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Impacts of Land Use Change on Water Quality Index in the Upper Ganges River near Haridwar, Uttarakhand: A GIS-Based Analysis

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Abstract: The water quality of rivers is deteriorating due to human interference. It is essential to understand the relationship between human activities and land use types to assess the water quality of a region. GIS is the latest tool for analyzing this spatial correlation. Land use land cover, and change detection are the best illustration for showing the human interactions with land features. This study assessed water quality index of the upper Ganges River near Haridwar, Uttarakhand, and spatially correlated it with changing land use to reach a logical conclusion. In the upper course of Ganges, along a 78-km stretch from Kaudiyala to Bhogpur, water samples were collected from five stations. For water quality index, physicochemical parameters like pH, EC, DO, TDS, $CaCO_3^-$, $CaCO_3$, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, F^-, Fe^{2+} were considered. The results of the spatial analysis were evaluated through error estimation and spatial correlation. The root mean square error between spatial land use and water quality index at the selected sampling sites was estimated to be 0.1443. The spatial correlation between land use change and site-wise differences in water quality index also showed a high positive correlation, with R^2 = 0.8455. The degree of positive correlation and root mean square error strongly indicated that the water quality of the river in the upper course of the Ganges is highly impacted by human activities.

Keywords: physico-chemical parameters; water quality index; land use land cover; GIS integration; special correlation

1. Introduction

Rivers are a natural gift that is highly vulnerable to land use change and anthropogenic activities. Due to undesirable human activities, the pollution of river water has become a major environmental concern [1,2]. Human interventions are directly or indirectly reflected in land use characteristics. The understanding of land use change and water quality management is very important for the management of water quality, land degradation and soil quality with respect to human interference [3,4]. The Ganges is the holiest and most important river system in India. Since ancient times, the Ganges has been directly or indirectly affected by human intervention [5]. Initially, civilization and economic activities evolved around the Ganges, and with the recent growth of industrialization, the whole river system has been impacted by various human activities like bathing, washing clothes, the bathing of animals, transmission of agricultural sewage, and dumping of various harmful wastes [6–11]. This situation was limited to the middle and lower course of the Ganges, but recently, many live stations in the upper course have also been declared as unfit for drinking or other human uses. Different types of tourism activities, agricultural development, deforestation, and construction activities are highly dependent on river water exploitation [12–14]. Hence, long-term land use changes and human intervention are significant factors in the deterioration of the quality of water [15]. The deterioration of river water quality due to careless human intervention has now become a key environmental concern [2]. Human activities are best depicted through the land use characteristics and their change [4]. It is important to correlate land use characteristics and water quality to better understand the relationship between them in order to develop better management strategies for minimizing the pollution rate [16]. With the passage of time, the developmental activities of communities, and the careless usage of water resources creates a threat to water monitoring [17]. In addition, unwanted and waste materials from different sources can cause both surface water and groundwater pollution [18].

The Ganges is the major river of India. It originates from the Gaumukh ice cave of the Gangotri Glacier and after covering a drainage basin area of 861,404 km^2, falls into the Bay of Bengal after crossing a length of more than 2525 km over the states of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal [8]. For religious reasons, the Ganges is pressured by billions of people every year for the purification of the soul, and for antimicrobial and medicinal relief [19,20]. Various famous cities like Haridwar, Kanpur, Allahabad, Varanasi, Patna, and Kolkata are situated on the bank of the river Ganges; from Gaumukh to Rishikesh, it flows through the hills of Himalayas, and afterward, it passes through the Gangetic plains and then enters into the Bay of Bengal. On this basis, the whole flowing course of the Ganges can be divided into three parts, i.e., the upper, middle and lower courses [21]. The Ganges in the middle and lower courses is heavily polluted due to industrialization, and the rapid urbanization and increasing population along the river have put tremendous pressure on water resources and their quality [22–25]. The river also passes 29 class-I cities (cities with population of more than 100,000), 23 class-II cities (cities with population of 50,000 to 99,999) and approximately 50 towns, because of which different types of waste such as industrial, sewage, etc., are released into it, potentially destroying the river eco-system and its natural quality [26–28]. It is a known fact that the Ganges near major towns like Varanasi, Allahabad, and Kolkata is highly polluted, and the water is strictly prohibited for drinking purposes even after purification [29]. However, the water in the upper Himalayan course is fresh, and within the acceptable limits for drinking and other uses. Recently, human intervention in the Himalayan ecosystem, including deforestation, agricultural activities, tourism and urbanization, have generally altered the natural balance, impacting land surface characteristics, water surface temperature, and changes in physico-chemical parameters of water [30–35].

Water quality monitoring is one of the highest priorities in environmental protection policy [36]. Many researchers have already focused on the current status of the physico-chemical characteristics of water for monitoring and assessment [37–39]. The government of India has also initiated many programs and action plans to reduce the level of pollution of the Ganges, and has spent millions of rupees on various stages of implementation. However, no positive results have been obtained [40]. For example, the Ganges Action Plan, or GAP, was a program launched by Rajiv Gandhi in 1986, with the main aim of reducing the pollution level, and INR 9017.1 million was spent. However, it was considered a failure, and withdrawn in 2000. The National Ganges River Basin Authority (NGRBA) was established in 2009 for cleaning and conservation, but 10 years after the establishment of the NGRBA, the quality of the river Ganges had not improved to desire level [41]. The National Democratic Alliance government launched Namami Gange in mid-May 2015, another plan with new hope to conserve the holy water of the Ganges, with a deadline of 2019 for great improvement. However, even after four years and an allotment of INR 22,000 million, the program was far from being a success [42]. Therefore, there is an urgent need to conduct more case studies for micro-level analysis to detect local factors affecting water quality.

In this study, an effort was made to detect local land use changes and their spatial correlation with surface water quality. Anthropogenic activities are the chief factor in land use change, and are also responsible for breaking down local biological systems, thereby affecting local environmental components like soil, air, and water. When we talk about water pollution and the deterioration of its quality, it is a linear process. The pollutants or unwanted materials first affect its chemical quality, and then systematically destroy the community, disrupting the delicate food web. In India, it is reported that about 70% of the available water is polluted. Therefore, looking toward such problems, the present study was aimed at finding a linear relationship between land use and water quality in the upper course of the river Ganges.

2. Materials and Methods

2.1. Study Area

The present study covers the upper Ganges River from Kaudiyala to Bhogpur village. Shivpuri, Rishikesh, and Haridwar are important tourist spots in Uttarakhand, which is situated on the right bank of Ganges and in the foothills of the Shivalik ranges. It is one of the most ancient towns in India, and is a very important pilgrim center, where people from all over the country come throughout the year to have a dip in the river Ganges. On average, around 200,000, people visit Haridwar and Rishikesh city daily. It is closely interwoven with aesthetic culture and tradition and health, and for years, the river has been indiscriminately polluted.

Kaudiyala is a village located 40 km east of Rishikesh, and is famous for river rafting and beach camping. Shivpuri is only 16 km from Rishikesh. These two sites have been relatively minimally impacted by human intervention, and are only crowded with adventure lovers. Rishikesh and Haridwar are famous for their religious significance. There are many temples and ashrams beside the river Ganges, and millions of people visit these places every day for religious purposes. These two places are overcrowded, and many construction activities are underway to facilitate the daily increase in the number of people. The last sampling station, Bhogpur, is located in the Himalayan foothills (about 250 m a.s.l). In this portion, the water of the Ganges is widely used for cultivating the surrounding areas (Figure 1).

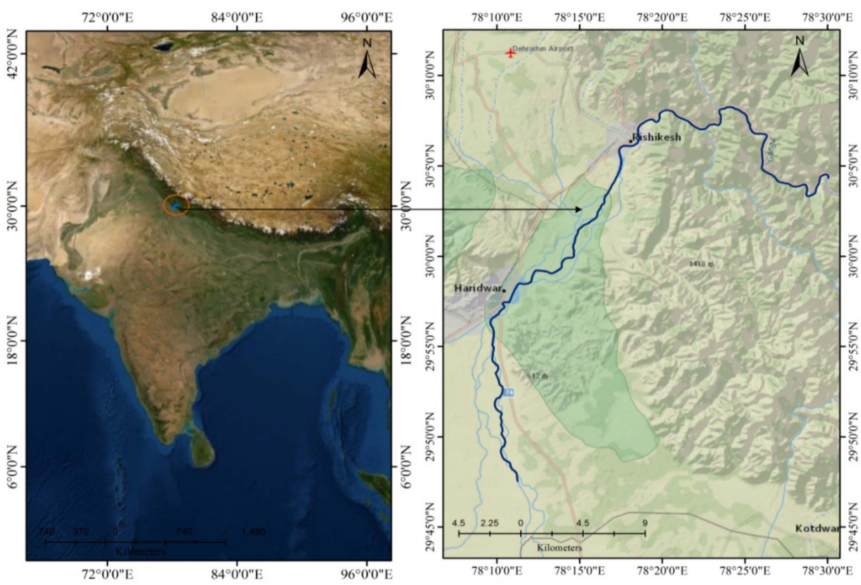

Figure 1. Map showing the case study area, upper Ganges near Haridwar, Uttarakhand.

