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

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Abstract

For sustainable development in a river basin it is crucial to understand population growth-Land Use/Land Cover (LULC) transformations-water quality nexus. This study investigates effects of demographic changes and LULC transformations on surface water quality of Upper Ganga River basin. River gets polluted in both rural and urban area. In rural area, pollution is because of agricultural practices mainly fertilizers, whereas in urban area it is mainly because of domestic and industrial wastes. First, population data was analyzed statistically to study demographic changes in the river basin. LULC change detection was done over the period of February/March 2001 to 2012 [Landsat 7 Enhanced Thematic Mapper (ETM+) data] using remote sensing and Geographical Information System (GIS) techniques. Further, water quality parameters viz. Biological Oxygen Demand (BOD), Dissolve Oxygen (DO) %, Flouride (F), Hardness $CaCO_3$, pH, Total Coliform bacteria and Turbidity were studied in basin for pre-monsoon (May), monsoon (July) and Post-monsoon (November) seasons. Non-parametric Mann-Kendall rank test was done on monthly water quality data to study existing trends. Further, Overall Index of Pollution (OIP) developed specifically for Upper Ganga River basin was used for spatio-temporal water quality assessment. From the results, it was observed that population has increased in the river basin. Therefore, significant and characteristic LULC changes are observed in the study area. Water quality degradation has occurred in the river basin consequently the health status of the rivers have also changed from range of acceptable to slightly polluted in urban areas.

Keywords: Land use/land cover, Overall Index of Pollution**,** Remote sensing, River basin.

1. Introduction

Demographic changes and anthropogenic activities are potential drivers affecting the quantity and quality of available water resources on local, regional and global scale. 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). Rapid increase in population and economic hardship is causing urbanization (Bjorklund et al. 2011). These affects cause changes in natural landscape characteristics and river morphometry; and increase in pollutant loads. Hence, LULC and water quality indicator parameters are often used in water quality assessment studies (Kocer and Sevgili 2014; Liu et al. 2016; Sanchez et al. 2007; Tu 2011). River has a capability to reduce its pollutant load, also known as self-purification (Hoseinzadeh et al. 2014). In extreme situations, ecosystem degradation caused by anthropogenic factors can be an irreversible change. Hence, it is crucial to understand effects of demographic changes and LULC transformations on water quality for pollution control and sustainable water resources development in a river basin (Milovanovic 2007; Teodosiu et al. 2013). Anthropogenic activities in a river basin are directly correlated with the decline in water quality (Haldar et al. 2014). In order to increase yield, farmers introduce chemicals in the form of fertilizers, pesticides, herbicides, etc., causing addition of pollutants in the river (Rashid and Romshoo 2013; Yang et al. 2013). Urban areas introduce pollutants from leachates of landfill sites, stormwater runoff and from direct dumping of waste (Tsihrintzis and Hamid 1997). Water quality impairment causes change in the various physico-chemical and bacteriological characteristics of the river water, viz. Biological Oxygen Demand (BOD), temperature, pH, Chloride (Cl), Colour, Dissolved Oxygen (DO), Hardness $CaCO_3$, Turbidity, Total Dissolved Solids (TDS), etc. These changes make the river water unfit for human health (Ballestar et al. 2003; Chalmers et al. 2007; Smith et al. 1999). Ban et al. (2014) observed that water quality monitoring programs monitor and produce large and complex datasets on parameters related to physico-chemical and bacteriological properties of the river water. Trends in the water quality vary both spatially and temporally, causing difficulty in establishing relationship between water quality and LULC changes (Phung et al. 2015; Russell 2015). Broadly, there are two methods to study the spatio-temporal variations in the water quality of a river: (i) Direct method where spatio-temporal variability in the water quality parameters are studied with the help of statistical analysis and graphs, and (ii) Indirect methods where different water quality/pollution indices based on environmental standards of surface water are used (Rai et al. 2011). Demographic growth, LULC changes and their effects on water quality of a region are very site specific. Hence, different regions/countries have developed their own water quality or pollution indices for different types of water uses based on their respective water quality standards/permissible pollution limits (Rangeti et al. 2015). Water quality index (WQI) is a single numerical value that reflects the health of a waterbody by giving combined effects of various water quality parameters. WQI is a simplest and fastest indicator to assess water quality of a river (Hoseinzadeh et al. 2014). Formulation of water quality indices are done in two ways: (i) in the first way there is increase in index numbers with the degree of pollution.

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It can be classified as 'water pollution indices' and (ii) in the second way there is decrease in the index numbers with degree of pollution. Hence, later can be classified as 'water-quality indices'. The difference between the two is just superficial. 'Water pollution' which indicates 'degraded water quality' of a waterbody is mere a special case of the general term 'water quality' (Abbasi and Abbasi 2012).

Several site specific water quality/pollution indices available in the literature are: Composite Water Quality Identification Index (CWQII) (Ban et al. 2014); River Pollution Index (RPI), Forestry Water Quality Index (FWQI) and National Sanitation Foundation Water Quality Index (NSFWQI) (Hoseinzadeh et al. 2014); Canadian Water Quality Index (CWQI) (Farzadkia et al. 2015); Comprehensive water pollution index of China (Li et al. 2015); Prati's implicit index of pollution (Prati et al. 1971); 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).

Water Quality Indices are often used to investigate the spatio-temporal variations in water quality of a river. Water quality indices study the combined effects of variations in water quality parameters on river health and to compare it along the river basin to estimate the permissible limits and their changing trends (Abbasi and Abbasi 2012). Remote sensing and GIS are efficient aids in preparing and analyzing spatial datasets such as satellite data, Digital Elevation Model (DEM) data, etc. Remote sensing technology is often used in preparing LULC maps of a region whereas GIS helps in delineation of river basin boundaries, extraction of study area, hydrological modeling, etc. (Kindu et al. 2015; Kumar and Jhariya 2015; Wilson 2015). Selection of appropriate method for a particular study is based on the specific objectives and availability of the data/tools required for the study. In this particular study, a WQI called 'Overall Index of Pollution' (OIP) developed specifically for Indian conditions by Sargoankar and Deshpande (2003) is used to assess the health status of surface waters across Ganga River basin. Thus, present study focuses on identifying the drivers associated with spatio-temporal variation of water quality in Upper Ganga River basin by considering the demographic changes and LULC changes. In this, seasonal studies are assessed at different monitoring stations and also the study aims to check the effectiveness of OIP method.

2. Study area

The Upper Ganges basin (UGB) is experiencing rapid rate of change in land cover and irrigation practices. A part of the Upper Ganga River basin is selected as the study area (Fig. 1). It is located in the parts of Uttarakhand, Uttar Pradesh, Bihar and Himanchal Pradesh states of India and covers total drainage area of 238347.74 km^2. The geographical extent of the river basin is between 24^0 32' 16''–31^0 57' 48'' N to 76^0 53' 33''–85^0 18' 25'' E. The altitude ranges from 7500 m in the Himalayan region to 100 m in the lower Gangetic plains. Some mountain peaks in the headwater reaches are permanently covered with snow. Annual average rainfall in the UGB is in the range of 550-2500 mm (Bharati and Jayakody 2010). Major rivers contributing this river basin are Bhagirathi, Alaknanda, Yamuna, Dhauliganga, Pindar, Mandakini, Nandakini, Ramganga, Tamsa (Tons), etc. Tehri Dam constructed on Bhagirathi River is an important hydropower project. This region comprises of major cities and towns such as Allahabad, Kanpur, Varanasi, Dehradun, Rishikesh, Haridwar, Moradabad, Bareilly Bijnor, Garhmukteshwar, Narora, Farrukhabad, Badaun, Chandausi, Amroha, Kannauj, Unnao, Fatehpur, Mirzapur, etc.

Most predominant soil groups found in the region are alluvial, sand, loam, clay and their combinations. Due to favorable agricultural conditions majority of the population practices agriculture and horticulture. However, a large portion of the total population lives in cities located mainly along Ganga River. Most of them work in urban or industrial areas.

