sampling method gives better results on smaller image size (Hashemian et al. 2004).

In systematic sampling, selection of samples is started at a random starting point and at fixed periodic interval but this method is not suitable for heterogeneous regions. In such regions systematic samples may not represent the properties of each class appropriately. In the cluster sampling design, pixels are clustered in groups and then random sampling is done. Again it is not suitable for heterogeneous regions as sample size is comparatively large. In simple random sampling, selection of sample units is done so that every possible distinct sample gets the equal chance of selection. This sampling method provides comparatively better results on large image size if the rule of thumb recommended by Congalton is followed i.e. minimum 50 samples should be selected for smaller images and 75-100 samples for large Images (Congalton 1991; Hashemian et al. 2004). The present study is conducted for a large river basin (238348 km^2), therefore simple random sampling design was used for collecting GCPs across the study region for accuracy assessment. Simple random sampling is appropriate and can produce good results if sufficient samples are selected to ensure that all the classes are represented adequately (Congalton 1991; Foody 2002; Goncalves et al. 2007; Kiptala et al. 2013; Samal and Gedam 2015). Following the Congalton's thumb rule for better accuracy in simple random sampling, GCPs were selected in the range of 94-137 for each LULC class in proportion to their areal extent on the image (Table 7). Therefore, sufficient spatial distribution of the sampling points was achieved for each LULC class. Previously published thematic and topographic maps of Government of India (GoI) were useful to decide it.

Comment 2: How many of the validation points were ground truthed? What was the accuracy of the validation point interpretations?

Response 2: For better reliability of the results in accuracy assessment, all the 649 points used were collected using dual frequency receiver GPS (SOKKIA: Model No. S-10) which provided the horizontal accuracy in the range of 2-5 m. Further accuracy assessment was performed using these GCPs and overall accuracy of 90.14% was achieved with Kappa statistics of 0.88. Table 7 shows the accuracy assessment of the 2012 LULC map produced from Landsat Enhanced Thematic Mapper Plus (ETM+) data representing both the confusion matrix and the Kappa statistics.

Table 7. Accuracy assessment of the 2012 LULC map produced from Landsat Enhanced Thematic Mapper Plus (ETM+) data, representing both the confusion matrix and the Kappa statistics

Classified Data	***Reference Data***						***Row Total***	***User's Accuracy (%)***	***Overall Kappa Statistics***
	Agricultural Land	**Built Up**	**Forest**	**Snow & Glacier**	**Wastelands**	**Water Bodies**			
Agricultural Land	**128**	0	6	0	3	0	137	93.43	
Built Up	2	**96**	2	5	1	0	106	90.57	
Forest	11	0	**88**	3	0	3	105	83.81	
Snow & Glacier	0	4	1	**103**	2	1	111	92.79	
Wastelands	1	2	0	7	**82**	2	94	87.23	0.88
Water Bodies	0	0	1	1	6	**88**	96	91.67	
Column Total	142	102	98	119	94	94	**649**		
Producer's Accuracy (%)	90.14	94.12	89.80	86.55	87.23	93.62			
Overall Classification Accuracy (%)	90.14								

Comment 3: How many GPS survey data points were used to train the MLC? How did you account for potential autocorrelation in the training data?

Response 3: Total 1365 GPS survey data points i.e. GCPs were used to train the Maximum Likelihood Classifier (MLC) in this study. Out of this, 830 GCPs were collected using GPS survey and remaining 535 were collected from Google Earth images. The accuracy of the GCPs collected from both GPS survey and Google Earth images were ensured before using them for MLC and the horizontal accuracy of 2-5 m was achieved. In a satellite image, when the presence, absence, or degree of pixel characteristic affects the presence, absence, or degree of the same characteristic in neighbouring pixels, it is referred to as spatial autocorrelation (Congalton 1991). Existing spatial autocorrelation in each LULC class affects the classification results, depending on properties viz. sensor resolution and landscape fragmentation. Study of spatial autocorrelation helps to select the training size and training methods for different LULC classes; selects the appropriate image scene models and spatial resolution during classification; identifies the parameters for effective classification; and helps understanding the classification errors during accuracy assessment (Chen 2004; Foody 2002). In the present study before image classification, an exploratory spectral analysis was done using histograms of each band to understand the spectral characteristics of the LULC classes. The spatial autocorrelation was analysed using semivariogram function which is measured by setting variance against variable distances. This method is efficient in measuring autocorrelation among different LULC features (Brivio et al. 1993). The estimated semivariogram was plotted to assess the spatial autocorrelation in respective bands in the satellite image. The range and shape (piecewise slope) of the semivariograms were examined visually to determine the appropriate sizes for training data, window size and sampling interval for spatial feature extraction (Chen 2004; Xiaodong et al. 2009). A window size of 7 × 7 was chosen for sampling the training data, which gives the better classification results on Landsat ETM+ images (Wijaya et al. 2007). While developing the spectral signatures for different LULC classes, information acquired from band histograms and Euclidean distances were used for class separability. Due to higher confusion between barren land and urban areas at few places, urban areas were classified independently by masking it on the image. Uncertainties in misclassification between forest and agricultural land were reduced by adding more training samples. This significantly improved the classification accuracy (Gebremicael et al. 2017).

