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Research Paper

Inland Wetlands' Effects on Groundwater Quality in the Tons-Ghaghara Interfluve

Mohammad Hashim*,
Research Scholar, Department. of Geography, Jamia Millia Islamai, New Delhi, India E-mail-hashim6107@gmail.com (Corresponding author)

Abstract
There is a crucial requirement for ample and high-quality water supplies in order for humanity to exist. When the amount of water begins to decline rapidly, the quality of water becomes critical. Regular quantitative and qualitative monitoring of wetlands and other water sources is essential to promote sustainable development. Water is not only a necessary component of all-natural life, but it is also required for its continuation and upkeep. Water is essential to many social, economic, and physical activities. The water quality of the wetland has an impact on the survival of various different plants and animals. It also has an impact on the environment. As a result, the water quality of 12 wetlands located in the Tons-Ghaghara interfluve ecosystem is examined and measured in this research using the Water Quality Index (WQI). The water samples were graded into five ordinal scales based on WQI indices: excellent, good, poor, extremely poor, and unfit for consumption. A total of 120 water samples were taken, 60 before and 60 after the monsoon season. The eleven physio-chemical parameters of the collected water samples from the wetlands were measured using standard laboratory equipment. The current study found that the water quality in the wetlands ranged from poor to unfit for consumption, and that adding fresh water during the monsoon season only minimally improved the water quality in the study area's wetlands. WQI values ranged from 74.70 to 218.06 (WQI) before the monsoon and from 60.20 to 199.12 (WQI) after the monsoon. Following the wetland water quality study, the impact of wetland water quality on nearby groundwater quality was evaluated. Groundwater quality was evaluated at depths of 40, 80, and 120 feet by combining various physiochemical parameters of groundwater. The quality of groundwater was then graded into five categories: Excellent, Good, Poor, Very Poor, and Unfit for drinking. 80% of the water in the handpump was classified as poor or extremely poor. Only 20% of the water was found to be of good quality, and none was found to be of excellent quality. The current paper serves as the foundation for developing improved management plans for enhancing wetland water quality.
KEYWORDS: -*Inland Wetland, Surface Water, Groundwater, WQI*

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I. Introduction

Wetlands play an important role in achieving the 17 Sustainable Development Goals (SDGs), including (a) responsible consumption and production (SDG 12), (b) life on land (SDG 15), and (c) clean water and sanitation (SDG 16). (SDG 6). Wetlands have a strong interaction with surface and groundwater, affecting watershed hydrology and water quality (Rafie et al., 2022). A wetland is defined by the Ramsar Convention as a fen, peatland, marsh, or area of water, whether constructed or natural, temporary or permanent, static or flowing water, fresh, salt, or brackish, including ocean depths of less than 6 metres at low tide (Roy et al., 2022). Groundwater recharge, silt capture, flood control, nutrient removal, carbon sequestration, biodiversity preservation, and toxic retention are all benefits of wetlands (Bassi, N. 2014; Jain, 2007; Verhoeven, J.T.A., 2006). Wetland plants such as Lemna, Typha, Azolla, Phragmites, and Eichhornia have the potential to detoxify heavy metals (Rai, 2008; Zhang, C. et al., 2016). Furthermore, these bodies of water served economic (forestry, livestock, and fishing), ecological (maintenance of biodiversity, nitrogen cycling, and groundwater recharge), and social (water supply) functions (Ghermandi, A. et al., 2022; Turner, R.K., 2000). Agriculture development, fast industrialisation, and urbanisation have all impacted the management and maintenance of wetlands in recent years (Goyal, V.C. et al., 2022; Prasad, S.N. et al., 2002; Verma, M., 2001).