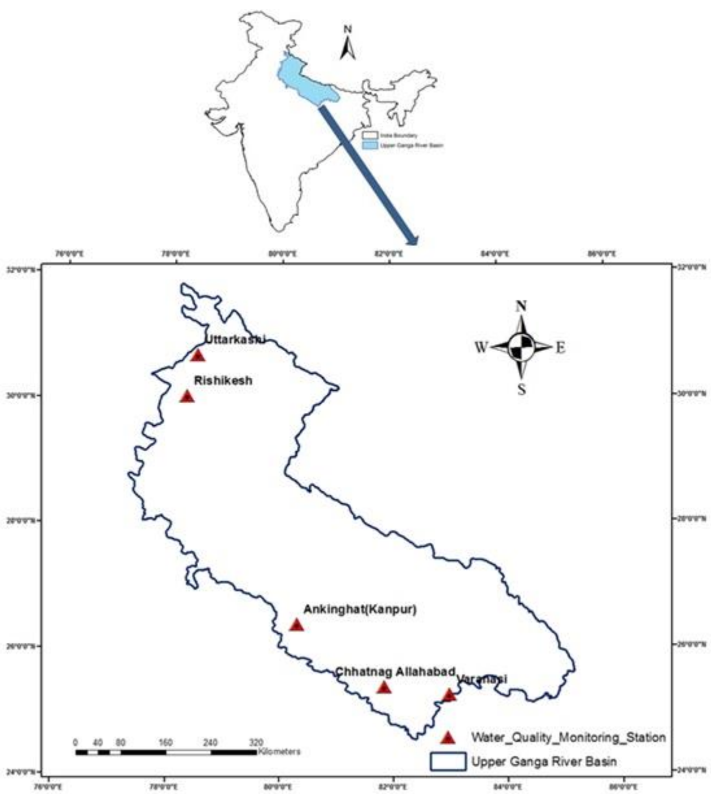

Figure 1. Location map of the study area in northern India and water quality monitoring stations across Upper Ganga River basin

3. Data description

3.1 Data acquired

In this study, two types of datasets were used: (i) Spatial datasets: (a) Shuttle Radar Topography Mission (SRTM) 1 arc-second global Digital Elevation Model (DEM) of 30 m spatial resolution; and (b) Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images, 23 in total, for the month of February/March in 2001 and 2012, having 30 m spatial resolution. Both SRTM DEM and time series Landsat dataset were collected from United States Geological Survey (USGS), United States of America (USA) (USGS 2016); (c) Survey of India toposheets of 1:50,000 scale from Survey of India (SoI), Government of India (GoI); (d) Published LULC, waterbodies, urban landuse and wasteland maps from Bhuvan Portal, Indian Space Research Organization (ISRO), Government of India (Bhuvan 2016). SoI toposheets and published maps were used as reference to improve the LULC classification results; and (e) For ground truthing of prepared LULC maps, Ground Control Points (GCPs) collected using Global Positioning System (GPS) during the field visit and Google Earth were used.

(ii) Non-spatial datasets were acquired from various departments of Government of India: (a) Census records and reports of the years 2001 and 2011 from Census of India (Census of India 2011); (b) Reports on LULC statistics from Bhuvan Portal, ISRO, GoI; (c) Monthly water quality datasets of the year 2001-2012 from Central Water Commission (CWC); and (d) Water quality reports from Central Pollution Control Board (CPCB), Uttar Pradesh Pollution Control Board (UPPCB), CWC and National Remote Sensing Centre (NRSC), ISRO, GoI.

3.2 Field data and water quality monitoring stations

The total of 649 validation points for LULC map of 2012 were selected by visual interpretation of high-resolution imagery on Google Earth and verified with ground truth data collected after a survey of the site in 2012. In addition, GPS survey was carried out and samples of LULC were collected in the Upper Ganga River basin. These ground truth GPS data were used to relate land

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cover to the supervised classifications results. To understand the impacts of LULC transformations on water quality of the Upper Ganga River basin, two water quality monitoring stations viz. Uttarkashi and Rishikesh were chosen in the upper reach of the river basin. This part of the river basin comprises of hilly undulating terrain with moderately less anthropogenic influences. Moreover, three water quality monitoring stations viz. Kanpur (Ankinghat), Allahabad (Chhatnag), and Varanasi were selected in the lower reach of the river basin. This part of the river basin falls under Gangetic plains with extreme anthropogenic activities. Spatio-temporal changes in the water quality of these monitoring stations were examined over a period of year 2001-2012.

4. Methodology

Flow chart of the methodology illustrated in Fig. 2 shows that the study is conducted in three phases: (i) In the first phase, remote sensing and GIS techniques are used. First SRTM DEM data is pre-processed by filling the sinks in the dataset using ArcGIS 10.1 Geo-processing tools. After pre-processing of the SRTM DEM, Arc Hydro tools are used to delineate the Upper Ganga River basin boundary using geo-processing techniques. Landsat satellite dataset of each year consisted of 23 images of February/March. The images of same months are used to reduce errors in LULC change detection due to LULC of different seasons. The satellite images are first geo-registered and mosaicked. To achieve the consistent radiometric and geometric images for LULC change analysis, relative geometric correction methods are employed to have good geometric consistency between the time series satellite images. 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 (Samal and Gedam 2015). After extracting the study area, samples are collected for each LULC class and Maximum Likelihood Classifier (MLC) of supervised classification approach is used to classify the time series satellite images of both 2001 and 2012 years into 6 LULC classes, viz. snow cover, forests, built-up lands, agricultural lands, water bodies and wastelands. Accuracy assessment is done using GCPs collected from field visit, SoI topographic maps and Google Earth images. SoI topographic maps and published LULC, waterbodies, urban landuse and wasteland maps of Bhuvan Portal are used as reference to improve the LULC classification results. A confusion matrix is generated showing accuracy statistics of the LULC map. Due to a lack of ground truth data of year 2001, the accuracy assessment is done for the LULC of the year 2012. Both time series satellite dataset are of Landsat ETM+ with spatial resolution of 30 m and a large number of GCPs are available for the year 2012. Hence, LULC map of year 2012 would represent the overall accuracy of both the maps.

Further, post classification change detection method is used for change detection in the study area; (ii) in the second phase, population data available for year 2001 and 2011 are analyzed statistically to understand the population growth in the region. Census of India, provides village wise population data for rural areas and ward/city wise population data for urban areas. The population data of 77 districts falling into Upper Ganga River basin are organized into rural and urban populations to study population change patterns in the study area between the years 2001 and 2011; and (iii) in the third phase, first the statistical analysis and non-parametric Mann-Kendall rank test are performed on seven monthly water quality parameters (BOD, DO%, Flouride (F), Hardness $CaCO_3$, pH, Total Coliform Bacteria and Turbidity) of the five water quality monitoring stations viz. Uttarkashi, Rishikesh, Kanpur (Ankinghat), Allahabad (Chhatnag), and Varanasi. Further, a Water Quality Index (WQI) called ‘Overall Index of Pollution’ (OIP) developed by Sargoankar and Deshpande (2003) is used to study spatio-

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temporal variations in the water quality of pre-monsoon, monsoon and post-monsoon seasons of Upper Ganga River basin.

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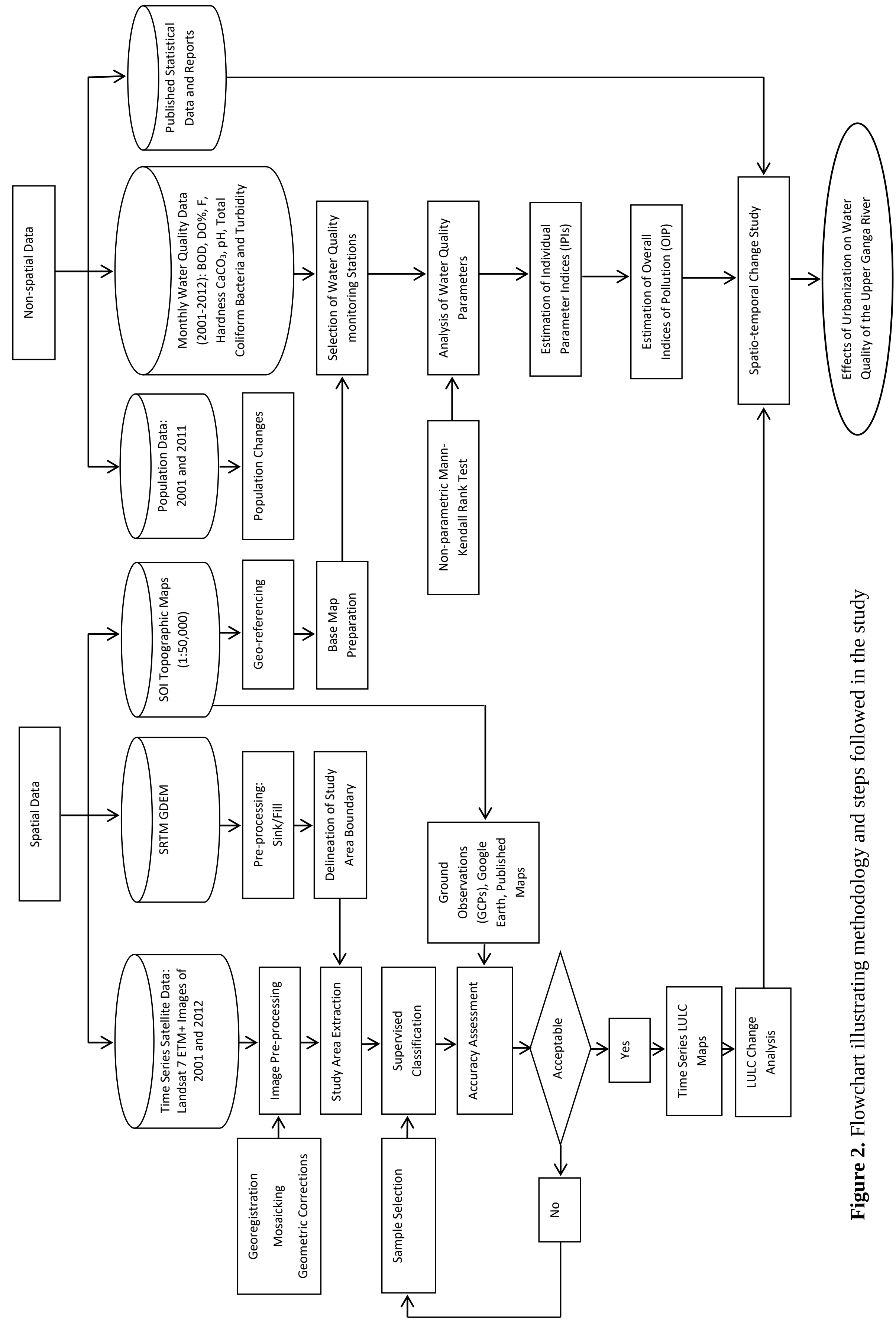