2.2. Decision Model

The decision model was designed to show the connections between human action through land use and land cover changes and water quality. The model shows three components and their interrelationships. The negative impact of human activities may cause the degradation of land features, i.e., major changes in land use and land cover, which have great consequences on the main abiotic components of the earth, i.e., water bodies. The model was structured in a sequential way to determine the causes of deterioration of water quality. The model was perception-based and was prepared to clarify the presumption that human interactions have a significant role in modifying land features, directly degrading the natural quality of water and making it unfit for human consumption and other uses, including agriculture (Figure 2).

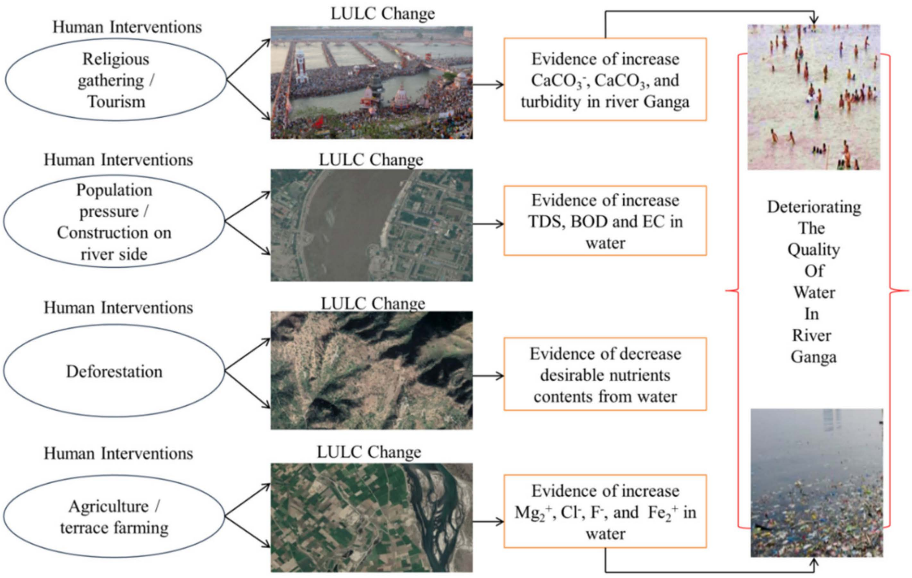

Figure 2. Decision model for assessing the impacts of human interventions and the degradation of water quality.

Thus, keeping the decision model in mind, the sample sites were chosen for water sample collection. The sample sites were selected so as to cover both places where maximum and minimum human levels of human intervention can be found. Concomitantly, land use land cover mapping and change detection analysis was performed to identify the impacts of such human intervention on the quality of nearby water.

2.3. Sample Sites

The most relevant factor regarding the selection of this study area and the sample sites is to identify human intervention on the river in the Himalayan region and its effects on the water. From the upper course of the river Ganges, 5 sites were chosen at which to collect water samples by considering the places where the least to the highest levels of human intervention could be observed along the 78-km-long stretch between Kaudiyala (436 m a.s.l) and Bhogpur (246 m a.s.l) (Figure 3).

Site 1—The site is situated near Kaudiyala, located at 30°4′25.15′′ N to 78°30′5.39′′ E. It is the victim of human disturbances to some extent, and receives waste from cattle washing, vehicle washing, idol immersion, cremation, and nirmalya immersion, and is also used for fishing activities and boating in this area.

Site 2—The site Shivpuri is located at 30°8′7.78′′ N to 78°23′27.27′′ E, representing a lotic that is less disturbed by various anthropogenic activities, although tourist activities in the area are increasing day by day. The site receives waste from sewage, clothes washing, vehicle cleaning, idol immersion, animal washing, fishing and several other activities to a minimal extent.

Site 3—The site Rishikesh is situated at 30°4′59.57″ N and 78°17′26.54″ E. Many human disturbances to the river water can be seen there due to Rishikesh being a holy place, and people from all over the country and from abroad come here for religious purposes. Overpopulation and contact with the Ganges are the main reasons for river water pollution here.

Site 4—The site Haridwar is an ancient city and an important Hindu pilgrimage site in Uttarakhand state, where the river Ganges exits the Himalayan foothills. The largest of several sacred ghats (bathing steps), har Ki Pauri hosts a nightly Ganges Aarti (river-worshipping ceremony), in which tiny flickering lamps are floated off the steps. Worshipers fill the city during major festivals like the annual Kanwar Mela. During this time, pollutants in the water can be observed due to their natural quality and color.

Site 5—The site Bhogpur village is located downstream about 20 km towards South Haridwar district. Agriculture and animal husbandry are the main professions of the residents of this village, who completely depend on river water. Different agricultural processing, irrigation, deforestation, etc., processes are the largest human interventions on the water of the Ganges at this site, resulting in more contamination compared to other sites. The details of the sample collection stations are provided below (Table 1).

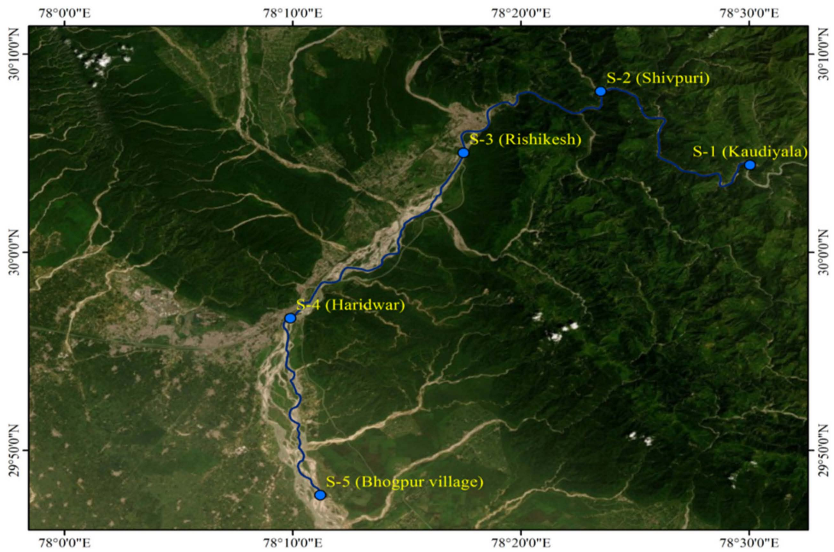

Figure 3. Satellite image of selected sampling sites.

Table 1. Descriptions of sampling sites on the basis of geocoordinate.

Site	Sampling Location	Latitude	Longitude	Height above MSL	Type of Area
S-1	Kaudiyala	30°4′25.15″ N	78°30′5.39″ E	436 m	Hilly
S-2	Shivpuri	30°8′7.78″ N	78°23′27.27″ E	386 m	Hilly
S-3	Rishikesh	30° 4′59.57″ N	78°17′26.54″ E	341 m	Hilly
S-4	Haridwar	29°56′47.30″ N	78°9′40.92″ E	288 m	Plane
S-5	Bhogpur	29°47′44.03″ N	78°11′14.59″ E	246 m	Plane

2.4. Sample Collection

Water samples were collected from the selected sites during the months of January 2018 to December 2018. From the above-mentioned sample sites, the water samples were collected in 2 L pre-cleaned polyethylene bottles. The water samples were collected for each month (January to December), and continuous monitoring involved comprehensive physicochemical analyses. The mean values are presented in Table 5. Physico-chemical parameters like pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved

Solids (TDS), Total Alkalinity (TA), Total Hardness (TH), Chloride (Cl^-), Calcium (Ca^+), Magnesium (Mg^+), Sodium (Na^+) and Potassium (K^+), Fluoride (F^-), and Ferrous iron (Fe^{2+}) of the water samples from the river Ganges were determined between 8.00 a.m. and 12.00 p.m.. The collected water samples were safely carried out and stored in the laboratory for further testing and analyzing.

2.5. Physico-Chemical Analysis

Parameters like pH, EC, TDS, and DO were estimated at the spot immediately after the collection of the samples, whereas water analysis relating to other chemical factors was performed in the laboratory, and the mean testing results of analysis over different time periods were used for water quality determination. Each sample was subjected to the relevant analytical (gravimetric/volumetric/calorimetric) procedure, and the mean values of observations were taken. The chemical analysis was carried out following the methods in [43], and standard analytical procedures were performed, as recommended in [44]. The detailed water sample parameters and the standard values recommended in the Bureau of Indian Standards [45] guidelines are given below (Table 2).

Table 2. Selected physicochemical parameters and their standard limits as recommended by BIS.

Parameters	Units	Method Used for Test	Desirable	Permissible
Temperature	°C	Electrode	NA	NA
pH		Electrode	6.5–8.5	6.5–8.5
Dissolved Oxygen (DO)	mg/L	Modified Winker's method	6	NA
COD	mg/L	Closed reflux method	NA	NA
BOD	mg/L	Modified Winker's method	3	6
Total Alkalinity ($CaCO_3^-$)	mg/L	Titrimetric	200	600
Total hardness ($CaCO_3$)	mg/L	EDTA titrimetric	300	600
Turbidity	NTU	Colorimetric	5	10
Electrical conductivity (EC)	µS/m	Conductivity-TDS meter	2000	3000
Total dissolved solids (TDS)	mg/L	Conductivity-TDS meter	1000	2000
Calcium (Ca^{2+})	mg/L	EDTA titrimetric	75	200
Magnesium (Mg^{2+})	mg/L	EDTA titrimetric	30	100
Sodium (Na^+)	mg/L	Flame photometric	100	200
Potassium (K+)	mg/L	Flame photometric	10	10
Chlorides (Cl^-)	mg/L	Argentometric titration	250	1000
Fluoride (as F^-)	mg/L	Electrode	1	1.5
Ferrous iron (Fe^{2+})	mg/L	Phenanthroline method	0.3	1

Note: the desirable and permissible limits are as per BIS 1998 [46] and 10,500 (2012).