Water quality, or the suitability of water for a specific use, is a complex subject. It is described as "the physical, chemical, or biological properties of water that the user uses to judge the acceptability of water" (CPCB, 2007). The problem of diminishing water quality is especially troublesome in small bodies of water due to siltation, encroachment, weed infestation, agricultural intensification, and fertiliser and pesticide application. Climate change-induced rising temperatures and changes in rainfall patterns pose yet another potential threat to degraded wetlands (Sinha, 2011; Verma, 2001). According to the Ramsar Sites Information Service (RSIS), agricultural pressure destroyed 50% of wetlands in 2019. (Courouble et al., 2021; Rafie et al., 2022). Wetlands are becoming increasingly endangered around the world, and restoring those biodiverse ecosystems is vital to regaining the health of lost services (Bentley et al., 2022).Similarly, built-up regions had a considerable impact on water quality due to pollution from E. coli, total coliform, EC, BOD, COD, TSS, Hg, Zn, and Fe. (Hua A.K. 2017). A diverse set of human and environmental variables from various locales suggests a site-specific relationship between LULC alteration and water supplies. Changes in LULC are a significant component behind changes in hydrological systems that create differences in runoff, such as peak flow frequency, discharge volume, and water quality. T.M. James, 2020.There are numerous methods for studying water quality. The quantification of water quality in terms of the Water Quality Index (WQI), which is more widespread and widely utilised in research, is one of them. Ustaglu tried to create a water quality index (WQI) by combining temperature, pH, conductivity, total dissolved solids, suspended particles, salinity, oxidation-reduction potential, alkalinity, and total hardness (Ustaglu et al. 2019). The National Sanitation Foundation Water Quality Index (NSF-WQI) was used to assess the anthropogenic alterations in Lake Muhazi, Rwanda. (E.D. Umwali et al.2021).

Tons-Ghaghara interfluve region is a densely inhabited area in the country and is part of the Indo-Gangetic plane. Favored terrain, such as plains, fertile land, and the availability of sufficient water, has altered land-use and land-cover patterns. Rapid urbanisation has resulted in a deterioration of surface water quality. In many parts of India, the quality of wetlands has been assessed using various physio-chemical analyses (Jindal and Sharma 2010; Chauhan and Sagar 2013; Sharma et al. 2013; Amin A et al. 2014; Bhat S A and Pandit A K (2014); Rupali 2014; Brraich and Saini 2015; Ajayan A and Kumar AKG (2016); Deepa P et al. 2016; Dubey M et al. 2016 However, to the best of our knowledge, no report on the water quality state of wetlands in the Tons-Ghaghara interfluve zone is available. As a result, the purpose of this research is to investigate the physio-chemical properties of inland wetlands and to determine how wetland water quality impacts groundwater quality.

II. Study area

The study area, Tons-Ghaghara interfluves, lies in Eastern Uttar Pradesh, about 24° 30' N latitude and 84° E longitude (Fig 1) and is a part of the Indo-Gangetic plain. The area encompasses the Ambedkar Nagar, Azamgarh, Mau, and Ballia districts. The ultimate point of Ghaghara and Tons' discharge into the Ganga River lies on the southeast side of the interfluves. All rivers flow mostly from northwest to southeast, which is the typical ground surface slope. Another river that travels through the middle of the district, across the Bhiti, Katehri, Akbarpur, Jalalpur, and Bhiyaon Blocks, is the Tons River, a tributary of the Ghaghara.