Figure 2. Flowchart illustrating methodology and steps followed in the study

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4.1 Overall Index of Pollution (OIP)

Overall Index of Pollution (OIP) is a Water Quality Index (WQI) developed by Sargoankar and Deshpande (2003) which assesses the health status of surface waters, specifically under Indian conditions. It is a general classification scheme based on the concept similar to Prati et al. (1971). It takes into consideration the water quality standards/classification scheme of various national and international agencies, viz. Central Pollution Control Board (CPCB), India; water quality standards of Indian Standards Institution-10500 (ISI); water quality standards of European Community (EC) and World Health Organization (WHO), etc. and reported pollution effects of important water quality indicator parameters. In this scheme, water quality status is reflected in terms of pollution effects caused by parameters considered under the study. There are total five classes, viz. C1: Excellent/pristine, C2: Acceptable/requires disinfection, C3: Slightly polluted/requires filtration and disinfection, C4: Polluted/requires special treatment and disinfection and C5: Heavily polluted/cannot be used. On the basis of water quality standards/limits of CPCB, the different concentration level of the parameters are put into these classes. In order to bring the different water quality parameters into a common unit, an integer value (also known as class index) 1, 2, 4, 8 and 16 is assigned to each class i.e. C1, C2, C3, C4 and C5 respectively in geometric progression. The class indices indicate the pollution level of water in numeric terms (Table 2). The concentration value of the parameter is then assigned to the respective mathematical equation of value function curves to obtain one number value called an Individual Parameter Index (IPI) or (*Pi*) (Table 3). Finally, the Overall Index of Pollution (OIP) is calculated as a mean of all the Individual Pollution Indices or (*Pi*) considered in the study and mathematically it is given by expression:

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

Where, *Pi* is the pollution index for the *i*th parameter, *i*=1, 2,…., *n* and *n* denotes the number of parameters. Table 1 presents the water quality parameters across Upper Ganga River basin for pre-monsoon, monsoon and post-monsoon seasons over periods of 2001 and 2012.

Using mathematical equations given in Table 3, Individual Parameter Indices (IPIs) are calculated for each parameter at a given time interval. Finally, OIP is estimated for each water quality monitoring station across the Upper Ganga River basin over a period of 2001 to 2012. OIP is developed by taking mean of IPIs of all the water quality parameters which is computed by mathematical expression Eq. (1). While calculating OIP, the mean of IPIs all the seven parameters, viz. BOD, DO %, Flouride (F), Hardness CaCO3, pH, Total Coliform Bacteria and Turbidity are used. It gives the combined effect of all the water quality parameters on the water quality status of a particular station in a given time. All the OIP were calculated for each station data in the basin for pre-monsoon, monsoon and post-monsoon seasons. Further, spatio-temporal variations in the water quality as a result of LULC transformations were studied for study basin using OIP.

Table 1. Water quality parameters across Upper Ganga River basin for pre-monsoon, monsoon and post-monsoon seasons over periods of 2001-2012

(i)

Parameters	Water Quality Monitoring Stations														
(Year 2001)	Uttarkashi			Rishikesh			Kanpur			Allahabad			Varanasi		
	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov
BOD	1.1	1.1	1.1	1.1	1.0	1.1	2.8	1.7	2.4	4.0	4.2	3.7	2.5	2.2	1.8
DO%	88	104	89	71	60	64	89	96	93	92	84	95	90	92	85
F	0.19	0.04	0.22	0.23	0.16	0.26	0.61	0.21	0.34	0.09	0.50	0.51	0.3	0.05	0.51
Hardness $CaCO_3$	65	60	68	76	67	74	99	78	86	95	194	159	99	176	142

pH	8.1	8.1	8.1	8.1	8.1	8.1	8.0	8.3	8.1	8.2	8.3	8.2	8.2	8.4	8.2
Total Coliform	-	-	-	-	-	-	-	-	-	3000	6200	6500	5100	5300	2400
Turbidity	-	-	-	-	-	-	2.0	3.1	2.3	0.1	0.2	0.1	0.1	0.1	0.1

(ii)

Parameters	Water Quality Monitoring Stations														
(Year 2012)	Uttarkashi			Rishikesh			Kanpur			Allahabad			Varanasi		
	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov	May	Jul	Nov
BOD	1.1	1.2	1.0	1.0	1.2	1.2	7.0	10.0	4.0	2.9	3.2	2.4	3.0	3.9	2.9
DO%	73	64	73	81	75	77	86	75	90	85	108	98	101	98	98
F	0.45	0.26	0.44	0.09	0.19	0.06	0.70	0.80	0.51	0.51	0.67	0.56	0.57	0.54	0.52
Hardness $CaCO_3$	45	24	34	33	23	56	110	102	90	97	85	92	89	75	81
pH	7.8	7.7	7.6	7.8	8.0	7.8	8.7	8.4	8.1	8.2	8.5	8.2	8.7	8.4	8.7
Total Coliform	-	-	-	-	-	-	-	-	-	5200	5800	4600	5600	7300	4700
Turbidity	-	-	-	-	-	-	4.0	6.0	5.4	0.1	0.5	0.1	0.1	0.2	0.1

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Table 2. Classification scheme of water quality (Source: Sargoankar and Deshpande 2003)

Classification	Class	Class Index (Score)	Concentration Limit / Ranges of Water Quality Parameters						
			BOD (mg/L)	DO (%)	F (mg/L)	Hardness $CaCO_3$ (mg/L)	pH (pH unit)	Total Coliform (MPN/100 mL)	Turbidity (NTU)
Excellent	C_1	1	1.5	88-112	1.2	75	6.5-7.5	50	5
Acceptable	C_2	2	3	75-125	1.5	150	6.0-6.5 and 7.5-8.0	500	10
Slightly Polluted	C_3	4	6	50-150	2.5	300	5.0-6.0 and 8.0-9.0	5000	100
Polluted	C_4	8	12	20-200	6.0	500	4.5-5 and 9-9.5	10000	250
Heavily Polluted	C_5	16	24	<20 and >200	<6.0	>500	<4.5 and >9.5	15000	>250

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1 **Table 3.** Mathematical expression for value function curves (Source: Sargoankar and Deshpande
2 2003)

S. No.	Parameter	Concentration Range	Mathematical Expressions
1.	BOD	<2	$x=1$
		2-30	$x=y/1.5$
2.	DO%	≤50	$x=\exp(-(y-98.33)/36.067)$
		50-100	$x=(y-107.58)/14.667$
		≥100	$x=(y-79.543)/19.054$
3.	F	0-1.2	$x=1$
		1.2-10	$x=((y/1.2)-0.3819)/0.5083$
4.	Hardness $CaCO_3$	≤75	$x=1$
		75-500	$x=\exp(y+42.5)/205.58$
		>500	$x=(y+500)/125$
5.	pH	7	$x=1$
		>7	$x=\exp((y-7.0)/1.082)$
		<7	$x=\exp((7-y)/1.082)$
6.	Total Coliform	≤50	$x=1$
		50-5000	$x=(y/50)**0.3010$
		5000-15000	$x=((y/50)-50)/16.071$
		>15000	$x=(y/15000)+16$
7.	Turbidity	≤10	$x=1$
		10-500	$x=(y+43.9)/34.5$