Comment 4: A comment is needed that assesses the impact of the scan line corrector failure on Landsat 7 imagery from 2003 onwards with regard to the 2012 image classifications.

Response 4: Due to failure in Scan Line Corrector (SLC) of the Landsat 7 satellite, all the images collected after May 31, 2003 are referred to as Landsat 7 ETM+ SLC off data. It resulted in 22% of data gap in each scene which has limited its scientific applications. However, with only 78% of data availability per scene it is some of the most radiometrically and geometrically accurate satellite dataset in the world and therefore it is still very useful for various studies (USGS 2018). A number of methods are developed to fill the data gaps in SLC off ETM+ datasets viz. Neighbourhood Similar Pixel Interpolator (NSPI), localized linear histogram match (LLHM), global linear histogram match (GLHM), Geostatistical Neighbourhood Similar Pixel Interpolator (GNSPI), and adaptive window linear histogram match (AWLHM) (Liu and Ding 2017). For heterogeneous regions, Neighbourhood Similar Pixel Interpolator (NSPI) is the simple and most effective method to interpolate the pixel values within the gaps with high accuracy (Chen et al. 2011; Gao et al. 2016; Zhu et al. 2012; Zhu and Liu 2014). The details on the NSPI algorithm are given in the research paper by Chen et al. (2011). In the present study, the Landsat ETM+ images of February/March 2012 had data gaps due to SLC off. Therefore, they were corrected using the IDL code for NSPI algorithm, which was run on software ENVI version 5.1. It is an open source algorithm developed by Chen et al. (2011) available freely on https://xiaolinzhu.weebly.com/open-source-code.html. As the study area is highly heterogeneous, this algorithm filled the data gaps in the satellite image with high accuracy i.e. Root Mean Square Error (RMSE) of 0.0367. As multiple scenes were involved in one image, necessary atmospheric, geometric and radiometric corrections were employed on the images to reduce the errors in classification. These corrections are explained in the Comment 5 and 6 of this draft. The accuracy assessment was done on the LULC map produced by 2012 image and it gave a very good accuracy i.e. overall accuracy of 90.14% and Kappa statistics of 0.88.

Comment 5: What radiometric correction was applied to ensure consistency of reflectance values across the large number of images used in your classifications?

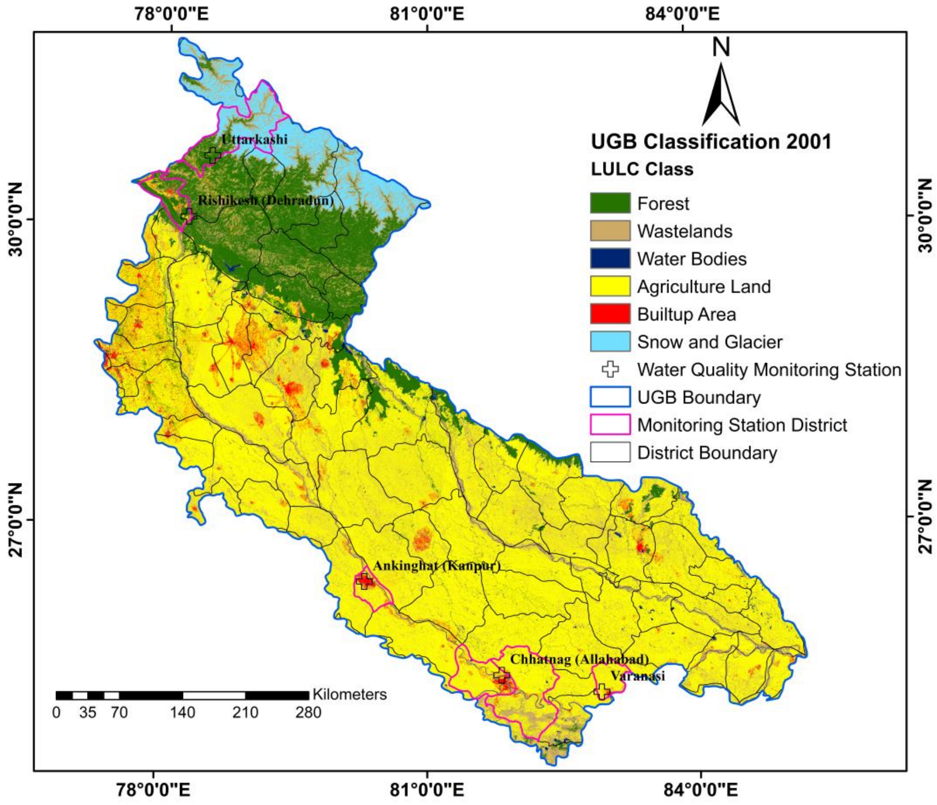
Response 5: First the satellite images were georeferenced to a common coordinate system i.e. World Geodetic System (WGS) 1984 Universal Transverse Mercator Zone 43 N. Total 75 control points were chosen from Survey of India (SoI) toposheets of scale 1:50,000 which were used as base map for georectification. It was done for proper alignment of features in the study area. To make the two satellite images comparable a good radiometric consistency and proper geometric alignment is required. But it is difficult to achieve due differences in atmospheric conditions, satellite sensor characteristics, phonological characteristics, solar angle, and sensor observation angle on different images (Shukla et al. 2017). Image pre-processing involves atmospheric, radiometric and geometric corrections; and temporal as well as topographic normalizations of the each satellite image to be used for LULC classification. For multi-temporal datasets image pre-processing is mandatory (Lu and Weng 2007). This study area is heterogeneous with rugged terrain and very undulating topography, therefore it is subjected to variations in the reflectance values due to temporal changes, hill shade effects, differences in viewing geometry, and solar illuminations. Hence to reduce the errors and get the actual reflectance values the Topographic and Atmospheric Correction for Airborne Imagery (ATCOR-2) algorithm available in ERDAS Imagine 2016 was used. The algorithm used Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) of 30 m spatial resolution to derive the characteristics viz. slope, aspect, shadow and skyview. This algorithm is well established and provides very good accuracy in removing haze, and in topographic and atmospheric corrections of the images (Gebremicael et al. 2017; Muriithi 2016). Finally image regression method was applied on the images to normalize the variations in the pixel brightness value due to multiple scenes taken on different dates.