2.6. Water Quality Index

The assessment of water quality index (WQI) offers a comprehensive picture of the overall water quality of ground and surface water [47]. The increasing rates of population, urbanization, and industrialization are the main factors responsible for degrading the water quality in developing countries like India [48]. Water quality index is a rating of different water parameters that reflect the composite influence of water quality [49]. Hence, it is necessary to calculate WQI in order to assess the suitability of ground/surface water for human consumption and other uses [50].

In this study, water quality index was calculated using 15 parameters, namely, pH, dissolved oxygen, biological oxygen demand, total alkalinity, total hardness, turbidity, electrical conductivity, total dissolved solids, calcium, magnesium, sodium, potassium, chlorides, fluoride, and ferrous iron, in order to determine the spatial variation of water quality. To calculate the water quality index from the collected sampled data, a number of different techniques have been used by researchers [51,52]. In this study, the WQI was calculated using Horton's method. The WQI is calculated using the expression given below:

$$\mathrm{WQI} = \frac{\Sigma qnWn}{\Sigma\, Wn} \tag{1}$$

where

qn indicates the quality rating of the nth water parameter.
Wn is the unit weight of the same parameter.

The quality rating (qn) is calculated using the following expression:

$$qn = \frac{(V_{n-}V_i)}{(V_{s-}V_i)} * 100 \tag{2}$$

where

V_n is the estimated value of the nth water quality parameter at a given sample location.
V_i is the ideal value for the nth parameter in pure water (e.g., for pH, this value is 7, and it is 0 for all other parameters)
S_n defines the standard permissible value of the nth water parameter as per the Bureau of Indian Standards [45] for each chemical parameter in mg/L except for electrical conductivity (µS/m), turbidity (NTU) and pH.

The unit weight (W_n) is computed using the following expression:

$$Wn = \frac{K}{Sn} \tag{3}$$

where

S_n is the standard permissible value of the nth parameter as recommended by the BIS.
K indicates the constant of proportionality, and is calculated by the expression given below:

$$K = \frac{Rn}{\Sigma Rn} \tag{4}$$

where Rn = 1, 2, 3, . . . , n.

2.7. Water Quality Standard and Unit Weights of Parameters for Use Purposes

The water quality parameters were selected on the basis of their direct involvement in the deterioration of water quality for human consumption. The standards for drinking water recommended by the Indian Council of Medical Research (ICMR) and the Indian Standards Institution (ISI) were adopted for the computation of the water quality index. For the purpose of calculating the WQI for the study area, 15 water quality parameters were selected. These were pH, DO, BOD, $CaCO_3^-$, $CaCO_3$, Turbidity, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, F^-, and Fe^{2+}. The standard values of the water quality parameters and their corresponding ideal values and unit weights are given below (Table 3). The values of some parameters were found to be above the permissible limits in some of the samples of the study area. Higher values of these parameters increase the WQI value. The details of the IS standard of water quality index, status, and limit for possible usage are shown in the following table (Table 4).

Table 3. Relevant criteria of the selected parameters for the computation of WQI.

Parameters	IS Desirable Limit (Sn)	Rank (Rn)	Unit Weight (Wn)
pH	8.5	3	0.0681
Dissolved Oxygen (DO)	6	2	0.0454
BOD	3	3	0.0681
Total Alkalinity ($CaCO_3^-$)	200	2	0.0454
Total hardness ($CaCO_3$)	300	3	0.0681
Turbidity	5	2	0.0454
Electrical conductivity (EC)	2000	3	0.0681
Total dissolved solids (TDS)	1000	5	0.1136
Calcium (Ca^{2+})	75	2	0.0454
Magnesium (Mg^{2+})	30	3	0.0681
Sodium (Na^+)	100	3	0.0681
Potassium (K^+)	10	2	0.0454
Chlorides (Cl^-)	250	3	0.0681
Fluoride (as F^-)	1	5	0.1136
Ferrous iron (Fe^{2+})	0.3	3	0.0681

Table 4. The ranges of WQI, the corresponding status of water quality, and their possible uses for drinking and irrigation suitability.

S. No.	WQI	Status	Possible Uses
1	<25	Excellent	Drinking, Irrigation and Industrial
2	25–50	Good	Domestic, Irrigation and Industrial
3	51–75	Fair	Irrigation and Industrial
4	76–100	Poor	Irrigation
5	101–150	Very Poor	Restricted use for Irrigation
6	>150	Unfit for Drinking	Proper treatment required before use

2.8. Preparation of the Land Use Map

Looking towards the main aim of this study, i.e., to show the relationship between land use and water quality, it is presumed that changes in land use and particular activities will have a great effect on water quality deterioration. Hence, it is necessary to prepare land use maps for different periods, in order to detect changes in land use and spatially correlate the water quality index with changing land features. For the same area, land use maps were prepared for two different periods, i.e., 2010 and 2020. Landsat TM and OLI (L-5 and L-8) images were used, which are available at the USGS web portal (https://earthexplorer.usgs.gov/ (accessed on 21 July 2020)). Band 4, 3, 2 for TM and 7, 6, 4 for OLI were combined to create FCC images. Based on the color composite and the real view from Google Earth Engine, signatures were created, and supervised image classification was performed in the GIS environment for both 2010 and 2020 (Figures 4 and 5).

Change detection was then performed to identify the types of changes occurring during the last ten years. The water samples were collected from 5 stations along a 78-km-long course of the upper Ganges River. Two buffers were created for the spatial analysis of land use change, i.e., a 10 km buffer along the river and a 5 km buffer around the sample collection stations and the 78-km-long course of the upper Ganges River (Figure 6). The pixel-based data on land use change were extracted and spatially correlated with WQI to test the presumption that the WQI is high where land use is changing due to human intervention.

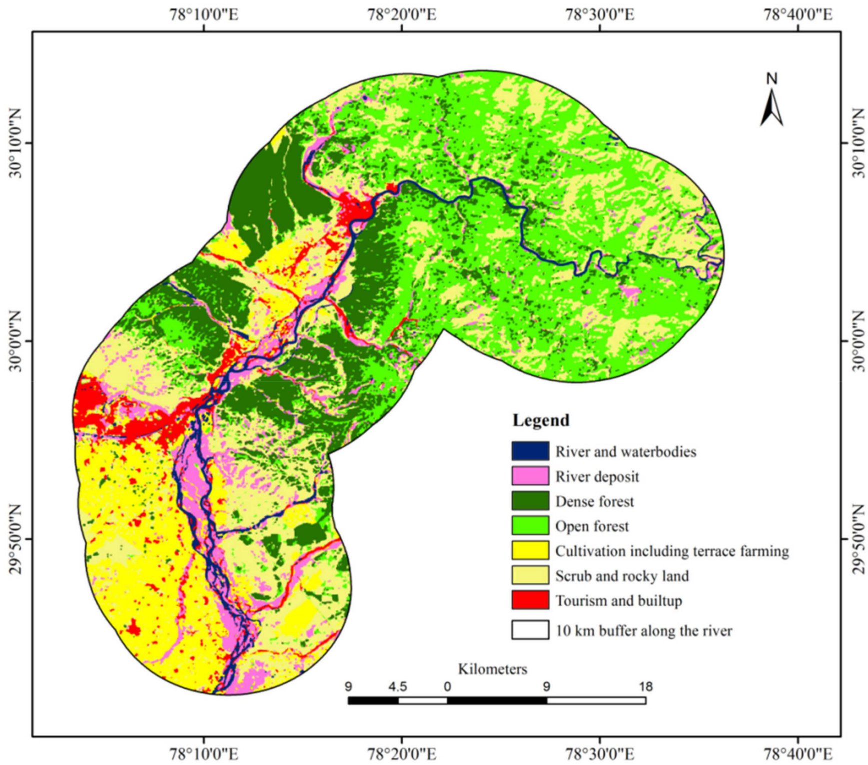

Figure 4. Land use map of 2010, derived from Landsat-5 TM.