3

4 **5. Results and discussion**

5 **5.1 Population dynamics in the Upper Ganga River basin**

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The first objective of the study was to understand how population has changed in the basin of Upper Ganga River basin. Time series population data of year 2001-2011 were analyzed for the basin. A total 77 districts of four different states, viz. Uttar Pradesh, Uttarakhand, Bihar and Himanchal Pradesh lie in Upper Ganga River basin boundary. Census data provided by Census of India, GoI, is available village wise for rural areas and ward/city wise for urban areas. It is used to estimate the urban and rural population of the study area to understand its demographic patterns. From the results it is observed that total population has increased tremendously over the past decades from 2001 to 2011 of UG basin. Total population of Upper Ganga River basin is 172,415,564 and 198,762,389 individuals in 2001 and 2011, respectively. Total rural population of basin is estimated to be 136,819,415 and 153,854,986 persons in 2001 and 2011, respectively whereas urban population varied from 35,596,149 persons in 2001 to 44,907,403 persons in 2011. Ganga River basin is the most sacred and populated river basins in India which is endowed with varying topography, climate and mineral rich alluvial soils in the Gangetic Plains area. Due to high soil fertility in the region, 60% of the population practise agricultural activities. This accounts for the high rural population in the region. Due to hilly terrain in the northern part of the basin, the population is less compared to the southern part of the basin. Due to its religious and economic significance a large number of densely populated cities and towns are located on the banks of the river mainly in the Gangetic Plain region, e.g. Kanpur, Agra, Meerut, Varanasi, Allahabad, etc. These cities have large growing populations and a rapidly expanding industrial sector (NRSC 2014). The percentage change from one period to another (population growth rate) is calculated for rural and urban population in the study area using Eq. 2 given below:

$$\mathrm{PGR} = \frac{(Ppresent - Ppast)}{Ppast} x100 \qquad (2)$$

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Where,

PGR - Population Growth Rate

P*present* - Present Population

P*past* - Past Population

Population growth rate of 15.28% is observed in the total population of complete river basin from 2001 to 2011. Fig. 3 illustrates the population growth rate in rural and urban population of Upper Ganga River basin between 2001-2011. It can be observed that the PGR of urban and rural population is 26.16% and 12.45% respectively. Hence, the PGR in urban areas is much higher than rural areas between 2001 to 2011. The high growth in the urban population is due to natural population growth in the various towns across the river basin and due to migration of the people not only just from villages but from different parts of the country especially to the cities of Kanpur, Varanasi and Allahabad. The total population of the districts consisting of the five monitoring stations, viz. Uttarkashi, Dehradun (Rishikesh), Kanpur, Allahabad and Varanasi was 295,013, 1,282,143, 5,731,335, 4,936,105, and 3,138,671 people in 2001 which increased to 330,086, 1,696,694, 6,377,452, 5,954,391 and 3,676,841 people in 2011, respectively. Population density of the Uttarkashi, Dehradun (Rishikesh), Kanpur, Allahabad and Varanasi districts are 41, 549, 1,024, 1,086 and 2,395 persons per square km respectively. It is be noticed that 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 the most populated districts in the country. All these districts are located on the banks of the Ganga River; therefore, a large amount of municipal sewage waste and toxic industrial effluents are introduced into the river water all along these districts. From various studies it has been already established that the water of Ganga River near Kanpur, Allahabad and

Varanasi cities is highly polluted (Gowd et al. 2010; Rai et al. 2010; Sharma et al. 2014). Therefore, it is important to understand the demography of these districts in addition to the population study of the complete river basin as they are directly affecting the water quality of the Ganga River.

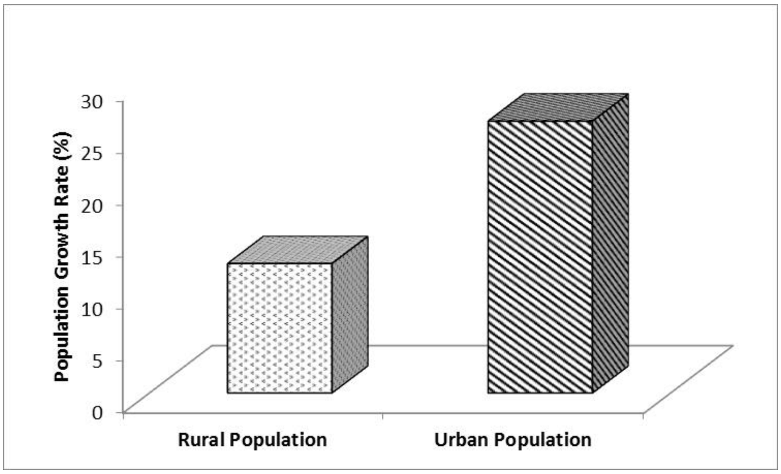

Figure 3: Population growth rate in rural and urban population of Upper Ganga River basin between 2001-2011

5.2 LULC changes in Upper Ganga River basin

The LULC maps of the UG basin for February/March 2001 and 2012 are shown in (Fig. 4a & 4b). The percentage area and changes in LULC are represented in (Fig. 5a & 5b). From the results it is observed that in the UG basin the agricultural lands, built-up lands, forest, and snow and glacier increased between the periods of 2001-2012 whereas the water bodies and wastelands decreased. The highest change is observed in built-up lands LULC class that has increased by about 43.4% (Table 4). In 2001, the wastelands were about 17.1% whereas in 2012 they decreased to about 11.4%. Therefore, the wastelands are the second most dynamic category with the significant decrease of about 33.6%. Agriculture land, forest and snow cover have also increased by about 2.9%, 14.5% and 1.1% respectively. Conversely, Water bodies decreased from 2.0% in 2001 to 1.8% in 2012 (Table 4). The wastelands and water bodies have mainly converted to agricultural lands and built-up lands. Therefore, significant increase in agricultural land class is observed in the river basin resulting in high water demand. In the UG basin, agricultural lands, forest and built-up lands increased on the expense of water bodies and wastelands. With the LULC classification the percentage change in the classes are computed and analyzed which is represented in the (Fig. 5a & 5b). The graph illustrates the significant increase in builtup area and forest on the cost of wastelands.

Table 4. Table showing LULC changes in the Upper Ganga River basin

LULC Class	Upper Ganga River basin		
	Area (%)		Changes (%)
	2001	2012	2001-2012
Agriculture Land	58.3	60.0	2.9
Builtup Area	5.3	7.5	43.4
Forest	13.3	15.2	14.5
Snow and Glacier	4.0	4.1	1.1
Wastelands	17.1	11.4	-33.6
Water Bodies	2.0	1.8	-10.6

5.3 Accuracy assessment

In thematic mapping from remotely sensed data, the term accuracy is used typically to express the degree of correctness of a classified map (Foody, 2002). The confusion matrix based accuracy assessment is a widely used approach that includes a simple cross-tabulation of the mapped class label against that observed on the ground (or reference data) for a sample of cases at specified locations. It is difficult to carry out accuracy assessment for all of the LULC maps

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due to a lack of ground truth data. The satellite sensors (Landsat ETM+) and spatial resolution (30 m) of both images is same. Therefore, the most recent Landsat ETM+ of 2012 used in the study would represent the overall accuracy of other classified map (Samal and Gedam 2015). Therefore, Landsat ETM+ data of 2012 was used for accuracy assessment. A large number of ground truth samples were available for the year 2012 and a confusion matrix was prepared using corresponding LULC map. A simple random sampling of 649 pixels belonging to corresponding image objects were selected and verified against reference data at an average of 108 points per each class of land use. As a rule of thumb, Congalton (1991) recommends a minimum of 50 sample points per category, which was reported by (Lillesand and Kiefer 2000) also. The results showed an overall accuracy of 90.14% and kappa index of agreement of 0.88 (Table 5).

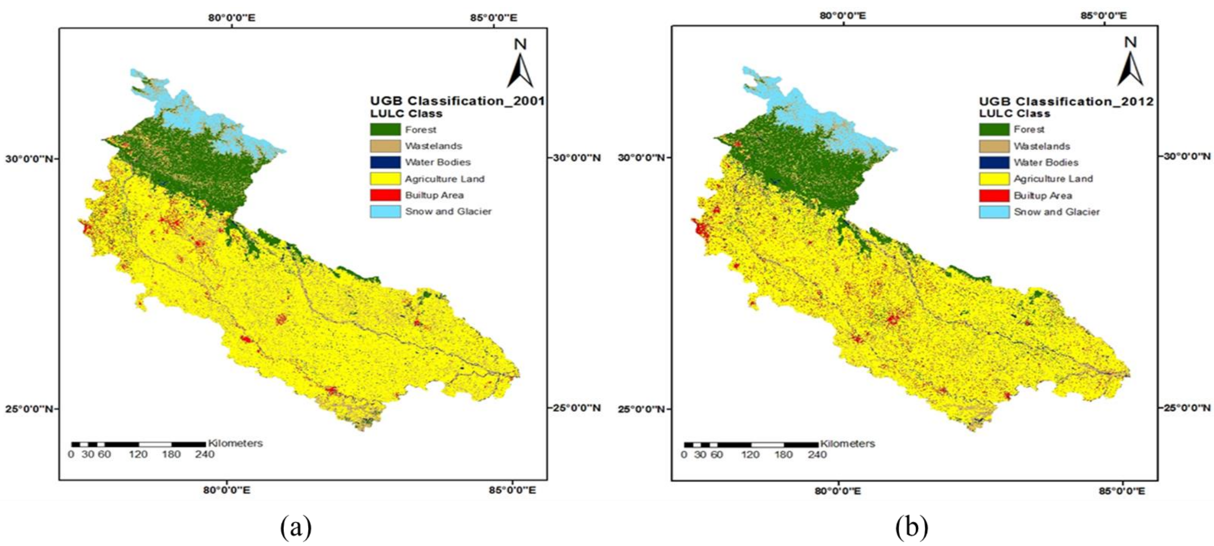
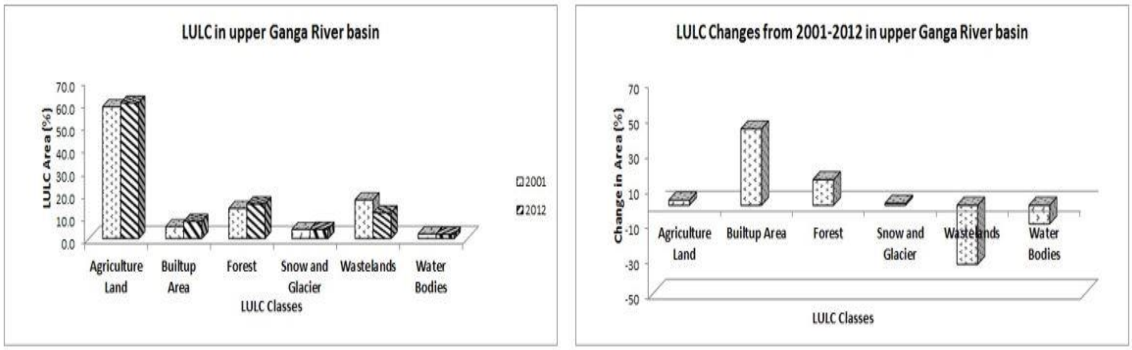