Comment 6: You refer to ’relative geometric correction’. What is this? What algorithm was used?

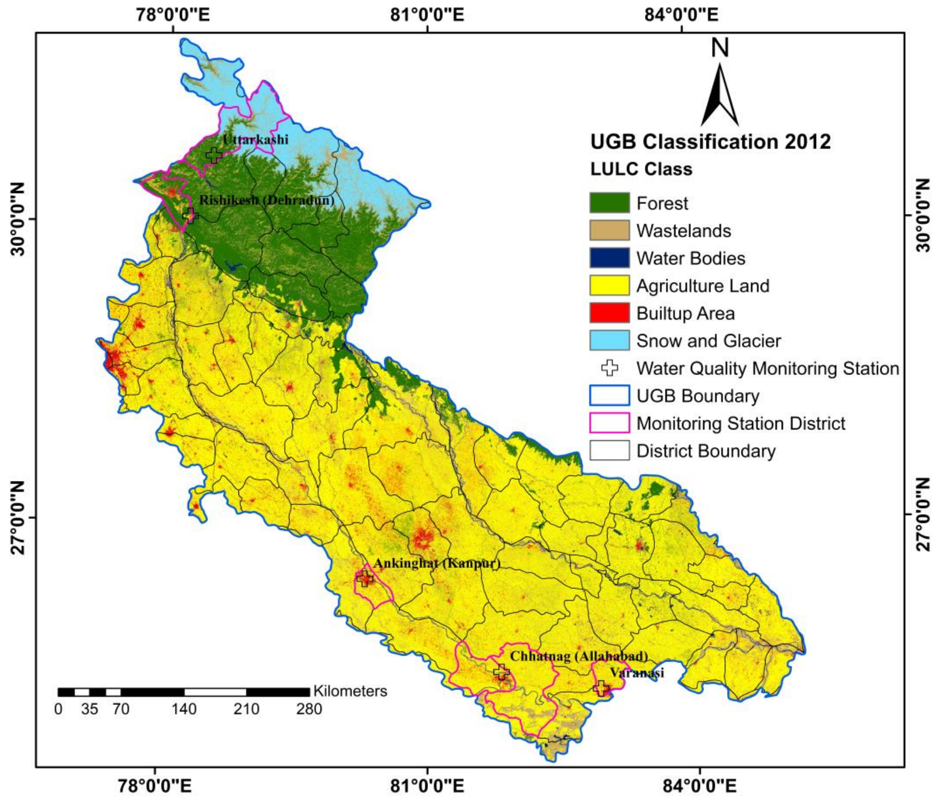
Response 6: Raw satellite images may contain geometric distortions due to the differences in platform, atmosphere, sensor, earth and the total field of view (Shukla et al. 2017). To compare and study the changes between multiple satellite images, similar and precise alignment of the features is essential. In the absence of geometric corrections, errors may introduce in the classification and change detection results. In this study, a relative geometric correction method was used to maintain geometric consistency of both the satellite images. In the relative geometric correction method, one image is used a reference image and other is corrected with respect to it (image to image coregistration). The recent Landsat ETM+ image of 2012 was used as reference image for coregistration and the image of 2001 was georectified with respect to it. It was conducted on ERDAS Imagine 2016 image processing software. The following steps were involved in geometric correction (Gill et al 2010): Polynomial geometric model was determined and the ground control “tie” points were established across the images. It was followed by computation of geometric transformation parameters which provides the error analysis and describes the accuracy of the correction. Then Nearest Neighbour resampling method was used to populate new output grid of georectified image. The geometrically rectified images must have Root Mean Square Error (RMSE) less than 0.5. This is the criteria often used for geometric corrections of the satellite images which ensure good accuracy (Samal and Gedam 2015).