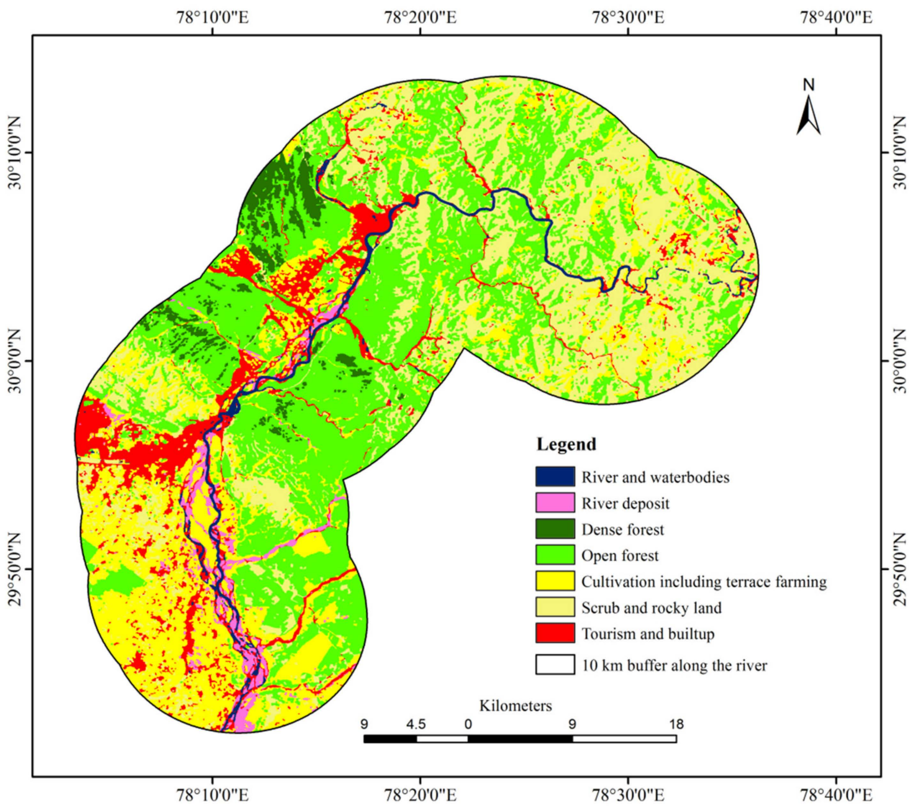

Figure 5. Land use map of 2020, derived from Landsat-8 OLI and TIRS.

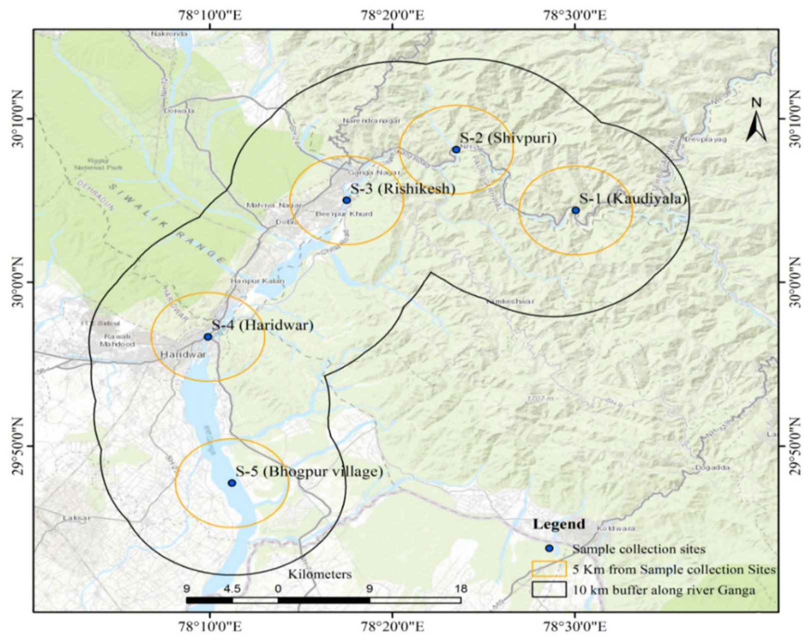

Figure 6. The buffer distance along the case study river and around the sampling stations used for spatial correlation with QWI.

3. Results and Discussion

3.1. Physico-Chemical Parameters of Water

The present study aimed to analyze human intervention on land surface and its impact on water quality. Thus, to reach this aim, a two-fold analysis was carried out. First of all, water sample collection sites were chosen along the upper Ganges river to assess the water quality index, while simultaneously, the changes in land use in that portion were determined in order to find a correlation between the human role in changing land features and the deterioration in the water quality. Briefly, the present study analyzed 15 water parameters and satellite images of two periods. First, water quality was analyzed. Since the water contains dissolved and suspended constituents in varying proportions, it has different chemical and physical properties, along with biological variation. The quality of the water may be affected in various ways by pollution. The water test results with respect to the different physico-chemical properties are summarized in the following table (Table 5).

The analyzed water parameters were Temperature, pH, DO, COD, BOD, $CaCO_3^-$, $CaCO_3$, Turbidity, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, F^-, and Fe^{2+}. We analyzed pH, DO, Temperature and Turbidity at the sample collection spot. The samples were collected in a sterilized PVC bottle and stored in an icebox to reduce the occurrence of changes in the water characteristics. Water temperature is a very important parameter, because it influences the biota in a water body by affecting activities such as behavior, respiration, and metabolism. The temperature values rangeed from 15.85 to 16.04 °C. It was observed that the temperature was higher during the summer, followed by rainy and winter seasons. pH measures the nature of water in terms of whether it is basic (>7) or acidic (<7). In the present study, the highest and lowest pH were observed to be 8.45 and 7.05 at sample sites 5 and 1, respectively. High water pH in the summer may be attributed to the use of free carbon dioxide in algal photosynthesis, resulting in high algal populations. Dissolved oxygen plays a significant role in supporting aquatic life and evaluating the freshness of water. The highest DO was found at site 4, and the lowest at site 3, i.e., 10.28 and 9.11 mg/L, respectively. A suitable amount of DO is required in water for aquatic life like fish and other organisms, and to maintain the diversity of all forms of life, but excess amounts indicate a degradation in the quality of water. BOD is the amount of oxygen required during the metabolization of organic matter, which is essential to aquatic ecosystems. The water at the sampled sites on the Ganges had a maximum alkalinity of 219.42 mg/L during the course of this study, decreasing gradually moving towards the upper course. The hardness of the water was found to have a maximum value of 309.8 mg/L and a minimum value of 110.12 mg/L, at sample sites 5 and 1, respectively. The Ganges water contained a maximum chemical oxygen demand of 8.86 mg/L, followed by a gradual decrease to a minimum value of 6.11 mg/L. Some parameters, like total alkalinity ($CaCO_3^-$), total hardness ($CaCO_3$), and turbidity were found to be above the desirable limits; this is because of increasing human intervention resulting from floating population, domestic sewage, the addition of nutrients, agricultural runoff, and organic matter in water. The EC of water is a direct indication of its total dissolved salts, and is used for measuring the total concentration of soluble salts in water. Our testing results showed that at the sampling sites, the concentration of EC was always below the desirable limit. Although high degrees of anthropogenic activities such waste disposal, sewage, and agricultural runoff are present at sites 3, 4, and 5, EC was found to have a good content, which may be due to water flowing towards the lower course, because EC fluctuates due to water flow. Total dissolved solids (TDS) primarily consist of inorganic salts like chlorides, sulphates, bicarbonates, carbonates, magnesium, sodium, potassium, phosphates, and nitrates of calcium, iron, etc. The values of TDS, in increasing order, were 227.08, 221.68, 344.83, 525.31, and 598.65 mg/L at sample sites 1, 2, 3, 4, and 5, respectively. The value of TDS at all sites was below the BIS desirable limit of l000 mg/L. the concentrations of calcium (Ca^{2+}), sodium (Na^+) and potassium (K^+) were also found to be below the desirable limit as recommended by the BIS standard. However, the values of magnesium (Mg^{2+}), chlorides (Cl^-), fluoride (as F^-), and ferrous iron (Fe^{2+}) were found to be above the desirable limit at some sites, such as 4 and 5. These parameters were found in higher proportions in these locations because of the increased pollution load due to sewage and agricultural runoff in the river water.

Table 5. Details of site-wise physicochemical parameters and their QWI (mean ± sd) during the observation.

Parameters	Units	Site 1	Site 2	Site 3	Site 4	Site 5	Min.	Max.
Temperature	°C	15.85 ± 2.36	16.56 ± 3.21	15.92 ± 1.25	16.85 ± 3.54	16.04 ± 2.54	14.25	17.46
pH		7.05 ± 0.25	7.31 ± 0.32	7.38 ± 0.51	8.31 ± 0.65	8.45 ± 0.45	7.3	8.3
Dissolved Oxygen (DO)	mg/L	9.12 ± 1.25	9.44 ± 1.74	9.11 ± 0.95	10.28 ± 1.24	10.09 ± 1.02	7.51	11.54
COD	mg/L	7.23 ± 1.31	6.11 ± 1.27	8.5 ± 1.41	8.86 ± 1.44	8.27 ± 1.12	5.64	9.52
BOD	mg/L	2.38 ± 0.24	2.37 ± 0.32	2.97 ± 0.41	2.57 ± 0.11	2.92 ± 0.42	1.87	3.52
Total Alkalinity ($CaCO_3^-$)	mg/L	145.14 ± 24.2	111.32 ± 10.5	178.32 ± 25.6	195.11 ± 12.8	219.42 ± 25.2	109.95	242.9
Total hardness ($CaCO_3$)	mg/L	110.12 ± 11.5	131.43 ± 9.32	226.34 ± 32.7	306.62 ± 35.28	309.8 ± 31.5	101.21	158.61
Turbidity	NTU	34.32 ± 4.51	29.41 ± 5.32	32.24 ± 7.54	21.51 ± 4.51	25.21 ± 6.21	24.2	36.85
Electrical conductivity (EC)	µS/m	225.8 ± 8.74	210.47 ± 9.65	221.21 ± 12.35	205.5 ± 18.54	201.7 ± 17.41	185.71	248.91
Total dissolved solids (TDS)	mg/L	227.08 ± 15.2	221.68 ± 18.4	344.83 ± 21.4	525.31 ± 34.7	598.65 ± 35.5	208.29	632.1
Calcium (Ca^{2+})	mg/L	19.25 ± 4.82	19.36 ± 5.54	18.11 ± 4.32	15.58 ± 3.67	17.36 ± 4.51	15.37	22.65
Magnesium (Mg^{2+})	mg/L	85.32 ± 6.27	80.65 ± 6.89	88.69 ± 7.27	57.3 ± 5.74	61.41 ± 6.32	55.4	99.58
Sodium (Na^+)	mg/L	78.21 ± 4.74	69.14 ± 5.47	72.41 ± 6.85	54.24 ± 7.32	65.31 ± 5.74	42.32	95.47
Potassium (K^+)	mg/L	1.54 ± 0.22	1.21 ± 0.09	1.25 ± 0.23	0.58 ± 0.81	0.98 ± 0.05	0.5	2.05
Chlorides (Cl^-)	mg/L	113.25 ± 9.32	102.45 ± 7.32	175.43 ± 8.64	190.14 ± 12.95	252.54 ± 13.74	100.37	378.52
Fluoride (as F^-)	mg/L	0.92 ± 0.32	0.76 ± 0.08	1.13 ± 0.08	1.37 ± 0.074	1.71 ± 0.121	0.71	2.1
Ferrous iron (Fe^{2+})	mg/L	0.13 ± 0.02	0.1 ± 0.002	0.26 ± 0.03	0.41 ± 0.04	0.67 ± 0.07	0.09	0.78
Water Quality Index (WQI)		74.45	70.97	99.79	121.61	135.98	61.78	147.45