Figure 4. LULC maps of Upper Ganga River basin (a) LULC map of February/March 2001, and (b) LULC map of February/March 2012



(a) (b)

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

Table 5. 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 (%)	Kappa
	AG	BU	F	SG	WL	WB			
AG	128	0	6	0	3	0	137	93.43	
BU	2	96	2	5	1	0	106	90.57	
F	11	0	88	3	0	3	105	83.81	
SG	0	4	1	103	2	1	111	92.79	0.88
WL	1	2	0	7	82	2	94	87.23	
WB	0	0	1	1	6	88	96	91.67	
Column Total	142	102	98	119	94	94	649		

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Producer's Accuracy	90.14	94.12	89.80	86.55	87.23	93.62			

*AG: Agricultural land, BU: Builtup Area, F: Forest, SG: Snow and Glacier, WL: Wastelands, WB: Water Bodies, Overall accuracy =90.14%

In terms of producer's accuracy, all classes were over 90%, except for three classes i.e. forest, wastelands and snow/glacier, while in terms of user's accuracy, all the classes were very close to or more than 90%. Both producer's and user's accuracy are found to be consistent for all LULC classes. A similar kind of accuracy level can be expected from past LULC maps with a very little deviation. From the accuracy assessment, it is evident that the present classification approach has been effective in producing LULC maps with good accuracy and hence can be used to study effect of urbanization induced LULC changes on river basin.

5.4 Effects of LULC changes on water quality of Upper Ganga River basin

First statistical analysis is done on monthly water quality data of January to December of the years 2001-2012. Standard Deviation (SD) is estimated separately for each month and Mann-Kendall rank test is performed to study the existing trends (Table 6). Z values, a statistics parameter used in Mann-Kendal test (Mann 1945; Kendall 1975) are shown in Table 6.

5.4.1 Mann-Kendall test for water quality data

In this study, Mann-Kendall rank (Mann 1945; Kendall 1975) test is used to understand the trends in the water quality parameters (2001-2012). Mann-Kendall test is a rank-based non-parametric statistical test. Being non-parametric in nature, therefore; it does not require the data to be normally distributed. In this test, the null hypothesis H_o assumes that there is no trend (data is independent and randomly ordered) and it is tested against the alternative hypothesis H_1, which assumes that there is a trend. While computation Mann-Kendall test considers the time series of n data points and T_i and T_j as two subsets of data where i=1, 2, 3… n-1 and j=i+l. i+2,

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i+3… n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The Mann-Kendall S-Statistic is computed as follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \mathrm{sgn}(x_j - x_i) \quad (3)$$

Where, N is number of data points. Assuming (x_j-x_i) = θ, the value of sgn (θ) is computed as follows:

$$\mathrm{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 1 \\ 0 & if \quad \theta = 1 \\ -1 & if \quad \theta < 1 \end{cases} \quad (4)$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N>10), the test is conducted using a normal distribution (Helsel and Hirsch 1992) with the mean and the variance as follows:

$$E[S] = 0 \quad (5)$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \quad (6)$$

Where, n is the number of tied (zero difference between compared values) groups, and t_k is the number of data points in the *k*th tied group. The standard normal deviate (Z-statistics) is then computed as (Hirsch et al. 1982).

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$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S>0 \\ 0 & if \quad S=0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S<0 \end{cases} \qquad (7)$$

The positive value of Z test shows a rising trend and a negative value of it indicates a falling trend in the series. In this study, the significance of Z test is observed on confidence level 90%, 95% and 99%. In case value of computed Z lies within the limits ±1.96, the null hypothesis of no trend in the series cannot be rejected at 95% level of confidence. Z is the Mann-Kendall test statistics that follows standard normal distribution with mean of zero and variance of one. Thus, in a two sided test for trend, the null hypothesis H_0 is accepted if $-Z_{1-\alpha/2} \leq Z_{mk} \leq Z_{1-\alpha/2}$ where α is the significance level that indicates the trend strength. Therefore, it is noted that a positive value of Z indicates an increasing trend whereas a negative value shows a decreasing trend. In this study, it is observed that the trend in each water quality parameter varies with time and location. It is a very site-specific phenomenon and therefore, no regular trends are observed. There are different point and non-point sources of pollution in the river water. Other than urbanization and industrialization, water quality parameters are highly affected by rainfall. Discharge of excess runoff water and pollutants into the rivers during rainfall events and changes in the flow patterns affect the physico-chemistry of the waterbodies. There are three significant seasons identified in the study area, viz. pre-monsoon (May), monsoon (July) and post-monsoon (November). Table 6 shows that water quality change is occurring in all the months over a given space and time. But the significant changes and comparatively high SD are observed in monsoon (July month) followed by pre-monsoon and post-monsoon months, respectively. As water quality varies with seasons, it is crucial to understand the effect of urbanization on water quality of different seasons. Therefore, taking into account the types of trends and SD in monthly water quality parameters over time and space; and effect of different seasons on water quality from a number of reported studies (Islam et al. 2017; Sharma and Kansal 2011; Singh and Chandna 2011), the water quality data is organized into three groups: pre-monsoon season (February-May), monsoon season (June-September) and post-monsoon season (October-January).

Then from each group one representative month is chosen which represented the best scenario of that particular season. For e.g. SD in BOD of Kanpur station in May, July and November months are 2.01, 2.67 and 1.04 respectively. In other months, SD value of the BOD is close to the SD value of the representative months considered in that particular season. Also, from Table 6 it is evident that trends for BOD and Turbidity in July month are significant in almost all the stations against other water quality parameters. They are increasing over the years from 2001-2012. Therefore, in this study, May month for pre-monsoon season, July month for monsoon season and November month for post-monsoon season are used. It reduced the redundancy of the dataset and avoided the confusion to be created due to large insignificant dataset of varying trends that makes no sense. Significant inter seasonal changes can be observed between May, July and November months. Pre-monsoon (May) data helped to understand effect of mainly point sources of pollution from various sewage drains and industrial effluents on the water quality of rivers. In addition to point sources of pollution, monsoon (July) data took into account effect of non-point source of pollution, e.g. discharge of surface runoff from urban areas into the nearby streams during rainfall on water quality of rivers. Post-monsoon (November) data helped to understand the water quality condition of the rivers after the rainfall is over. Therefore, in this study water quality data is analyzed mainly for three months, viz. May (pre-monsoon), July (monsoon) and (post-monsoon).

5.4.2 Spatio-temporal variations in water quality of the Upper Ganga River basin

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LULC and pollution indices are often used as important indicators to understand the effects of anthropogenic activities on water quality. LULC changes significantly affect the water quality of a region. Therefore, understanding of spatio-temporal relationship between LULC changes and water quality is crucial for better planning and management of river basins. From the results, it is observed that uncontrolled population increase in UG basin has resulted in the colossal changes in LULC of the river basin. The changes are observed in all the six LULC classes. Built-up lands, agricultural lands, snow cover and forest have increased in the river basin over the period from 2001 to 2012 (Table 4). Conversely, wastelands and water bodies have diminished. OIP is computed by considering the average of IPIs for all the seven parameters. The estimated numerical value of the OIPs (index score) corresponded to following meaning: OIP value of 0-1 belongs to class C1 which denotes excellent water quality, 1-2 belongs to class C2 which denotes acceptable water quality, 2-4 belongs to class C3 which denotes slightly polluted water quality, 4-8 belongs to class C4 which denotes polluted water quality, and 8-16 belongs to class C5 which denotes heavily polluted water quality. It was found that index score of IPIs increased as the parameter value increased for BOD, total coliform, F, Turbidity, and Hardness $CaCO_3$.