Comment 7: The districts you have selected for analysis should be included on the maps of LULC (Figure 4) to give the reader of the paper the spatial context for them.

Response 7: Authors are sincerely thankful to the reviewer for pointing out this. As per reviewer suggestion, the authors have been included the district boundaries on both the LULC maps. There are total 77 districts in the complete river basin but the water quality of the monitoring stations is mainly affected by the districts in which they are located. It is to be noted that due to religious, economic and historical importance of River Ganga, the most important cities of the districts selected for analysis are located on the banks or in the proximity to River Ganga. Hence, the district boundaries are overlaid and highlighted in magenta colour on the LULC maps (Figure 4) to give the reader of the paper the spatial context for them. The modified Figure 4 is as below:



(a)



(b)

Figure 4. LULC maps of Upper Ganga River basin **(a)** LULC map of February/March 2001, and **(b)** LULC map of February/March 2012

Comment 8: 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.

Response 8: Authors are sincerely grateful to the reviewer for suggesting the use of district wise changes in LULC classes to relate changes in the water quality of the monitoring station. Earlier in the manuscript LULC changes of complete river basin were used to relate the Overall Index of Pollution (OIP) of the river basin which could only provide the broad overview and causal links between LULC changes and water quality status of the study area at a regional scale. But study of district wise LULC changes is extremely helpful in comprehending the water quality changes at the local scale and to identify source of pollutants at a particular monitoring station. The statistics presented in Table 6 given below is important to explain the changes in LULC of the districts in Section 5.2 of the revised manuscript. It is further used in developing the relationship between the LULC and OIP of the river basin which is explained in detail in Subsection 5.4.2. All the reviewers have suggested removing redundant information from the revised manuscript especially if tables and figures are showing same information.

Reviewer#1 (Comment 7): *The population statistics on page 18 should be presented as a table with the PGR statistics given for each district. Figure 3 on page 19 is repetition of the data that will be presented in the table so remove figure 3.*

Reviewer#2 (Comment 5): *Find a clear argument that flows throughout the paper and only select figures and data that make it easier for the reader to understand this argument. E.g. remove superfluous data such as the city populations on page 18.*

Reviewer#3 (Comment 5): *Table 4 and Figure 5 present the same results. Only one of them should be included in the paper to avoid repetition of information.*

In addition to the revised manuscript, LULC maps in very high resolution will be provided as a supplementary file (Figure 4). District boundaries are now highlighted on the LULC of both the years therefore; very high-resolution image file can be used to visually depict the changes in the LULC between 2001 and 2011. Keeping all the above reasons in mind, instead of figures Table 6 is presented illustrating district wise changes in LULC of Upper Ganga River basin.

Table 6. District wise changes in LULC **(a)** Uttarkashi, **(b)** Dehradun, **(c)** Kanpur, **(d)** Allahabad, and **(e)** Varanasi

(a)

Uttarkashi (LULC Class)	**2001 %**	**2012%**	**% Change (2001-2012)**
Forest	39.3	39.7	1.1
Wastelands	10.3	8.3	-19.3
Water Bodies	1.4	1.5	4.6
Agricultural Land	0.6	1.4	122.8
Builtup Area	0.2	0.6	186.3
Snow and Glacier	48.2	48.6	0.8
Total Area %	100.0	100.0	

(b)

Dehradun (LULC Class)	**2001 %**	**2012%**	**% Change (2001-2012)**
Forest	59.8	59.8	0.1
Wastelands	18.8	3.4	-82.1
Water Bodies	4.8	4.3	-9.8
Agricultural Land	13.5	20.3	50.6
Builtup Area	3.2	12.2	283.9
Total Area %	100.0	100.0	

(c)

Kanpur (LULC Class)	**2001 %**	**2012%**	**% Change (2001-2012)**
Forest	0.3	0.3	8.7
Wastelands	23.4	4.7	-79.8
Water Bodies	2.5	2.6	3.8
Agricultural Land	63.7	67.0	5.2
Builtup Area	10.1	25.3	152.1
Total Area %	100.0	100.0	

(d)

Allahabad (LULC Class)	**2001 %**	**2012%**	**% Change (2001-2012)**
Forest	1.5	1.5	-1.2
Wastelands	22.1	16.0	-27.8
Water Bodies	3.0	3.1	1.3
Agricultural Land	70.5	73.4	4.2
Builtup Area	2.8	6.0	111.7
Total Area %	100.0	100.0	

(e)

Varanasi (LULC Class)	**2001 %**	**2012%**	**% Change (2001-2012)**
Forest	0.6	0.7	24.4
Wastelands	16.8	6.0	-64.5
Water Bodies	3.1	3.3	7.1
Agricultural Land	76.8	79.4	3.4
Builtup Area	2.7	10.5	291.8
Total Area %	100.0	100.0	

Comment 9: In place of table 4, I would present a cross tabulation table of the 2001 and 2012 LULC classes. This will clearly show the reader what has changed to what and then the gross and net changes can be shown in figure 5.