3.2. Water Quality Index

Using the above data (Table 3), the water quality index was calculated for the upper Ganges River at Haridwar on the basis of the samples collection from the five sites. The computed WQI was categorized into five classes, i.e., excellent (<25), good (25–50), fair (51–75), poor (76–100), very poor (101–150), and unfit for drinking (>150). In the present analysis, the WQI values ranged between 121 ± 72. It is evident from the analysis that the WQI values at sites 1 (Kaudiyala) and 2 (Shivpuri) fell under good to fair condition, while the other three sites (Rishikesh, Haridwar, and Bhogpur) fell under the poor to very poor category (Figure 7). The main reasons behind the poor quality of the water in Rishikesh and Haridwar are human intervention or anthropogenic activities in the water, the region becoming impacted by residential hotels, shops, and transportation due to human interest in coming to stay in this religious place. Bhogpur is a residential village located at a lower elevation. Here, the WQI was found to be very poor (135.98), which is because of high levels of human interfeerence with the water for agricultural purpose. The river deposits are also used here for cultivation, and large amounts of agricultural effluents mix with the river water. Meanwhiles, sites 1 and 2 (Kaudiyala and Shivpuri) were found to have better conditions, and WQI was also found to be in a good range, because only low levels of human intervention could be observed, and the river is still in contact with nature (Figure 8).

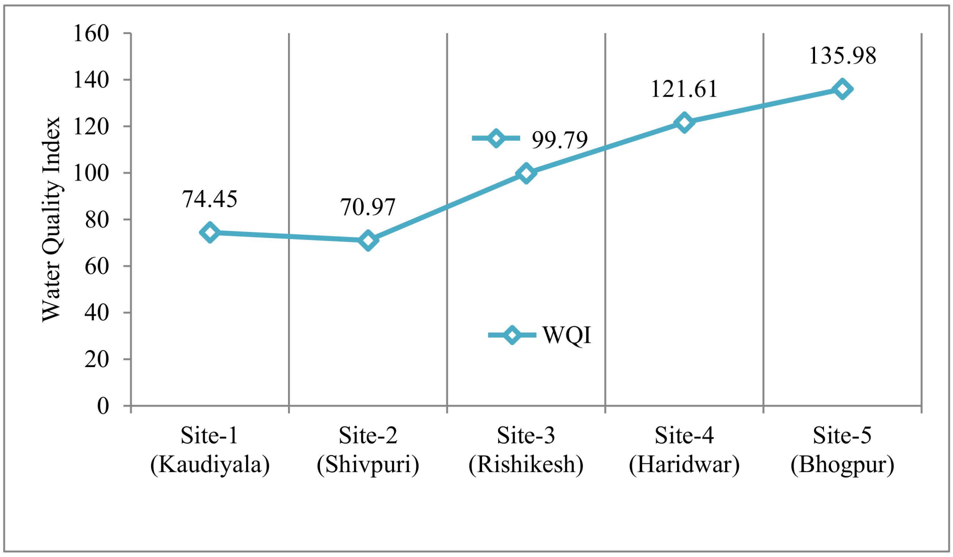

Figure 7. Graphical representation of water quality index at selected sample sites.

3.3. Land Use Change and WQI

The area under study has faced many changes in terms of land use. The pixel-based change detection between the 2010 and 2020 images reveal that the maximum changes had occurred in forest. A 23.13% portion of dense forest was converted into open forest, scrub and rocky areas. River and water bodies were reduced by about 1.94%, while cultivation, including terrace farming, tourism, and built-up areas increased by about 3.94% and 6.06%, respectively (Table 6). Therefore, on the whole, it can be said that in the last 10 years, the majority of land use changes in this area have been due to public involvement through deforestation, construction, and cultivation.

This changing phenomenon of land use was superimposed and correlated with WQI to draw a conclusion as to the degree to which human activity was responsible for the deterioration of the natural quality of the river water. The area exhibiting the maximum change was extracted to compare the WQI values and to fit the presumption that land use change has affected the quality of the water (Figure 9). The spatial assimilation shows that Rishikesh, Haridwar, and Bhogpur village are subject to maximum human intervention. Seasonal religious gatherings, religious mela, tourist activities and cultivation occur continuously in these locations, placing a great burden on the water of the Ganges. Excluding Kaudiyala and Shivpuri, the mean water quality index was found to be close to or above 100, making it unfit for human use as well as irrigation, because contamination can be transmitted through the food chain, causing long-term health problems.

Figure 8. Recent, high-resolution satellite view of the selected sample sites showing the human interventions on the river water and the surrounding land areas (red polygons indicate areas under cultivation).

Table 6. Tabulated representation of change detection statistics for land use between 2010 and 2020.

	River and Waterbodies	River Deposit	Dense Forest	Open Forest	Cultivation Including Terrace Farming	Scrub and Rocky Land	Tourism and Built-Up
River and waterbodies	13,567	2489	79	137	206	987	7496
River deposit	8716	4405	64	147	4103	1746	21,631
Dense forest	18	17	43,819	4153	43	322	66
Open forest	760	26,710	199,537	218,345	2656	224,478	3120
Cultivation including terrace farming	2872	41,349	2475	21,340	142,524	151,170	37,271
Scrub and rocky land	3125	26,181	77,721	244,238	18,668	95,040	4340
Tourism and built-up	8230	18,594	2105	4588	22,364	22,742	82,845
Total pixels	37,288	119,745	325,800	492,948	190,564	496,485	156,769
Class change	23,727	115,369	281,981	274,603	48,044	401,465	73,924
Change detection 2010–2020	−12,547	−79,094	−277,443	183,001	208,619	−26,963	4748
Class change 2010–2020 (%)	1.95	9.46	23.13	22.53	3.94	32.93	6.06

Note: the value of each land cover class is expressed in pixels.

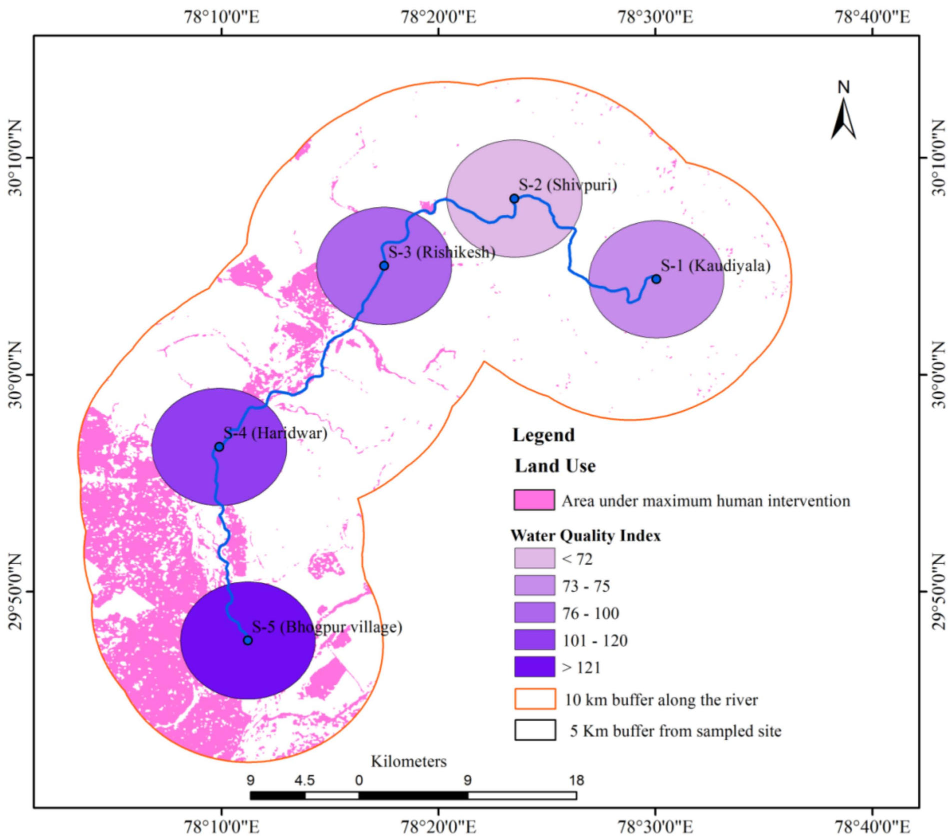

Figure 9. Overlay image shows the spatial correlation between areas under human intervention and the respective water quality index of the river water in the upper Ganges River.