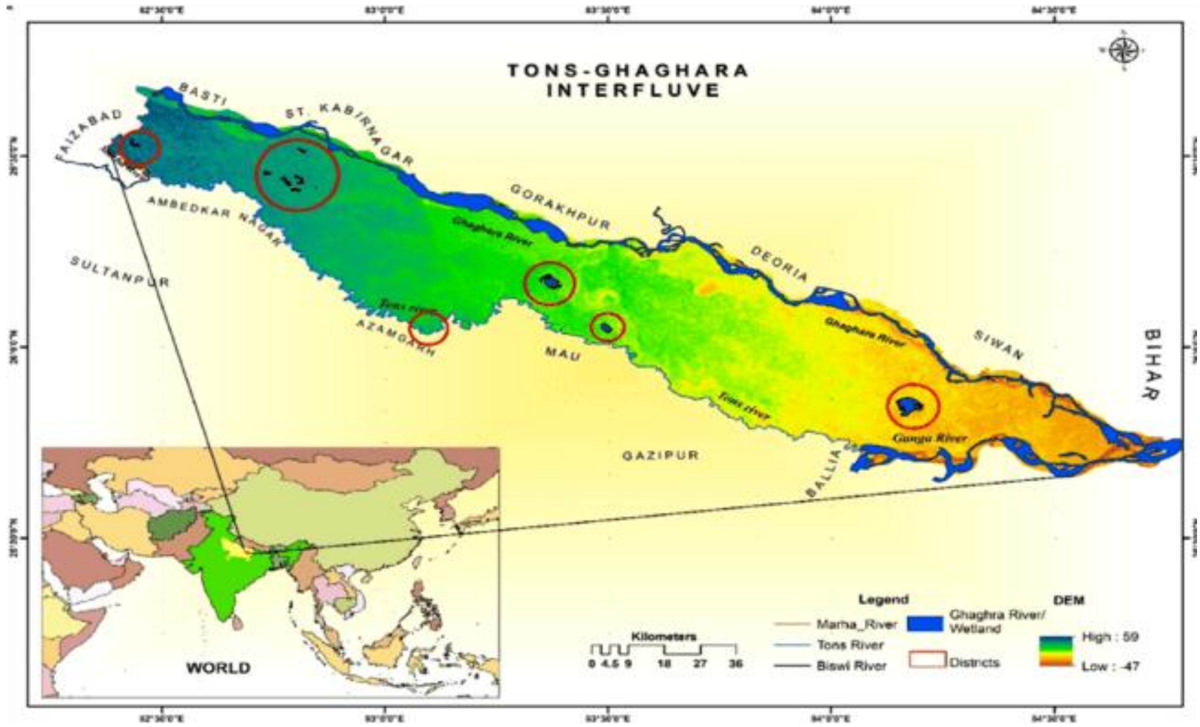

Figure 1 Study Area

Table 1 Detail of Selected wetlands

S.No	Name of Wetlands	Type of wetlands	District	Latitude	Longitude	Area (ha.)
1	Bukiya and Sandha wetland	Ox-bow Lake/cut-off meanders	Ambedkar Nagar	26.4283816	82.81070708	118.06
2	Darwan wetland	Lake/ponds	Ambedkar Nagar	26.53233705	82.4317937	118.22
3	Garha wetland	Ox-bow Lake/cut-off meanders	Ambedkar Nagar	26.40827375	82.8079847	71.31
4	Gaira wetland	Lake/ponds	Ambedkar Nagar	26.51429871	82.82096928	58.23
5	Darul Aman wetland	Ox-bow Lake/cut-off meanders	Ambedkar Nagar	26.44028343	82.76754548	106.02
6	Banaul wetland	Ox-bow Lake/cut-off meanders	Ambedkar Nagar	26.45251468	82.73256114	66.56
7	Sheotara wetland	Waterlogged	Ambedkar Nagar	26.41707629	82.84379514	2.95
8	Hanumangari wetland	Waterlogged	Azamgarh	26.06819625	83.17727255	1.15
9	Radopur wetland	Waterlogged	Azamgarh	26.06042325	83.18950548	1.38
10	Salona wetland	Lake/ponds	Azamgarh	26.15669917	83.37155596	745.7
11	Suraha wetland	Lake/ponds	Ballia	25.82540474	84.15904389	1669.58
12	Fatehpur Narja wetland	Lake/ponds	Mau	26.05074259	83.5039865	362.59

Wetlands are classified into three types: lake/pond, Ox-bow Lake/Cut off Menders, and waterlogged. The majority of the wetland's area is taken up by Ox-bow Lake and the cut-off meanders on the Indo-Gangetic plain. A set of Survey of India (SOI) toposheets were used to demarcate the principal wetlands in this region for mapping (2010). Wetlands were covered in Darwan, Bukiya&Sandha, Garha, Gaira, Darul Aman, Banaul, Sheotara, Hanumangari, Radopur, Salona, and Suraha. Among these wetlands are the Suraha andGarha wetlands, which are also Ramsar sites.

III. Data Source and Methodology

This study's approach is divided into three sections. The first is a physio-chemical investigation of the wetland, followed by an evaluation of the wetland water quality, and finally, an assessment of the impact of wetland quality on groundwater quality.

3.1 Physio-chemical analysis of wetland

The physio-chemical examination of all selected wetlands was carried out at this stage. Water samples were obtained from each marsh for this purpose. Five water samples were collected from each wetland throughout the pre- and post-monsoon seasons. In total, 120 water samples were collected, 60 during the pre-monsoon season (March 2022) and 60 during the post-monsoon season (November 2021). The acquired water samples were tested for the various water quality standards using standard laboratory procedures. pH, total dissolved solids (TDS), calcium, magnesium, total hardness, fluorine, chlorine, electrical conductivity, turbidity, nitrate (NO3), and sulphate are examples of these (SO4).