Response 9: We acknowledge the suggestions reviewer has given. Table 5 given below presents the cross tabulation table of the 2001 and 2012 which shows what LULC class has changed to what. Gross and net changes are shown in Figure 5 as suggested. Further a paragraph is added in Section 5.2 of the revised manuscript describing the change matrix and it is explained why it has happened. As district wise LULC change tables are also added to this section, editing is done accordingly.

Table 5. Change matrix showing LULC interconversion between the year 2001 and 2012 in Upper Ganga River basin

LULC Class	F	WL	WB	AG	BU	SG	LULC 2001
F	13.3	0.0	0.0	0.0	0.0	0.0	**13.3**
WL	1.7	11.4	0.0	1.7	2.2	0.1	**17.1**
WB	0.2	0.0	1.8	0.0	0.0	0.0	**2.0**
AG	0.0	0.0	0.0	58.3	0.0	0.0	**58.3**
BU	0.0	0.0	0.0	0.0	5.3	0.0	**5.3**
SG	0.0	0.0	0.0	0.0	0.0	4.0	**4.0**
LULC 2012	**15.2**	**11.4**	**1.8**	**60.0**	**7.5**	**4.1**	**100.0**

* Figures indicate the percentage of basin area

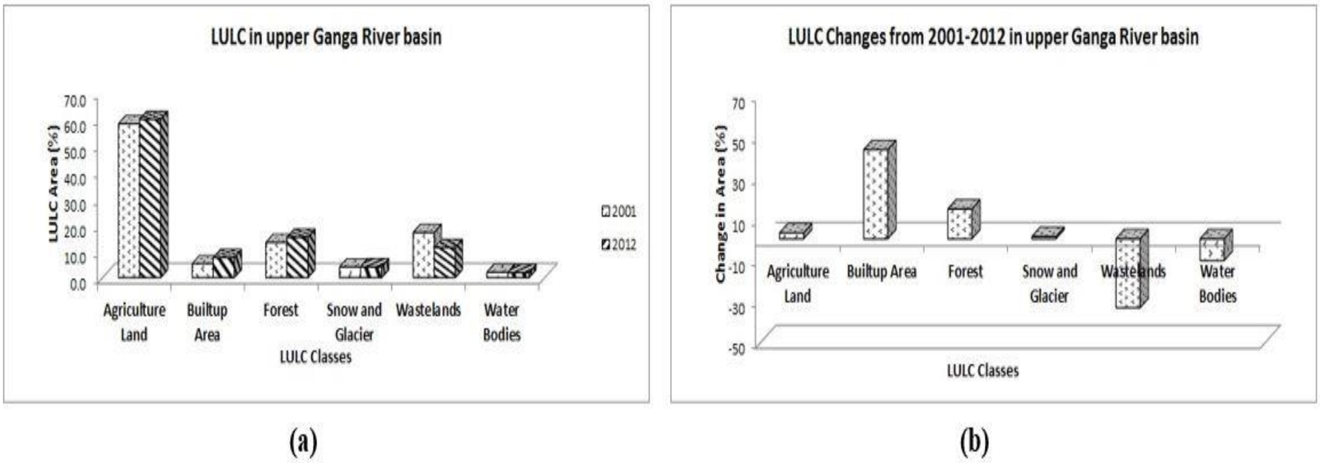


Figure 5. Graph showing LULC of the years 2001-2012 (a) LULC area in percentage (%) and (b) LULC changes from 2001-2012 in Upper Ganga River basin

Technical Comments:

Comment 1: Repetition is a problem in several places through the text. The worst example of this is presenting results back again in the conclusions. Go through the paper carefully and remove the repetition.

Response 1: Reviewer suggestions regarding the repetition of the words in the manuscript have been changed in the revised manuscript. Section 6 (Conclusions) is edited as required. Our endeavour will be that the revised paper is much better than the current version.

Comment 2: The English needs to be corrected throughout the paper. Please find a native English speaker to go through the paper to correct for missing words, improve the phraseology used and correct the grammar.

Response 2: The whole manuscript has been checked and modified suitably. Authors have corrected the missing words and grammar, improved the phraseology and checked the English in whole manuscript.

Comment 3: Avoid the use of superlatives e.g. ’tremendous’ and ’colossal changes’. These terms cannot be substantiated and so should not be used.

Response 3: Authors remove the use of superlatives words in whole manuscript and used appropriate words in revised manuscript whenever required.

Comment 4: The long list of water quality indicators is excessive. Highlight only those that could be relevant to the data available for this study and those commonly used.