Our study findings suggest that human intervention in land use change has had significant impacts on the quality of the water in the study area. The physicochemical analysis of the water parameters reveals that the quality of the water not satisfactory in those areas with maximum land subject to human intervention. Land use under natural forest cover acts as nutrient retention, offering a rich biological system favorable to water and aquatic life [53]. However, the opposite results appear with high anthropogenic inputs [54,55]. Concomitantly, breakdown of the natural system and land use change plays a significant role in total dissolved solids, and nitrogen and phosphorous deposition, which may highly be influenced by both point and non-point source pollution [56]. The high concentrations of $Mg_2{}^+$, Na^+, K^+, Cl^-, F^-, and $Fe_2{}^+$ are also indicative of the discharge of a large amount of sewage and agricultural waste without proper treatment into the river at the study sites. This is in agreement with similar findings d from previous studies suggesting that water quality is highly influenced by untreated waste [57–59].

Land use change has a diverse range of impacts on local temperature, natural ecosystems, socio-economic drivers, and even on policy making and implementation [60–63]. Several studies have emphasized the relationship between land use change and the seasonal change in water quality [64–67]. Although the mean results were analyzed here, the water quality varies between the dry and the rainy season, and between pre- and post-religious gathering, which is direct evidence of the role of anthropogenic activities. The water quality is poorer during the dry season than the rainy season, because in the dry season, the river is in low flow and is more affected by point source pollutants, but these become mobile with the increased velocity of the river water during the rainy season [68].

However, in our findings, the spatial differences in water quality index in the study area were explained by the tourism, built-up and agricultural land uses. These finding are in agreement with similar results found throughout the world [69,70]. These results evidently support the presumption of the present study that land use change and human intervention have a great impact on water quality due to increased human pressure and agricultural effluents.

3.4. Assessment and Validation

The extent of land use change and its role in the deterioration of water quality was correlated spatially. The results reveal that the water quality was poor in areas that are subjected to the highest levels of human intervention. Of the five sampled sites, two were found to possess a QWI greater than 100 (restricted for irrigation and unfit for drinking purposes), and these sites exhibited the highest degree of land use change in the last ten years. Pixel-based values were taken to assess the accuracy of the results and to test the presumption. The root mean square error (RMSE) and mean absolute percentage error (MAPE) were considered here for the same. The pixel-based land use change was taken as an independent variable (x), and the corresponding water quality as the dependent variable (y), and their error were calculated to weight the result. Statistically, RMSE is the square root of mean square error (MSE), it is expressed as:

$$\text{MSE} = \frac{\Sigma\,(x-y)^2}{n} \tag{5}$$

where x and y are the independent and dependent variables, respectively and n is the number of variables. Consequently, MAPE was also considered, which is the summation value of absolute error (d) divided by the total number of variables. It can be expressed as:

$$\text{MAPE} = \frac{\Sigma d}{n} \tag{6}$$

For the assessment and validation of the present analysis, the pixel-based root mean square error was considered between the area of high human intervention and water quality index of respective sample sites (Table 7).

Table 7. Error estimation statistics for the spatial correlation of land use and water quality index.

Class Change	Pixel Count	Maximum Change between Sampled Sites	Land Use Change (p/t)	Change in WQI (d/100)	Error	Absolute Error	Square of Error	Absolute Value of Error/Actual Vale
River and waterbodies	23,727	Negligible	–	–	–	–	–	–
River deposit	115,369	S4 to S5	0.0946	0.1437	0.0491	0.0491	0.0024	0.5191
Dense forest	281,981	S3 to S4	0.2313	0.2181	−0.0131	0.0131	0.0001	0.0569
Open forest	274,603	S3 to S4	0.2252	0.2181	−0.0071	0.0071	0.00001	0.0316
Cultivation including terrace farming	48,044	S4 to S5	0.0394	0.1437	0.1043	0.1043	0.01089	2.6480
Scrub and rocky land	401,465	S1 to S2	0.3293	0.0347	−0.2945	0.2945	0.0867	0.8944
Tourism and built-up	73,924	S3 to S4	0.0606	0.2181	0.1574	0.1574	0.02480	2.5971
MAD = 0.1043, MSE = 0.0208, RMSE = 0.1443, MAPE = 1.1245								

The results of the error calculation reveal that the RMSE between spatial land use and the water quality index of the selected sampled sites was 0.1443, and the MAPE was 1.1245. The recorded water quality index was observed to be not good at sample sites 3, 4, and 5. The spatial overlay similarly illustrates that these sites are being subjected to human intervention in the form of deforestation, cultivation, terrace farming and other uses that cause pollutants to be discharged into the river water (Figure 10).

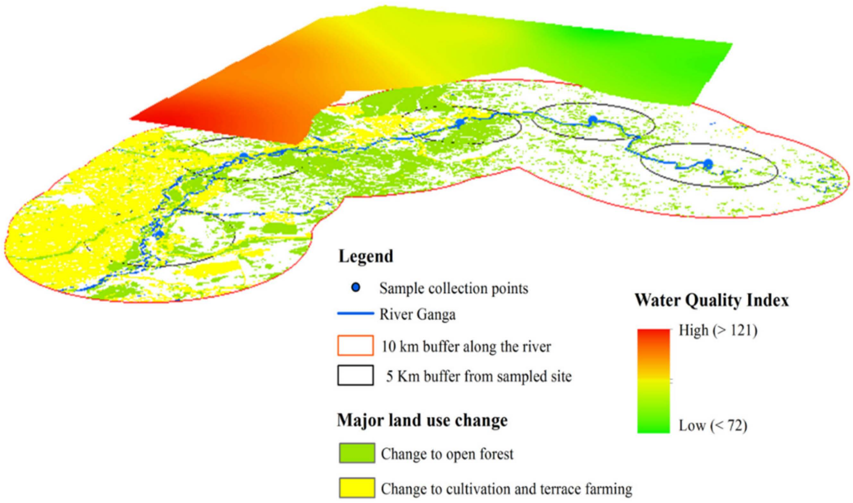

Figure 10. Spatial overlay and scene view of land use change and water quality index.

The correlation between pixels-based land use change (x) and site-wise differences in water quality index (y) resulted in a high positive correlation, with R^2 = 0.8455 (Figure 11). The degree of positive correlation strongly indicates acceptance of the presumption and the results. It is also evident from the above figure that land use classes such as cultivation and terrace farming underwent comparatively less change in the last 10 years than scrub and rocky land, but the WQI was very high in those classes. Consequently, the pixel area under tourism and built-up land uses also possessed high WQI. Hence, from the error estimation and spatial correlation analysis, it can be found that human interventions have a severe impact on water quality.

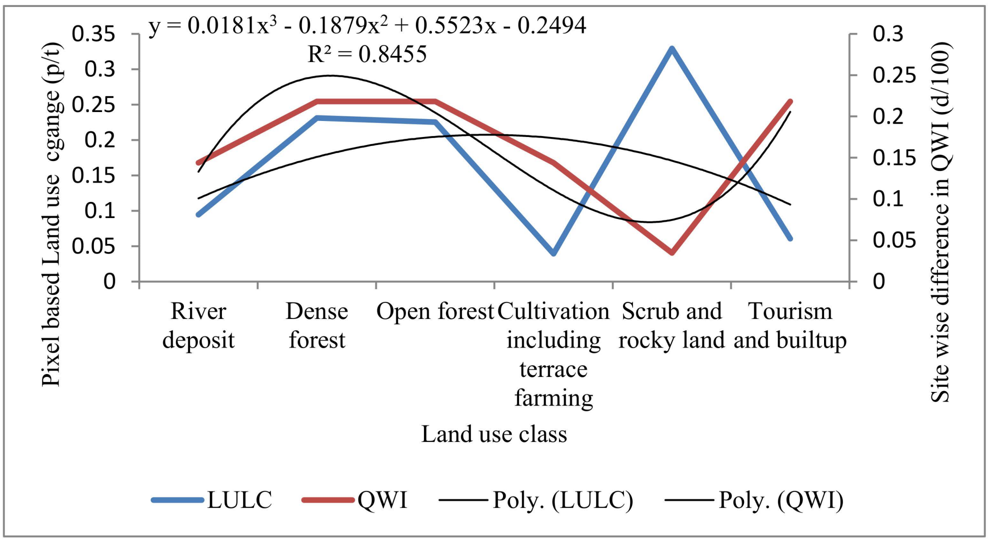

Figure 11. Spatial correlation between pixels-based land use change and site-wise differences in water quality index.