Table 6. Trends in monthly water quality parameters from 2001 to 2012 across Upper Ganga River basin (Z value, a Mann-Kendal statistics parameter is shown. (*), (**), (***) and +ve suffix indicate different significance levels)

Station	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Uttarkashi	BOD	-2.4 (*)	1.3	-2.2 (*)	0.0	1.2	-0.4 (**)	2.8	-1.9 (+)	-2.2 (*)	0.0	1.9 (+)	1.3
	DO%	1.2	-1.5	0.5	0.0	-3.3 (**)	-2.8 (**)	-2.2 (*)	-3.3 (**)	1.4	0.0	-2.6 (**)	-1.5

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	F	-1.9 (+)	2.0 (*)	-3.2 (**)	1.1	-3.0 (**)	0.8	2.0 (*)	2.0 (*)	1.1	1.9 (+)	1.1	-3.0 (**)
	Hardness	1.3	-2.5 (*)	1.8 (+)	-1.1	-1.9 (+)	-2.1 (*)	-2.5 (*)	-1.9 (+)	1.2	1.8 (+)	-1.1	-2.5 (*)
	pH	2.7 (**)	-1.3	1.2	-0.1	-0.2	0.0	-1.5	-1.1	-0.2	-1.3	-1.3	-1.1
	TC	-	-	-	-	-	-	-	-	-	-	-	-
	Turbidity	-	-	-	-	-	-	-	-	-	-	-	-
Rishikesh	BOD	-0.1	0.0	0.6	1.9 (+)	0.4	-2.5 (*)	2.4 (*)	2.0 (*)	2.6 (*)	-1.3	1.3	-0.5
	DO%	-1.3	1.5	2.3 (*)	-2.3 (*)	3.0 (**)	-2.3 (*)	2.9 (**)	0.6	0.5	3.4 (***)	3.2 (**)	-3.6 (***)
	F	-1.0	-0.5	2.2 (*)	-1.2	1.2	-1.7 (+)	1.7 (+)	2.7 (**)	-0.8	-0.6	0.0	2.5 (*)
	Hardness	1.4	-1.6	0.6	2.7 (**)	-2.3 (*)	0.6	-2.4 (*)	1.3	0.0	3.2 (**)	-1.6	-2.7 (**)
	pH	-1.6	0.0	0.0	-0.7	-0.9	0.2	-0.2	1.1	1.9 (+)	1.6	-0.8	0.3
	TC	-	-	-	-	-	-	-	-	-	-	-	-
	Turbidity	-	-	-	-	-	-	-	-	-	-	-	-
Kanpur	BOD	2.0 (*)	2.7 (**)	2.6 (**)	2.3 (*)	3.0 (**)	3.4 (***)	3.4 (***)	2.7 (**)	1.7 (+)	0.6	1.6	2.2 (*)
	DO%	-2.7 (**)	-2.0 (*)	-0.3	-1.1	-0.5	-0.3	-2.1 (*)	-0.5	-0.1	-0.8	-1.0	-1.8 (+)
	F	1.5	2.0 (*)	1.7 (+)	1.6	1.2	2.1 (*)	2.4 (*)	2.2 (*)	2.6 (**)	2.4 (*)	1.7 (+)	2.0 (*)
	Hardness	0.4	0.2	0.1	0.1	0.0	1.2	1.7 (+)	0.0	0.0	-0.2	-1.0	-1.0

	pH	0.3	-0.2	0.7	1.9 (+)	1.7 (+)	0.2	1.2	-0.9	-0.3	-1.0	-0.4	-1.2
	TC	-	-	-	-	-	-	-	-	-	-	-	-
	Turbidity	3.5 (***)	1.7 (+)	1.7 (+)	-0.4	-0.2	0.8	0.8	1.7 (+)	-1.6	0.0	1.9 (+)	0.3
Allahabad	BOD	0.8	0.2	-1.3	0.3	-0.1	0.2	-1.0	-0.1	-0.5	-0.1	-0.4	0.0
	DO%	0.6	-0.5	0.6	0.0	-0.2	0.4	1.0	1.7 (+)	0.7	1.0	-0.3	-0.2
	F	1.6	1.2	2.0 (*)	2.6 (**)	1.6	1.4	2.2 (*)	2.2 (*)	2.7 (*)	1.7 (+)	1.6	1.0
	Hardness	-0.8	0.0	-1.3	-0.3	0.2	0.1	-0.1	0.3	-0.1	0.4	0.5	1.5
	pH	-1.0	-1.3	0.1	-0.3	0.2	0.1	1.0	0.1	-1.1	-0.4	0.4	0.0
	TC	-1.1	-1.0	-1.4	-1.0	-1.1	0.6	-0.5	-2.0 (*)	-1.7 (+)	-1.4	-1.1	-0.3
	Turbidity	-0.9	0.2	-0.6	-0.2	-1.4	0.9	0.4	0.6	0.4	-0.3	0.0	-1.4
Varanasi	BOD	2.4 (*)	1.5	1.1	1.4	2.2 (*)	2.8 (**)	2.7 (**)	1.9 (+)	2.4 (*)	2.9 (**)	2.6 (**)	3.0 (**)
	DO%	1.2	1.4	2.2 (*)	2.3 (*)	1.7 (+)	0.8	1.5	2.5 (*)	3.2 (**)	3.3 (***)	2.5 (*)	2.5 (*)
	F	2.5 (*)	2.1 (*)	2.4 (*)	2.4 (*)	1.6	1.8 (+)	2.1 (*)	2.1 (*)	3.0 (**)	2.2 (*)	1.2	2.2 (*)
	Hardness	-0.3	-0.3	0.0	0.1	-0.5	-0.7	-0.5	0.1	0.3	0.8	0.3	1.9 (+)
	pH	0.0	0.0	1.9 (+)	1.5	0.4	0.2	0.4	0.2	1.8 (+)	0.4	0.6	0.2
	TC	0.8	0.6	0.8	0.6	0.3	-0.1	0.5	0.9	1.0	1.4	1.4	1.4
	Turbidity	-0.5	0.0	0.0	-0.2	-0.6	-1.8 (+)	-0.9	0.9	0.0	-1.4	0.2	-0.2

*** trend at α = 0.001 level of significance; ** trend at α = 0.01 level of significance; * trend at α = 0.05 level of significance; + trend at α = 0.1 level of significance; If there is no sign after values in the table then, the significance level is greater than 0.1 (Amnell et al. 2002).

Increase in these parameters indicates increasing water pollution. But high DO% indicates good water health because more oxygen is available for water organisms. Hence, the index score of IPIs increased with decreasing DO%. The pH depicts the acidity or alkalinity of water. 7.0 is considered the neutral pH of a water. Acidity of water increases if pH decreases below 7.0 and alkalinity increases if it rises above 7.0. Hence, in case of pH, index score of IPIs increased if the pH increased above 8.0 or decreased below 6.0.

Spatio-temporal variations in the water quality of the UG basin are studied using OIPs. Water quality data of three different seasons viz. pre-monsoon (May), monsoon (July) and post-monsoon period (November) months from the year 2001-2012 are used in this study (Fig. 6 (a), (b) & (c)). Rainfall is an important driver affecting surface water quality parameters of a particular place or region. During rainfall different water quality parameters behave in different way. This phenomenon is very site specific. The post-monsoon variation of water quality at a station is highly dependent on rainfall amount, duration and intensity of a particular region. Other factors such as type of LULC, type of soils, amount and type of waste generation, treatment facilities, etc. also affect the water quality. Therefore, different trends of water quality are observed at different stations. It was observed that the water quality of the UG basin has degraded in monsoon and post-monsoon season (Fig. 6b & 6c)). Water quality parameters viz. Hardness $CaCO_3$, F, pH and Turbidity generally increase during post-monsoon season due to addition of various pollutants and sediments in the river water. Increase in these parameters causes water pollution. Overall quality of river water is a result of cumulative effect of changes in all water quality parameters during a period. Therefore, at some places water quality may seem to improve but at other places it may seems to degrade (Fig. 7 (a), (b) & (c)). Therefore, in post-monsoon season, a regular pattern of changes in OIPs is not observed between different stations. These variations can be attributed to variations in the rainfall at different space and time. Hence, OIPs can be used as an indicator of effects of urbanization on water quality of urban area.

The values of 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 are given in Table 7. Water quality monitoring stations of Uttarkashi and Rishikesh are located in the hilly upper reaches of the Ganga River with relatively less population and small towns. These stations are least influenced by human intervention. Therefore, all the water quality parameters at these stations are in acceptable range with no significant variations in the IPI values of the parameters over time. For example, IPI for pH in 2001 remained 2.76 in both the stations. In 2012 the pH ranged between 1.74 (post-monsoon season) to 2.09 (pre-monsoon season) at Uttarkashi station. At Rishikesh station it ranged between 2.09 (pre and post-monsoon season) to 2.52 (monsoon season) which is slightly better than the IPI values in 2001. Hence, OIP values indicate that the overall water quality of Uttarkashi and Rishikesh remain in acceptable class (C2) for all the three seasons. Therefore, in the upper reach segment of the river basin, change in the water quality of Uttarkashi and Rishikesh stations are mainly influenced from the generation of silts and climatic factor such as rainfall.

As the Ganga River descends down to Gangetic Plains a large number of tributaries e.g. river Yamuna that passes from metropolitan city of New Delhi and other cities joins river Ganga at

Allahabad. It carries a large amount of pollutant load from both municipal and industrial areas of New Delhi and other cities on its way and adds to the river Ganga. Also, a large domestic and industrial waste is discharged into the river which further escalates the pollution problem. Also, many Class I cities (population>100000) are located all across the river basin. During rainfall, toxic urban runoff is discharged to the river directly or through storm water drains. Water pollution at Kanpur is caused by urban domestic wastes and industries mainly tanneries. At Varanasi river water is again affected due to municipal and industrial discharges into the river.