Response 4: Authors acknowledge the points the reviewer is making. For selecting water quality index the following criteria is followed (Abbasi and Abbasi, 2012; Horton 1965): (i) limited number of variables should be handled by the used index to avoid making the index unwieldy; (ii) the variables used in the index should be significant in most areas, (iii) only reliable data variables for which the data are available should be included. Therefore, the water quality parameters are chosen for this study with care. If each and every possible parameter is included in the index then it will become unwieldy and will not represent the water quality status of the particular region. Hence, only those water quality parameters, which together reflect the overall water quality at a location or for a given end use should be considered. The acceptability criteria of water quality indices vary from region to region due to differences in the water quality standards by the Government organizations of the region. The water quality standards vary for different countries due to the differences in the climatic and LULC characteristics of the region; and physico-chemical properties of the water body under study. They affect the water quality parameters therefore, the water quality standards vary for different countries.

Overall Index of Pollution (OIP) developed by Sargaonkar and Deshpande (2003) is a general water quality classification scheme developed 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 takes 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 helps to evaluate the surface water quality status with respect to particular individual parameter whereas the OIP helps to assess the overall water quality status specifically in the Indian context. This index uses only those water quality parameters that are important to Indian context. Therefore, of all the water quality parameters available, only 7 most important ones i.e. BOD, DO%, Total Coliform (TC), F, Turbidity, pH and Hardness $CaCO_3$ that are affected due to changes in LULC are chosen after extensive literature review. For example BOD, DO%, and Total Coliform (TC) are affected by urban pollution. F, Turbidity and pH are general water quality parameters affected by both natural and anthropogenic factors. However, Hardness $CaCO_3$ is a parameter affected mainly by agricultural activities and urban pollution. It was discussed in the Section 1 "introduction" of the earlier manuscript. This section is slightly edited and updated in the revised manuscript. While discussing the results in Section 5.4.2, Individual Parameter Indices (IPIs) of only those water quality parameters are highlighted whose values are in "*polluted*" category and those are discussed in detail where significant change is observed over a period of 2001 to 2011. The IPIs and OIPs in polluted category are highlighted in the Table 9 given below.

Table 9. Individual parameter indices (IPIs) and overall indices of pollution (OIPs) computed at various water quality monitoring stations of Upper Ganga River basin over periods of 2001 and 2012 for pre-monsoon, monsoon and post-monsoon seasons

(i)

Parameters	Water Quality Monitoring Stations														
	Uttarkashi			Rishikesh			Kanpur			Allahabad			Varanasi		
	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov
BOD	1.00	1.00	1.00	1.00	1.00	1.00	2.87	2.40	2.60	2.67	2.80	2.47	1.67	1.47	1.20
DO%	1.33	1.28	1.27	2.49	3.24	2.97	1.27	0.79	0.99	1.06	1.61	0.86	1.20	1.06	1.54
F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hardness $CaCO_3$	1.00	1.00	1.00	1.78	1.00	1.00	1.99	1.80	1.87	1.95	3.16	2.66	1.99	2.89	2.45
pH	2.76	2.76	2.76	2.76	2.76	2.76	2.52	3.33	2.76	3.03	3.33	3.03	3.03	3.65	3.03
Total Coliform	-	-	-	-	-	-	-	-	-	3.43	4.60	4.98	4.02	3.48	3.21
Turbidity	-	-	-	-	-	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
OIP (2001)	**1.42**	**1.41**	**1.41**	**1.81**	**1.80**	**1.75**	**2.61**	**2.49**	**2.54**	**2.02**	**2.50**	**2.29**	**1.99**	**2.08**	**1.92**

(ii)

Parameters	Water Quality Monitoring Stations														
	Uttarkashi			Rishikesh			Kanpur			Allahabad			Varanasi		
	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov
BOD	1.00	1.00	1.00	1.00	1.00	1.00	4.67	6.67	2.67	1.93	2.13	1.60	2.00	2.60	1.93
DO%	2.36	2.97	2.36	1.81	2.22	2.08	1.47	2.22	1.20	1.54	1.49	0.65	1.13	0.65	0.65
F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hardness $CaCO_3$	1.00	1.00	1.00	1.00	1.00	1.00	2.10	2.02	2.91	1.97	1.86	1.92	1.90	1.00	1.82
pH	2.09	1.91	1.74	2.09	2.52	2.09	4.81	3.65	2.76	3.03	4.00	3.03	4.81	3.65	4.81
Total Coliform	-	-	-	-	-	-	-	-	-	4.05	4.11	3.90	4.14	5.97	3.93
Turbidity	-	-	-	-	-	-	1.00	1.20	1.08	1.00	1.00	1.00	1.00	1.00	1.00
OIP (2012)	**1.49**	**1.58**	**1.42**	**1.38**	**1.55**	**1.44**	**2.51**	**2.79**	**2.77**	**2.07**	**2.23**	**1.87**	**2.28**	**2.27**	**2.16**

Comment 5: Avoid excessive precision e.g. 238,347.74 km^2. At the scale you are working expressing to the nearest km^2 is appropriate.

Response 5: Authors have rounded off and changed the value to 23,8348 km^2 approximately (total drainage area) in the revised manuscript in place of 238,347.74 km^2.