4. Conclusions

The present study was an attempt to investigate the impacts of human interactions and activities on water quality. A complex presumption was taken into consideration that the changing land use phenomena due to human intervention may responsible for deteriorating the quality of the water in the upper course of the river Ganges. For the same water, samples were collected to test the physico-chemical properties at predefined stations by considering places where minimal and maximal degrees of human intervention can be observed, including construction, tourism, deforestation, and cultivation. GIS techniques were used to prepare land use mapping and change detection to perform a spatial correlation with water quality index. The results revealed that out of the five selected sampled sites, three (sites 3, 4, and 5) were under human effects, and high degrees of human engagement in land modification such road construction, habitation, religious gatherins, deforestation and cultivation imposed maximal pressure on the river water directly or indirectly, resulting in the water quality also being found to be in poor to very poor condition. The spatial autocorrelation also exhibited a highly positive correlation, with a value of 0.8455. The present investigation also evidenced that temporary changes in land use and human interaction with the natural system have a great impact on surface water quality, resulting in deterioration of the water quality index, making water unfit for irrigation and other uses.

Our study findings demonstrate that spatial and temporal investigation using GIS and multivariate statistical techniques could offer an overview of the relationship between land use and water quality. Our study findings also show that GIS has great efficacy for the correlation and analysis of spatial relationships from small to large scale. It is evidenced that public interventions play a great role in changing land features, as well as surface water quality. Therefore, it is of keen interest to plan some management strategies that could serve as remedial measures with respect to the pollution levels in the upper Ganges River, making the water of an acceptable standard for drinking and other uses.

5. Suggestions

The following suggestions could be effective in this regard:

(i) Site-based water quality analysis in our study indicates that agricultural land use and human gatherings for religious purposes affect water quality. Therefore, water restoration in critical areas should be employed to improve the quality.

(ii) Deforestation should be strictly restricted and the local community should be engaged in preserving the forest, which could improve the nutrient composition in the water and enrich the overall quality of the water.

(iii) The major pollutants in the river in the study area are derived from human waste and agricultural effluent. Therefore, it is essential to develop effective sewage conveyance systems and efficient water treatment plants in affected and critical areas.

(iv) Large human gatherings and bathing are the main issues at Rishikesh (site 3) and Haridwar (site 4), due to religious practices. Therefore, Government measures should be implemented to reduce the public interventions in the water.

(v) Last but not least, more public concern, awareness and active participation should require at the local level to save the water and enrich the quality of life.

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References

1. Withers, P.J.; Jarvie, H.P. Delivery and cycling of phosphorus in rivers: A review. *Sci. Total Environ.* **2008**, *400*, 379–395. [CrossRef] [PubMed]
2. Chen, J.; Lu, J. Effects of Land Use, Topography and socio-economic factors on river water quality in a mountainous watershed with intensive agricultural production in east China. *PLoS ONE* **2014**, *9*, e102714. [CrossRef] [PubMed]
3. Yadav, K.K.; Gupta, N.; Kumar, V.; Arya, S.; Singh, D. Physico-chemical analysis of selected ground water samples of Agra city, India. *Recent Res. Sci. Technol.* **2012**, *4*, 51–54.
4. Kang, J.; Lee, S.W.; Cho, K.H.; Ki, S.J.; Cha, S.M.; Kim, J.H. Linking land use type and stream water quality using spatial data of fecal indicator bacteria and heavy metals in the Yeongsan river basin. *Water Res.* **2010**, *44*, 4143–4157. [CrossRef] [PubMed]
5. Rai, B. Pollution and conservation of Ganga river in modern India. *Int. J. Sci. Res. Pub.* **2013**, *3*, 1–4.
6. Sharma, M.; Tobschall, H.; Singh, I. Environmental impact assessment in the Moradabad industrial area (rivers Ramganga-Ganga interfluve), Ganga Plain, India. *Environ. Geol.* **2003**, *43*, 957–967. [CrossRef]
7. Yadav, K.K.; Gupta, N.; Kumar, V.; Choudhary, P.; Khan, S.A. GIS-based evaluation of groundwater geochemistry and statistical determination of the fate of contaminants in shallow aquifers from different functional areas of Agra city, India: Levels and spatial distributions. *RSC Adv.* **2018**, *8*, 15876–15889. [CrossRef]
8. Singh, M.; Singh, A.K. Bibliography of environmental studies in natural characteristics and anthropogenic influences on the Ganga river. *Environ. Monit. Assess.* **2007**, *129*, 421–432. [CrossRef] [PubMed]
9. Paul, D.; Sinha, S.N. Isolation and characterization of a phosphate solubilizing heavy metal tolerant bacterium from river Ganga, West Bengal, India Songklanakarin. *J. Sci Technol.* **2015**, *37*, 651–657.
10. Conley, K.; Clum, A.; Deepe, J.; Lane, H.; Barbara, B. Wastewater treatment plants as a source of microplastics to an urban estuary: Removal efficiencies and loading per capita over one year. *Water Res. X* **2019**, *3*, 100030. [CrossRef] [PubMed]
11. Hamilton, L. What Are the Impacts of Himalayan Deforestation on the Ganges-Brahmaputra Lowlands and Delta? Assumptions and Facts. *Mt. Res. Dev.* **1987**, *7*, 256–263. [CrossRef]
12. Maurya, P.K.; Malik, D.S. Distribution of heavy metals in water, sediments and fish tissue (*H. fossilis*) in Kali river of western U.P. India. *J. Fish. Aquat. Stud.* **2016**, *4*, 208–215.
13. Agrawal, A.; Pandey, R.S.; Sharma, B. Water pollution with special reference to pesticide contamination in India. *J. Water Resour. Prot.* **2010**, *2*, 432–448. [CrossRef]
14. Gupta, N.; Yadav, K.K.; Kumar, V.; Singh, D. Assessment of physicochemical properties of Yamuna River in Agra City. *Int. J. Chem. Technol. Res.* **2013**, *5*, 528–531.
15. Yadav, K.K.; Kumar, V.; Gupta, N.; Kumar, S.; Rezania, S.; Singh, N. Human health risk assessment: Study of a population exposed to fluoride through groundwater of Agra city, India. *Regul. Toxicol. Pharmacol.* **2019**, *106*, 68–80. [CrossRef]
16. Sanchez, E.; Colmenarejo, M.F.; Vincente, J. Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. *Ecol. Indic.* **2007**, *7*, 315–328. [CrossRef]
17. Maurya, P.K.; Malik, D.S.; Yadav, K.K.; Amit, K.; Sandeep, K.; Kamyab, H. Bioaccumulation and potential sources of heavy metal contamination in fish species in River Ganga basin: Possible human health risks evaluation. *Toxicol. Rep.* **2019**, *6*, 472–481. [CrossRef] [PubMed]
18. Nautiyal, C.S. Scientific validation of incorruptible self-purificatory characteristic of Ganga water. *Asian Agri-Hist.* **2009**, *13*, 53–56.
19. Maurya, P.K.; Malik, D.S. Accumulation and distribution of organochlorine and organophosphorus pesticide residues in water, sediments and fishes, *Heteropneustis fossilis* and *Puntius ticto* from Kali river, India. *J. Toxicol. Environ. Health Sci.* **2016**, *8*, 30–40.
20. Trivedi, R.C. Water quality of the Ganga River—An overview. *Aquat. Ecosyst. Health Manag.* **2010**, *13*, 347–351. [CrossRef]
21. Biswas, S.P.; Boruah, S. Ecology of the river Dolphin (*Platanista gangetica*) in the upper Brahmaputra. *Hydrobiologia* **2000**, *430*, 97–101. [CrossRef]
22. Yadav, K.K.; Gupta, N.; Kumar, V.; Sharma, S.; Arya, S. Water quality assessment of Pahuj River using water quality index at Unnao Balaji, M.P., India. *Int. J. Sci. Basic Appl. Res.* **2015**, *19*, 241–250.
23. Matta, G. A study on physico-chemical Characteristics to assess the pollution status of river Ganga in Uttarakhand. *J. Chem. Pharm. Sci.* **2014**, *7*, 210–217.
24. Haritash, A.K.; Gaur, S.; Garg, S. Assessment of water quality and suitability analysis of River Ganga in Rishikesh, India. *Appl. Water Sci.* **2016**, *6*, 383. [CrossRef]
25. Beg, K.R.; Ali, S. Chemical contaminants and toxicity of Ganga river sediment from up and down stream area at Kanpur. *Am. J. Environ. Sci.* **2008**, *4*, 362–366. [CrossRef]
26. Gupta, A.; Rai, D.K.; Pandey, R.S.; Sharma, B. Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environ. Monit. Assess.* **2009**, *157*, 449–458. [CrossRef] [PubMed]
27. Joshi, D.M.; Bhandari, N.S.; Kumar, A.; Agrawal, N. Statistical analysis of physicochemical parameters of water of River Ganga in Haridwar district. *Rasayan J. Chem.* **2009**, *2*, 579–587.
28. Rai, P.K.; Mishra, A.; Tripathi, B.D. Heavy metal and microbial pollution of the River Ganga: A case study of water quality at Varanasi. *Aquat. Ecosyst. Health Manag.* **2010**, *13*, 352–361. [CrossRef]