3.2 Water quality monitoring of wetland

1.1 The water quality index assigns a numerical value to the overall quality of the water. It is oneof the most useful indexes for water quality management decision-makers. The WQI wascalculated using the "weighted arithmetic index technique" (Brown et al. 1970). The WQIwas built using eleven water quality indicators (WQIs): pH, total dissolved solids (TDS),calcium, magnesium, total hardness, fluorine, chlorine, electrical conductivity, turbidity,nitrate (NO3), nd sulphate (SO4).

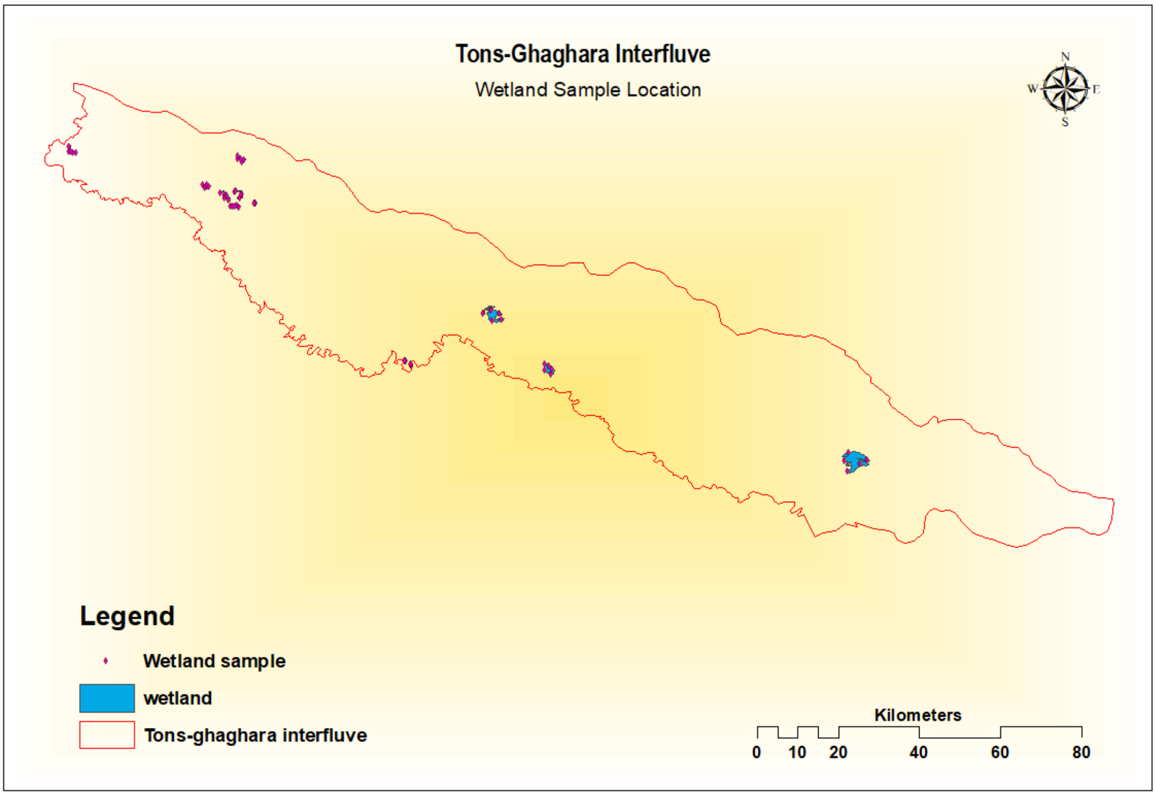

Figure 2Wetland Sample Collection Sites

In the laboratory, the amount of each water quality parameter was determined. The water quality index (WQI) for each selected wetland was determined using the following equation (Eq. 1) for both the pre-monsoon and post-monsoon seasons:

\ $$WQI = \frac{\sum_{n}^{n} + 1QnWn}{\sum Wn} \quad (1)$$

where Qn is the quality rating of the nth water quality parameter and Wn is the unit weight of the nth water quality parameter

Except for pH, each parameter's quality rating Qn was calculated by multiplying the observed value by the relevant standard. The outcome was then multiplied by 100, as illustrated in the equation (Eq. 2):

$$Qn = \frac{(\mathrm{Vn} - \mathrm{Vi})}{(\mathrm{Vs} - \mathrm{Vi})} \times 100 \quad (2)$$