Therefore, a significant degradation in the water quality of the stations located in the lower reaches of the river basin is observed from the year 2001-2012. From the temporal study of OIP across these stations, it is noticed that the water quality has deteriorated at all three stations from 2001 to 2012 (Fig. 7 (a), (b) & (c)). This sharp decline in the quality of the Ganga River water is attributed to the increasing pollution from urban and industrial areas. Daily a huge amount of untreated urban wastes and industrial effluents are discharged into the river. In 2001, Allahabad is the most polluted station followed by Varanasi and Kanpur. However, in 2012, Kanpur is the most polluted station followed by Varanasi and Allahabad due to changes of LULC and population growth (Fig. 7 (a), (b) & (c)). The reason is OIP values are much higher at Kanpur, Varanasi and Allahabad than Uttarkashi and Rishikesh. Other than this most of the time the water quality at all the three stations at lower reaches remained in the acceptable to slightly polluted range.

Table 7. 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

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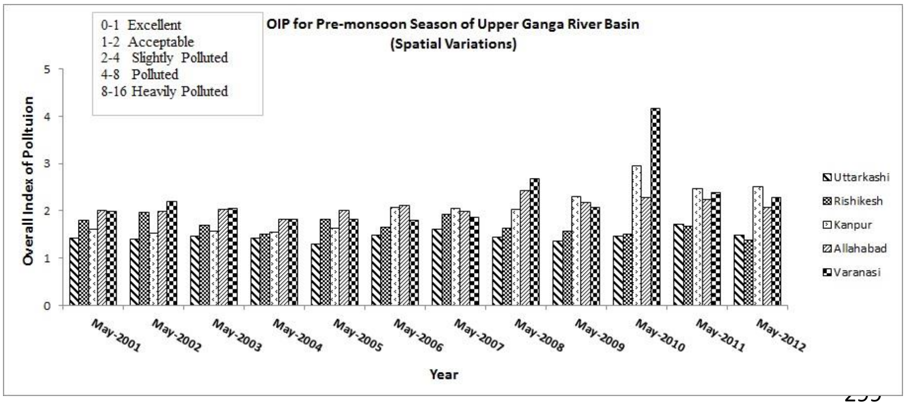
(i)

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	1.87	1.00	1.60	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**	**1.61**	**1.49**	**1.54**	**2.02**	**2.50**	**2.29**	**1.99**	**2.08**	**1.92**

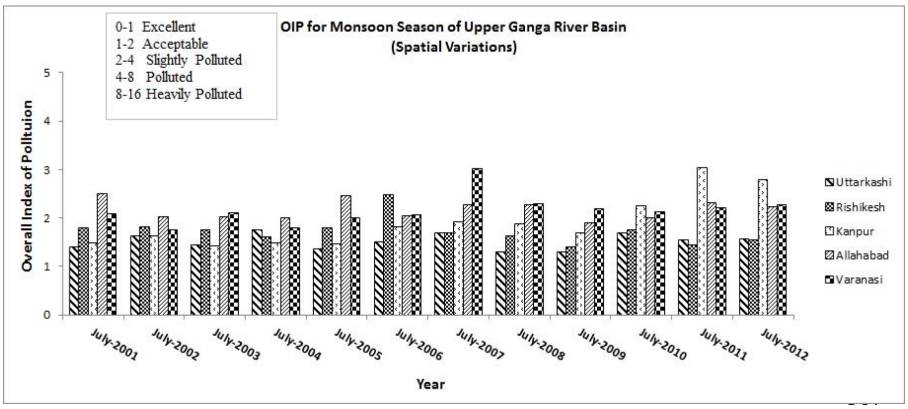
(ii)

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	1.91	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**	**1.77**	**2.07**	**2.23**	**1.87**	**2.28**	**2.27**	**2.16**

(a)


0-1 Excellent
1-2 Acceptable
2-4 Slightly Polluted
4-8 Polluted
8-16 Heavily Polluted
OIP for Pre-monsoon Season of Upper Ganga River Basin
(Spatial Variations)
Overall Index of Poltuion
Year
May-2001
May-2002
May-2003
May-2004
May-2005
May-2006
May-2007
May-2008
May-2009
May-2010
May-2011
May-2012
Uttarkashi
Rishikesh
Kanpur
Allahabad
Varanasi

(b)


0-1 Excellent
1-2 Acceptable
2-4 Slightly Polluted
4-8 Polluted
8-16 Heavily Polluted
OIP for Monsoon Season of Upper Ganga River Basin
(Spatial Variations)
Overall Index of Poltuion
Year
July-2001
July-2002
July-2003
July-2004
July-2005
July-2006
July-2007
July-2008
July-2009
July-2010
July-2011
July-2012
Uttarkashi
Rishikesh
Kanpur
Allahabad
Varanasi

(c)

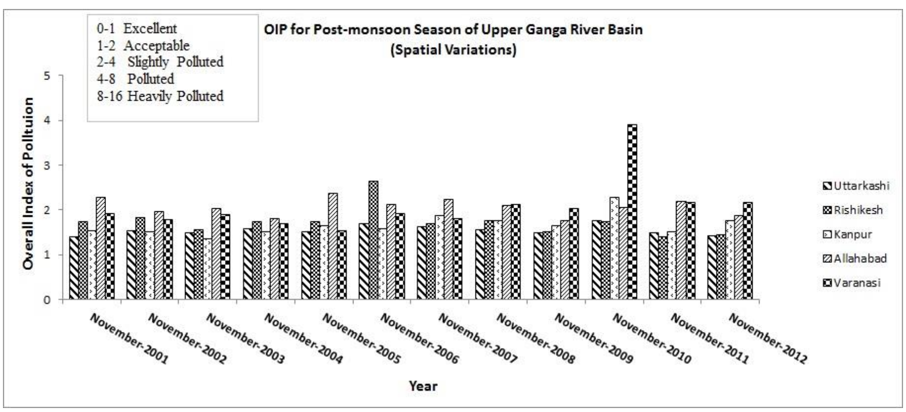

0-1 Excellent
1-2 Acceptable
2-4 Slightly Polluted
4-8 Polluted
8-16 Heavily Polluted
OIP for Post-monsoon Season of Upper Ganga River Basin
(Spatial Variations)
Overall Index of Poltuion
Year
November-2001
November-2002
November-2003
November-2004
November-2005
November-2006
November-2007
November-2008
November-2009
November-2010
November-2011
November-2012
Uttarkashi
Rishikesh
Kanpur
Allahabad
Varanasi

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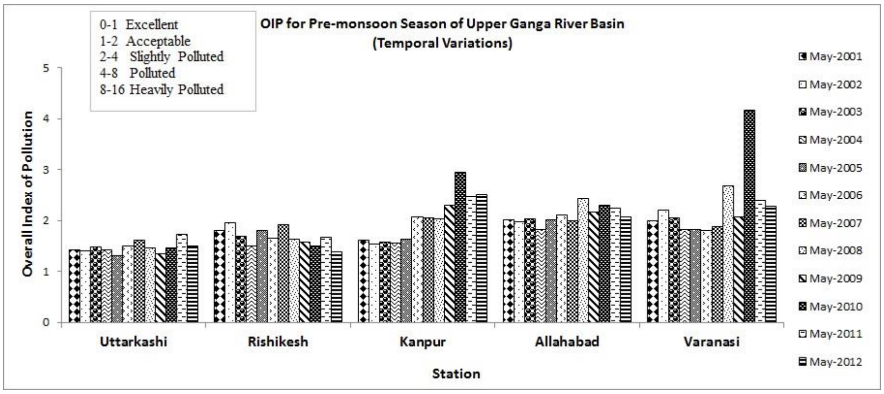
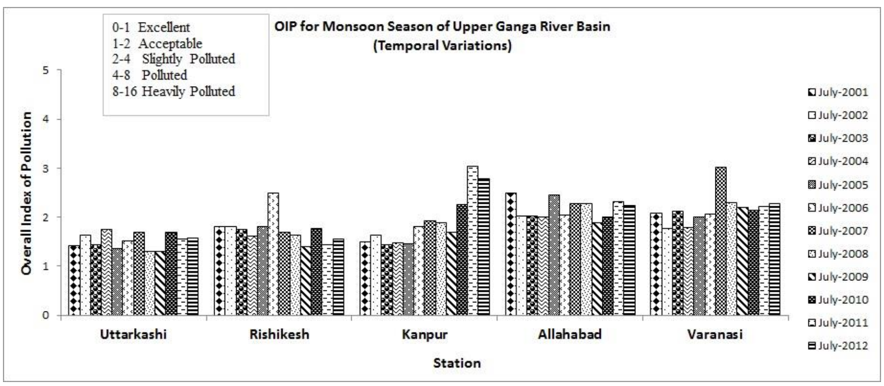
Figure 6. Spatial variations in the overall indices of pollution of upper Ganga River basin for (a) Pre-monsoon period (b) Monsoon period, (c) Post-monsoon period