Comment 6: Figure 1 - The inset map should be inside the map frame, the water quality monitoring station location labels conflict with the basin boundary line - change the position of the labels so that this doesn't occur, remove the underscore characters from the legend text (this also applies to figure 4).

Response 6: Authors have modified Figure 1 according to the reviewer suggestions. The modified figure has no conflict between the basin boundary and labels of water quality monitoring stations. The updated Figure 1 is given below and the same has been updated in the revised manuscript. Authors have removed underscore characters from the legend text of Figure 4 and it is updated in the revised manuscript. The updated Figure 4 is already given above in Response 7 of this draft.

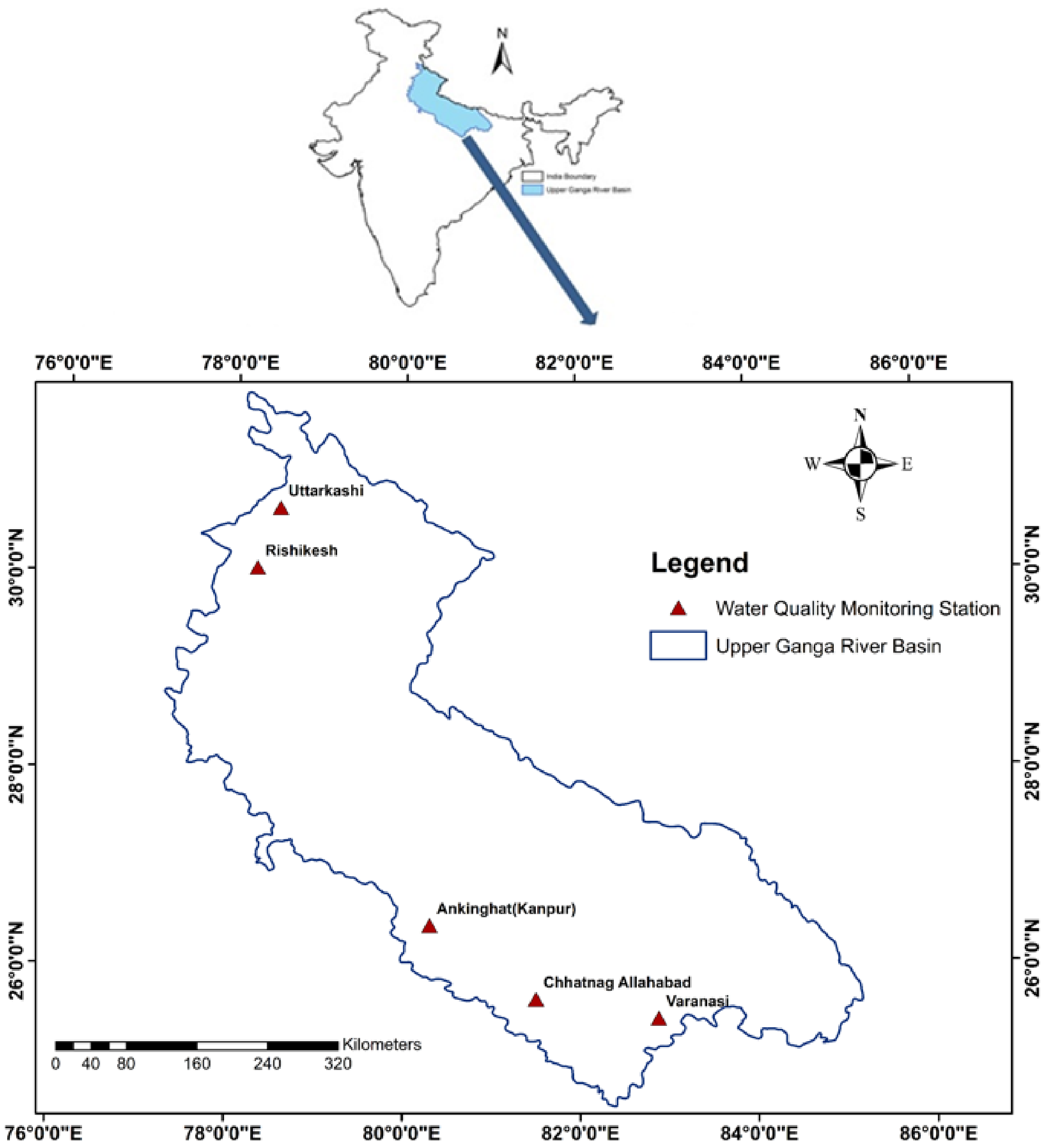


Figure 1. Location map of the study area in northern India and water quality monitoring stations across Upper Ganga River basin

Comment 7: The population statistics on page 18 should be presented as a table with the PGR statistics given for each district. Figure 3 on page 19 is repetition of the data that will be presented in the table so remove figure 3.

Response 7: As per reviewer suggestion, the population statistics have been presented in Table 4 (revised manuscript) showing the Population Growth Rate (PGR) and total population in the census years 2001 and 2011. A discussion on this table is made in the Section 5.1 of the revised manuscript. Figure 3 have been removed in revised manuscript.