Vi is the parameter's ideal value (Vi = 0), with the exception of pH (Vi = 7), and Vs is the recommended standard value for the nth water quality parameter. Vn is the parameter's measured value. The unit weight (Wn) for each water quality parameter has been established using the following equation (Eq. 3):

$$Wn = \frac{K}{Sn} \quad (3)$$

When Wn is the unit weight and Sn is the greatest value that may be used for the nth parameter, the proportionality constant K and its formula are written as (Eq. 4)

$$K = \frac{1}{\sum\left(\frac{1}{Sn}\right)} \quad (4)$$

Following that, the water quality of the twelve wetlands was evaluated using specific metrics. The Water Quality Index (WQI) was used to assess water quality, which was rated as excellent (0-25), good (26-50), bad (51-75), extremely poor (75-100), and unfit for consumption (> 100). Because the water quality of wetlands is affected by a variety of factors, a correlation matrix for all of the selected water quality metrics with WQI was created for the pre-monsoon and post-monsoon seasons. The correlation matrix explained the relationship between several parameters as well as the relationship between WQI and different parameters.

3.3 Impact assessment of wetland water quality on the groundwater quality

The impact of wetland quality on groundwater quality was determined in the study's last section. This impact evaluation was carried out in the wetlands' adjacent region. The same method used to calculate WQI for wetlands was also used to calculate groundwater WQI for groundwater quality evaluation. Groundwater samples were collected at 40 feet, 80 feet, and 120 feet below the handpump (Fig 2). A total of 20 groundwater samples were collected (Fig 4). Water samples were obtained between 10 and 2000 metres distant from the wetland. The WQI of groundwater was calculated using the pH, TDS, calcium, magnesium, total hardness, fluorine, chorine, electrical conductivity, turbidity, nitrate, and sulphate parameters. In order to determine the amount of each characteristic present in water samples, different laboratory techniques were utilized.

IV. Results and Discussion

4.1 Physio-chemical Analysis of Wetlands

The following are the water quality characteristics of each selected wetland with various parameters:

4.1.1 Bukiya & Sandha wetland

There are four parameters. During the pre-monsoon season, magnesium, total hardness, electrical conductivity, and turbidity were found to be above the allowed range of BIS with values of 41 mg/l (BIS value = 30 mg/l), 325 mg/l (BIS = 200 mg/l), 938 S (BIS = 300 S), and 25 NTU (BIS = 5 NTU) (Table 2). Three indicators were found to be extremely high in the post-monsoon season: magnesium (36 mg/l), electrical conductivity (941 S), and turbidity (22 NTU). Post-monsoon values for all parameters were lower than pre-monsoon values. The pH value was determined to be in the BIS range (6.5-8.5), with values of 6.6 and 7.01 during the pre- and post-monsoon seasons, respectively. TDS levels increased from 123 mg/l before the monsoon to 149 mg/l after the monsoon, which is less than the BIS value of 500 mg/l. Calcium levels were found to be 38 mg/l in the pre-monsoon season and 35 mg/l in the post-monsoon season.

4.1.2 Darwan wetland

During the pre-monsoon and post-monsoon seasons, pH was measured at 6.8 and 7.1, respectively, within the range of 6.6 to 7.01. (BIS standard). TDS, chlorine, fluorine, calcium, nitrate, and sulphate levels were low in the pre-monsoon season, with values of 193 mg/l, 25 mg/l, 0.31 mg/l, 49 mg/l, 17 mg/l, and 7.3 mg/l, respectively. Wetlands were more effective in removing nitrates, conductivity, chloride, and other pollutants during low flow periods (Carol A. et al.1990). During the pre-monsoon season, however, magnesium (35 mg/l), electrical conductivity (937 S), total hardness (336 mg/l), and turbidity (39 NTU) were found to be at high levels. The electrical conductivity was more than twice the standard BIS value (300 S). The value for turbidity was extremely high. It was around eight times greater than the BIS benchmark (5 NTU). The TDS value increased to 234 mg/l during the post-monsoon season, and the electrical conductivity was 957 S. During both seasons, high turbidity and electrical conductivity were measured (Table 2).