29. Vega, M.; Pardo, R.; Barrado, E.; Debán, L. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Res.* **1998**, *32*, 3581–3592. [CrossRef]
30. Tong, S.T.Y.; Chen, W. Modeling the relationship between land use and surface water quality. *J. Environ. Manag.* **2002**, *66*, 377–393. [CrossRef] [PubMed]
31. Strayer, D.L.; Beighley, R.E.; Thompson, L.C.; Brooks, S.; Nilsson, C.; Pinay, G.; Naiman, R.J. Effects of land cover on stream ecosystems: Roles of empirical models and scaling issues. *Ecosystems* **2003**, *6*, 407–423. [CrossRef]
32. Allan, J.D. Landscapes and riverscapes: The influence of land use on stream ecosystems. *Ann. Rev. Ecol. Syst.* **2004**, *35*, 257–284. [CrossRef]
33. White, M.D.; Greer, K.A. The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Peñasquitos Creek, California. *Landsc. Urban Plan.* **2006**, *74*, 125–138. [CrossRef]
34. Lee, S.; Hwang, S.; Lee, S.; Hwang, H.; Sung, H. Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics. *Landsc. Urban Plan.* **2009**, *92*, 80–89. [CrossRef]
35. Khan, N.; Mathur, A.; Mathur, R. A study on drinking water quality in Laskhar (Gwalior). *Indian J. Environ. Prot.* **2004**, *25*, 220–224.
36. Kumar, P.; Kaushal, R.K.; Nigam, A.K. Assessment and management of ganga river water quality using multivariate statistical techniques in India. *Asian J. Water Environ. Pollut.* **2015**, *12*, 61–69. [CrossRef]
37. Maurya, P.K.; Malik, D.S. Bioaccumulation of xenobiotics compound of pesticides in riverine system and its control technique: A critical review. *J. Ind. Pollut. Control.* **2016**, *32*, 580–594.
38. Dwivedi, S.; Mishra, S.; Tripathi, R.D. Ganga water pollution: A potential health threat to inhabitants of Ganga basin. *Environ. Int.* **2018**, *117*, 327–338. [CrossRef]
39. The Hindu Ganga. Action Plan Bears No Fruit. Chennai, India. Archived. 2004. Available online: https://www.thehindu.com/todays-paper/tp-national/tp-newdelhi/ganga-action-plan-bears-nofruit/article27660726.ece (accessed on 13 March 2020).
40. Kaur, B. Namami Gange: 5 Reasons Why Ganga Will Not Be Clean by 2020. Down To Earth. Archived. 2019. Available online: https://www.downtoearth.org.in/coverage/water/namami-gange-5-reasons-why-ganga-will-not-be-clean-by-2020-61891 (accessed on 27 February 2020).
41. Trivedy, R.K.; Goel, P.K. *Chemical and Biological Methods for Water Pollution Studies*; Environmental Publication; UBS Publisher: Karad, India, 1986.
42. American Public Health Association (APHA). *Standard Method for Examination of Water and Wastewater*, 21st ed.; APHA, AWWA, WPCF: Washington, DC, USA, 2005.
43. Bureau of Indian Standards (BIS). *Indian Standard Drinking Water Specification (Second Revision) BIS 10500:2012*; Bureau of Indian Standards (BIS): New Delhi, India, 2012.
44. BIS. *Indian Standard Specification for Drinking Water, IS: 10500*; Bureau of Indian Standards: New Delhi, India, 1998.
45. Ravikumar, P.; Mehmood, M.A.; Somashekar, R.K. Water quality index to determine the surface water quality of Sankey tank and Mallathahalli lake, Bangalore urban district, Karnataka, India. *Appl. Water Sci.* **2013**, *3*, 247–261. [CrossRef]
46. Malik, D.S.; Maurya, P.K. Heavy metal concentration in water, sediment, and tissues of fish species (*Heteropneustis fossilis* and *Puntius ticto*) from Kali river, India. *Toxicol. Environ. Chem.* **2015**, *96*, 1195–1206.
47. Yadav, K.K.; Kumar, S.; Quoc, B.P.; Gupta, N.; Rezania, S.; Kamyab, H.; Yadav, S.; Jan, V.; Kumar, V.; Doan Quang Tria, D.Q.; et al. Fluoride contamination, health problems and remediation methods in Asian groundwater: A comprehensive review. *Ecotoxicol. Environ. Saf.* **2019**, *182*, 109362. [CrossRef] [PubMed]
48. Avvannavar, S.M.; Shrihari, S. Evaluation of water quality index for drinking purposes for river Netravathi, Mangalore, South India. *Environ. Monit. Assess.* **2008**, *143*, 279–290. [CrossRef]
49. Paul, D.; Sinha, S.N. Assessment of various heavy metals in surface water of polluted sites in the lower stretch of river Ganga, West Bengal: A study for ecological impact. *Discov. Nat.* **2013**, *6*, 8–13.
50. Fathi, E.; Zamani Ahmad, M.R.; Zare Bidaki, R. Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. *Appl. Water Sci.* **2018**, *8*, 210. [CrossRef]
51. Gardner, K.K.; McGlynn, B.L. Seasonality in spatial variability and influence of land use/land cover and watershed characteristics on stream water nitrate concentrations in a developing watershed in the Rocky Mountain West. *Water Resour. Res.* **2009**, *45*, W08411. [CrossRef]
52. Yadav, K.K.; Gupta, N.; Kumar, V.; Khan, S.A.; Kumar, A. A Review of Emerging Adsorbents and Current Demand for Defluoridation of Water: Bright Future in Water Sustainability. *Environ. Int.* **2018**, *111*, 80–108. [CrossRef] [PubMed]
53. Piatek, K.B.; Christopher, S.F.; Mitchell, M.J. Spatial and temporal dynamics of stream chemistry in a forested watershed. *Hydrol. Earth Syst. Sci.* **2009**, *13*, 423–439. [CrossRef]
54. Ding, J.; Jiang, Y.; Fu, L.; Liu, Q.; Peng, Q.; Kang, M. Impacts of Land Use on Surface Water Quality in a Subtropical River Basin: A Case Study of the Dongjiang River Basin, Southeastern China. *Water* **2015**, *7*, 4427–4445. [CrossRef]
55. Dudgeon, D. Endangered ecosystems: A review of the conservation status of tropical Asian rivers. *Hydrobiologia* **1992**, *248*, 167–191. [CrossRef]
56. Ho, K.C.; Hui, K.C. Chemical contamination of the East River (Dongjiang) and its implication on sustainable development in the Pearl River Delta. *Environ. Int.* **2001**, *26*, 303–308. [CrossRef]

57. Jiang, Y.; Ding, Z.; Peng, Q.; Liao, J.; Lv, L. Spatial Distribution and Corresponding Factors of Heavy Metals Concentrations in the Dongjiang River Basin, Southeast China. *Res. J. Environ. Earth Sci.* **2012**, *4*, 448–459.
58. Quintas-Soriano, C.; Castro, A.J.; Castro, H.; García-Llorente, M. Impacts of land use change on ecosystem services and implications for human well-being in Spanish drylands. *Land Use Policy* **2016**, *54*, 534–548. [CrossRef]
59. Geneletti, D.; Zardo, L. Ecosystem-based adaptation in cities: An analysis of European urbanclimate adaptation plans. *Land Use Policy* **2016**, *50*, 38–47. [CrossRef]
60. Liu, Y.; Feng, Y.; Zhao, Z.; Zhange, Q.; Su, S. Socioeconomic drivers of forest loss and fragmentation: A comparisonbetween different land use planning schemes and policy implications. *Land Use Policy* **2016**, *54*, 58–68. [CrossRef]
61. Nayak, S.; Mandak, M. Impact of land use and land cover changes on temperature trends over India. *Land Use Policy* **2019**, *89*, 104–238. [CrossRef]
62. Johnson, L.; Richards, C.; Host, G.; Arthur, J. landscape influences on water chemistry in midwestern stream ecosystems. *Freshw. Biol.* **1997**, *37*, 193–208. [CrossRef]
63. Sliva, L.; Williams, D.D. Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Res.* **2001**, *35*, 3462–3472. [CrossRef]
64. Petry, J.; Soulsby, C.; Malcolm, I.A.; Youngson, A.E. Hydrological controls on nutrient concentrations and fluxes in agricultural catchments. *Sci. Total Environ.* **2002**, *294*, 95–110. [CrossRef]
65. Yates, A.G.; Brua, R.B.; Corriveau, J.; Culp, J.M.; Chambers, P.A. Seasonality driven variation in spatial relationships between agricultural land use and in-stream nutrient concentrations. *River Res. Appl.* **2014**, *30*, 476–493. [CrossRef]
66. Ali, S.A.; Ahmad, A. Analysing water-borne diseases susceptibility in Kolkata Municipal Corporation using WQI and GIS based Kriging interpolation. *GeoJournal* **2019**, *85*, 1151–1174. [CrossRef]
67. Woli, K.P.; Nagumo, T.; Kuramochi, K.; Hatano, R. Evaluating river water quality through land use analysis and N budget approaches in livestock farming areas. *Sci. Total Environ.* **2004**, *329*, 61–74. [CrossRef]
68. Malik, D.S.; Maurya, P.K.; Kumar, H. Alteration in haematological indices of Heteropneustis fossilis under stress heavy metals pollution in the Kali river, Uttar Pradesh, India. *Int. J. Curr. Res.* **2015**, *7*, 15567–15573.
69. Kumar, A.; Jaiswal, D.; Watal, G. Studies on chemical composition and energy transformation in river Ganga at Kanpur and Varanasi due to environmental degradation. *J. Environ. Biol.* **2009**, *30*, 445–450. [PubMed]
70. Sahu, P.; Sikdar, P.K. Hydrochemical framework of the aquifer in and around East Kolkata wetlands, West Bengal, India. *Environ. Geol.* **2008**, *55*, 823–835. [CrossRef]