(a)



(b)



(c)

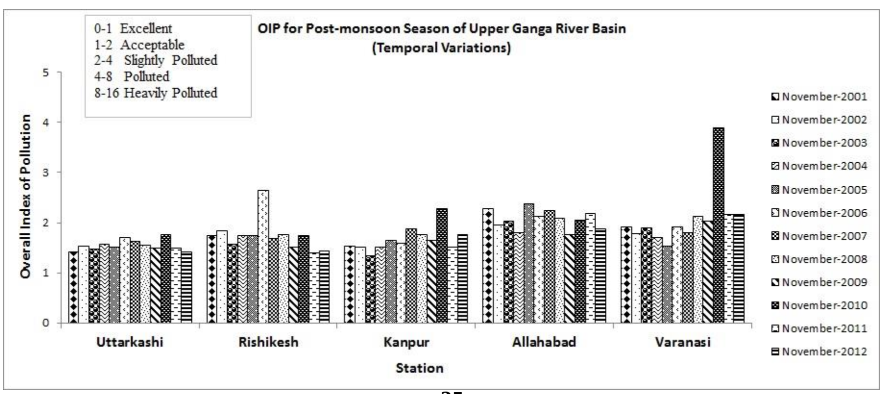


Figure 7. Temporal variations in the overall indices of pollution of upper Ganga River basin for (a) Pre-monsoon period (b) Monsoon period, (c) Post-monsoon period

From Table 7 it is observed that the OIP of Kanpur station changed from 1.61 to 2.51, 1.49 to 1.54 and 2.79 to 1.77 in pre-monsoon, monsoon and post-monsoon seasons respectively. It is the most polluted station with most inferior water quality with maximum OIP of 2.79 (Table 7 (ii)). Similarly, OIP for Allahabad station changed from 2.02 to 2.07, 2.50 to 2.23 and 2.29 to 1.87 in three consecutive seasons whereas OIP for Varanasi changed from 1.99 to 2.28, 2.08 to 2.27 and 1.92 to 2.16. Total population of all the three cities is very high and Kanpur has the highest population (6,377,452) amongst them. Varanasi has the highest population density in the region. These cities are the biggest centres of commercial activities in the river basin. All these cities are rapidly urbanizing with a number of industries mainly located near Ganga River bank. The main types of industries in Allahabad are glass, wire products, battery, etc. whereas the Varanasi consists of textile, printing, electrical machinery related industries. In the lower reaches of the Ganga River, major industrialization has occurred in and around Kanpur. Tanneries are the major types of industries in Kanpur, majority of them are located in the Jajmau area close to Ganga River. Other than tanneries, agro-based, textile, paper, mineral, metal and furniture based industries are also present. Unnao is other industrial town located close to Kanpur. Rapid urbanization and industrialization has highly affected the Ganga River water quality in this region. Large amount of municipal sewage generated in the urban areas and industrial effluents are discharged into the water. In total, 6087 MLD of wastewater is discharged into Ganga River. Out of complete river basin, six sub region namely Kanpur, Unnao, Rai-Bareeilly, Allahabad, Mirazapur and Varanasi alone discharge 3019 MLD of wastewater directly/indirectly into the river. Cities of Kanpur, Allahabad and Varanasi contribute about 598.19 MLD, 293.5 MLD and 410.79 MLD of wastewater into the river respectively (CPCB 2013; NRSC 2014).

Municipal sewage water is characterized by high BOD and Total Coliform bacteria count. Table 7 illustrates that a very high IPI is observed in the BOD of Kanpur (6.67), Allahabad (2.13) and Varanasi (2.60) for the year 2012. It has increased from 2001 to 2012. Similarly, in the year 2012 IPI of Total Coliform bacteria count is found in the range of minimum 3.90 (Allahabad) to 5.97 (Varanasi). It falls in the class of slightly polluted to polluted. DO% is a parameter which is dependent on various factors viz. elevation, temperature, atmospheric pressure, streamflow, rainfall, etc. DO% IPI is within acceptable to slightly polluted range in all the stations in 2012. Flouride (F) occurs in the nature but sometimes it is introduced to the river from industries. Turbidity has changed over the years but remains mainly in the acceptable class range. In this study region, F is not changing much and is mainly within excellent class range of IPI, i.e. 1.0. Industrial effluents from various industries and tanneries affect the water quality parameters, viz. BOD, Hardness $CaCO_3$, pH and Turbidity. The wastewater generated from various tanning operations, viz. soaking, liming, deliming and tanning, etc. result in increased levels of organic loading, salinity and specific pollutants such as sulfide and chromium. These are very toxic for pollutants (Rajeswari 2015). Hence, due to wastewater from tanneries and municipal discharges high IPI values of Hardness $CaCO_3$ (2.10) and pH (4.81) are observed for Kanpur station in 2012. Hardness $CaCO_3$ (1.90) and pH (4.81) IPI of Varanasi is just lower to Kanpur followed by Allahabad which showed a close IPI value of 1.97 and 4.00, respectively. These cities do not have tanneries but their urban sewage and industrial effluents affect water quality of the river.

Between seasons, comparatively high IPI and OIP values are observed in monsoon season followed by pre-monsoon and post-monsoon season for all three stations viz. Kanpur, Varanasi and Allahabad as per Table 7 (i-ii). It is due to the likely discharge of toxic urban runoff during heavy storm events. River water quality is affected due to rainfall and increased stream flow during monsoon and post-monsoon season. During rainfall, different water quality parameters behave differently. This phenomenon is very site specific. Runoff generated from the rainfall discharges pollutants from the land surface to the nearby stream, but it also improves the river water quality by dissolving and transporting some pollutants to other places through various natural processes. Hence, water quality of the stations at lower reaches of Ganga River are slightly polluted due to urbanization effects. Water quality is fairly good at stations located in the upper reaches due to less urbanization effect in these zones. Geospatial technologies along with OIP are advantageous in studying LULU changes across a large river basin. Therefore, water quality assessment using OIP could help to manage the available water resources sustainably. The future scope of this study comprises the understanding of hydrologic and ecological response of the water quality changes across the river basin.

6. Conclusions

A comprehensive study is done to understand the effects of demographic changes and land transformations on seasonal surface water quality of the Upper Ganga River basin. Total population near to monitoring stations has been increased in the basin from 2001 to 2011. From the results, it is evident that total population has increased in the UG basin. In the urban areas PGR is about 26.16% which is higher than PGR of rural areas which is 12.45%. Population of the cities located along the river Ganga i.e. Kanpur, Varanasi and Allahabad also increased. This basin has experienced rapid urbanization and industrialization in the past few decades. Due to population changes, characteristic LULC changes are observed in the UG basin. Between the years, 2001-2012, in the UG basin highest increase of about 2.9% was observed in LULC class

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of agricultural lands. Built-up lands, snow cover and forest were increased by 43.4%, 1.1% and 14.5% respectively. Conversely, decrease of 33.6% and 10.6% were observed in wastelands and water bodies classes respectively. Due to increase in food demands of growing population, agricultural lands also increased in the river basin. New waterbodies were constructed to fulfill mainly the irrigation requirements of the basin. Builtup-lands also increased all over the river basin due to increase in urban population in urban cities/towns and in industrial areas. Agricultural lands, and built-up lands increased on the expense of wastelands. New waterbodies were constructed in this basin to mainly fulfill the domestic and industrial water demands of the growing urban population. Water quality degradation has occurred in the basin consequently affecting the health status of the river. From Table 6, it can be inferred that BOD and turbidity show consistently an increasing trend for most of the months of a year and this certainly indicates the severity of pollution in the industry dominated urban city of Kanpur.

OIP estimates across the river basin demonstrate that the water quality of Uttarkashi and Rishikesh remained in acceptable class for all the three seasons. These observation stations are surrounded by hills and due to less population, they are not much influenced by human intervention. Therefore, in the upper reach segment of the river basin, change in the water quality of Uttarkashi and Rishikesh stations is mainly influenced from the generation of silts and climatic factor such as rainfall. A significant degradation in the water quality of the stations located in the lower reaches of the river basin is observed from the year 2001-2012. This sharp decline in the quality of the Ganga river water is attributed to the increasing total population and LULC changes. In 2001, Allahabad is the most polluted station followed by Varanasi and Kanpur. However, in 2012, Kanpur is the most polluted station followed by Varanasi and Allahabad due to changes of LULC and population growth. Other than this most of the time, the water quality at all the three stations remained in the slightly polluted range. From the spatial and temporal study of OIP across these stations, it is noticed that the water quality has deteriorated at all three stations from 2001 to 2012.

OIP is a promising tool to study the effect of demographic changes and LULU transformations on the spatio-temporal variations in the water quality across a river basin. Geospatial technologies are advantageous in studying LULU changes over a large river basin. Therefore, water quality assessment using OIP tool could help to assess and solve local and regional water quality related problems over a river basin. This could help the policy makers and planners to understand the status of water pollution so that suitable strategies could be made for sustainable development in a river basin.

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