Table 2 *Physio-chemical values (average) of selected water quality parameters*

S.NO	Name of Wetlands	District	latitude	longitude	BIS Standard Value	PH	TDS (mg/l)		Calcium (mg/l)		Magnesium (mg/l)		Total Hardness (mg/l)		Fluorine(F) (mg/l)		Chlorine (CL) (mg/l)		Conductivity (mg/l)		Turbidity (NTU)		Nitrate NO3 (mg/l)		Sulphate SO4 (mg/l)	
					6.5-8.5		500		75		30		200		1		250		300		5		45		200	
					Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	Bukiya & Sandha wetland	Ambedkar Nagar	26.42838	82.81071	6.6	7.01	123	149	38	35	41	36	325	294	0.22	0.21	31	23	938	941	25	22	16	18	8.1	7.26
2	Darwan wetland	Ambedkar Nagar	26.53234	82.43179	6.8	7.21	193	234	49	42	35	33	336	248	0.31	0.24	25	20	937	957	39	31	17	15	7.3	6.8
3	Garha wetland	Ambedkar Nagar	26.40827	82.80798	6.73	7.86	137	160	47	46	46	41	302	256	0.26	0.21	33	31	897	847	35	29	17	16	6.45	7.2
4	Gaira wetland	Ambedkar Nagar	26.5143	82.82097	6.62	7.36	210	271	36	44	54	52	251	238	0.34	0.3	28	22	896	871	38	24	18	15	6.95	7.17
5	Darul aman wetland	Ambedkar Nagar	26.44028	82.76755	6.43	7.54	212	354	27	38	40	33	300	287	0.39	0.36	34	30	613	534	42	30	16	11	7.55	6.79
6	Banaul wetland	Ambedkar Nagar	26.45251	82.73256	6.72	7.1	214	174	52	46	44	39	234	215	0.27	0.24	27	26	758	710	35	26	14	13	6.28	5.84
7	Sheotara wetland	Ambedkar Nagar	26.41708	82.8438	6.29	7.82	122	311	34	34	63	64	361	321	0.4	0.37	37	35	741	688	55	41	21	20	9.5	8.25
8	Hanuman gari wetland	Azamgarh	26.0682	83.17727	6.77	6.96	372	309	25	27	71	55	399	384	0.5	0.45	64	56	1026	724	60	53	32	30	24.01	15.2
9	Radopur wetland	Azamgarh	26.06042	83.18951	6.68	7.47	365	378	21	30	54	50	321	298	0.51	0.47	56	52	958	714	62	55	33	29	22.25	16.4
10	Salona wetland	Azamgarh	26.1567	83.37156	6.6	7.3	160	149	44	42	51	37	520	443	0.43	0.42	35	29	641	594	31	29	15	19	11.6	8.9
11	Suraha taal	Ballia	25.8254	84.15904	6.23	7.14	61	70	59	67	34	28	202	184	0.45	0.34	24	15	456	420	15	11	6	8	5.6	7.4
12	Fatehpur Narja wetland	Mau	26.05074	83.50399	6.68	7.46	242	174	39	25	59	55	295	264	0.31	0.28	34	28	536	451	24	17	21	15	10.1	8.6

4.1.3 Garha wetland

This wetland's pre- and post-monsoon pH levels were 6.73 and 7.86, respectively. The results were within the BIS-recommended pH range (6.5-8.5). The calcium concentration was found to be nearly equal in both seasons, at 46 mg/l. TDS was measured at 137 mg/l during the pre-monsoon season and 160 mg/l during the post-monsoon season. Both TDS measurements were determined to be less than the 500 mg/l BIS recommendation range. The hardness concentration was 302 mg/l during the pre-monsoon and 256 mg/l during the post-monsoon seasons, respectively. Both values exceeded the BIS's overall hardness criterion of 200 mg/l. Magnesium concentrations were higher than the BIS limit of 30 mg/l in both seasons, reaching 46 mg/l prior to the monsoon and 41 mg/l afterward. Pre- and post-monsoon fluorine content values were 0.26 mg/l and 0.21 mg/l, respectively (Table 2). There were extremely low calcium traces in the post-monsoon. High electrical conductivity was measured as 897 S in the pre-monsoon season and 847 S in the post-monsoon season. The Garha wetland recorded unusually high turbidity measurements of 35 NTU and 29, respectively, during the pre-monsoon and post-monsoon seasons.