Table 4. Table showing Population Growth Rate (PGR) % and total population in the census years 2001 and 2011

S. No.	Districts	Total Population (2001)	Total Population (2011)	Population Growth Rate (PGR) %
1	Agra	3620436	4418797	22.1
2	Aligarh	2992286	3673889	22.8
3	Allahabad	4936105	5954391	20.6
4	Almora	630567	622506	-1.3
5	Ambedkar Nagar	2026876	2397888	18.3
6	Azamgarh	3939916	4613913	17.1
7	Bageshwar	249462	259898	4.2
8	Baghpat	1163991	1303048	11.9
9	Bahraich	2381072	34,87,731	46.5
10	Ballia	2761620	32,39,774	17.3
11	Balrampur	1682350	2148665	27.7
12	Barabanki	2673581	3260699	22.0
13	Bareilly	3618589	4448359	22.9
14	Basti	2084814	24,61,056	18.0
15	Bhojpur	2243144	2728407	21.6
16	Bijnor	3131619	36,82,713	17.6
17	Budaun	3069426	3681896	20.0
18	Bulandshahar	2913122	3499171	20.1
19	Buxar	1402396	1706352	21.7
20	Chamoli	370359	391605	5.7
21	Champawat	224542	259648	15.6
22	Dehradun	1282143	1696694	32.3
23	Deoria	2712650	3100946	14.3
24	Etah	15,61,705	1774480	13.6
25	Faizabad	2088928	2470996	18.3
26	Farrukhabad	1570408	1885204	20.0
27	Fatehpur	2308384	26,32,733	14.1
28	Firozabad	2052958	2498156	21.7
29	Gautam Buddha Nagar	1202030	1648115	37.1
30	Ghaziabad	3290586	4681645	42.3
31	Ghazipur	3037582	3620268	19.2
32	Gonda	2765586	3433919	24.2
33	Gopalganj	2152638	2562012	19.0
34	Gorakhpur	3769456	4440895	17.8
35	Hardoi	3398306	4092845	20.4
36	Haridwar	1447187	1890422	30.6
37	Hathras	1336031	1564708	17.1
38	Jaunpur	3911679	4494204	14.9
39	Jyotiba Phule Nagar	1499068	1840221	22.8

40	Kannauj	1388923	1656616	19.3
41	Kanpur Dehat	1563336	1796184	14.9
42	Kanpur Nagar	4167999	4581268	9.9
43	Kaushambi	1293154	1599596	23.7
44	Kheri	3207232	4021243	25.4
45	Kinnaur	78334	84121	7.4
46	Kushinagar	2893196	3564544	23.2
47	Lucknow	3647834	4589838	25.8
48	Maharajganj	2173878	2684703	23.5
49	Mainpuri	1596718	1868529	17.0
50	Mau	1853997	2205968	19.0
51	Meerut	2997361	3443689	14.9
52	Mirzapur	2116042	2496970	18.0
53	Moradabad	3810983	4772006	25.2
54	Muzaffarnagar	3543362	4143512	16.9
55	Nainital	762909	954605	25.1
56	Patna	4718592	5838465	23.7
57	Pauri Garhwal	697078	687271	-1.4
58	Pilibhit	1645183	2031007	23.5
59	Pithoragarh	462289	483439	4.6
60	Pratapgarh	2731174	3209141	17.5
61	Rae Bareli	2872335	3405559	18.6
62	Rampur	1923739	2335819	21.4
63	Rudraprayag	227439	242285	6.5
64	Sant Kabir Nagar	1420226	1715183	20.8
65	Sant Ravidas Nagar	1353705	1578213	16.6
66	Saran	3248701	3951862	21.6
67	Shahjahanpur	2547855	3006538	18.0
68	Shravasti	1176391	1117361	-5.0
69	Siddharthnagar	2040085	2559297	25.5
70	Sitapur	3619661	4483992	23.9
71	Siwan	2714349	3330464	22.7
72	Sultanpur	3214832	3797117	18.1
73	Tehri Garhwal	604747	618931	2.3
74	Udhamsingh Nagar	1235614	1648902	33.4
75	Unnao	2700324	3108367	15.1
76	Uttarkashi	295013	330086	11.9
77	Varanasi	3138671	3676841	17.1
Total	**Upper Ganga River basin**	171186859	206188401	20.45

Comment 8: The information on pH on page 30 can be regarded as a known fact and so does not need to be explained.

Response 8: As per reviewer suggestion, pH information on page 30 has been removed and suitably modified in manuscript.

Comment 9: The discussion that follows the pH description needs to be written with reference to just the set of figures showing the OIP values plotted against the stations. The other figure is effectively repetition so remove the other figure.

Response 9: As per reviewer suggestion, Figure 6 (a), 6 (b) and 6 (c) has been removed. The discussion that follows the pH description is rewritten with reference to the OIP values plotted against the stations. It is updated in the revised manuscript in Section 5.4.2.

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