4.1.4 Gaira Wetland

This wetland has a higher TDS level than the wetlands in Bukiya&Sandha, Darwan, and Garha. Pre-monsoon levels were 210 mg/l, but post-monsoon levels were 271 mg/l. There was a lot of turbidity, a lot of electrical conductivity, and a lot of magnesium. They were 54 mg/l (BIS = 30 mg/l), 896 S (BIS = 300 S), and 38 NTU (BIS = 5 NTU) in the pre-monsoon season, and 52 mg/l (BIS = 30 mg/l), 871 S (BIS = 300 S), and 24 NTU (BIS = 5 NTU) in the post-monsoon season, respectively (Table 2). In both seasons, fluorine, chlorine, nitrate, and sulphate concentrations were found to be acceptable. During the pre-monsoon season, extremely small levels of sulphate (6.95 mg/l) and chlorine (28 mg/l) were detected in the wetland's water.

4.1.5 Darul Aman Wetland

This wetland's pre- and post-monsoon pH levels were 6.43 and 7.54, respectively (Table 2). TDS levels were 212 mg/l before the monsoon and 354 mg/l afterward. The pre-monsoon calcium concentration was 27 mg/l, while the post-monsoon calcium concentration was 38 mg/l, both of which were below the calcium acceptable limit (BIS = 75 mg/l). The magnesium level in the Darul Aman wetland was 40 mg/l in the pre-monsoon season and 33 mg/l in the post-monsoon season, both of which were greater than the BIS standard (30 mg/l). The overall hardness was also found to be higher than the BIS standard value (200 mg/l). It was 300 mg/l in the pre-monsoon and 287 mg/l in the post-monsoon, respectively. The water in the marsh had extraordinarily high levels of electrical conductivity and turbidity. The electrical conductivity level was 613 S during the pre-monsoon season and 534 S during the post-monsoon season, which was more than twice the BIS standard (300 S). Pre-monsoon turbidity was 42 NTU, and post-monsoon turbidity was 30 NTU. Turbidity was eight times greater in the pre-monsoon and six times higher in the post-monsoon compared to the BIS standard value (5 NTU).

4.1.6 Banaul wetland

The pH variation in this wetland was found to be quite modest during the pre and post-monsoon seasons. It was 6.72 before the monsoon and 7.1 thereafter. TDS, calcium, fluorine, chlorine, nitrate, and sulphate concentrations were all within normal limits (BIS standard). The magnesium level was higher than the BIS value (30 mg/l) in pre-monsoon and post-monsoon, at 44 mg/l and 39 mg/l, respectively. Total hardness was also found to be higher than 200 mg/l (BIS) during the pre-monsoon and post-monsoon seasons, with values of 234 mg/l and 215 mg/l, respectively. Pre-monsoon electrical conductivity was 758 S and post-monsoon electrical conductivity was 710 S. Turbidity was also exceptionally high, with a pre-monsoon value of 35 NTU and a post-monsoon value of 26 NTU (Table 2).

4.1.7 Sheotara wetland

In the pre-monsoon season, the pH in this wetland was 6.29, while in the post-monsoon season, it was 7.82. TDS, on the other hand, was measured in the medium range for both seasons. Similarly, magnesium concentrations in the pre-monsoon season were 63 mg/l and 64 mg/l in the post-monsoon season. The magnesium concentration was more than double the BIS threshold of 30 mg/l (Table 2). The water in the wetland included trace amounts of chlorine and sulphate (Table 2). During both seasons, electrical conductivity and turbidity were extremely high. Pre-monsoon electrical conductivity was 741 S and post-monsoon electrical conductivity was 688 S. Turbidity was measured at 55 NTU and 41 NTU during the pre- and post-monsoon seasons, respectively, much exceeding the BIS standard of 5 NTU.

4.1.8 Hanuman Gari wetland

During both seasons, this wetland had extremely high levels of magnesium, total hardness, electrical conductivity, and turbidity. However, during the post-monsoon season, the concentration of these parameters was lower (Table 2). The highest electrical conductivity was reported in the pre-monsoon season at 1026 S, which decreased to 724 S in the post-monsoon season. TDS levels were greater in the pre-monsoon season, reaching 372 mg/l. The pre-monsoon sulphate concentration was higher (24.01 mg/l) than the post-monsoon concentration (15.2 mg/l), however this was within the BIS limit (200 mg/l). During both seasons, the average nitrate level was found to be 31 mg/l, which was less than the BIS threshold of 45 mg/l. Again, very high turbidity was measured, with a pre-monsoon value of 60 NTU and a post-monsoon season value of 53 NTU.

4.1.9 Radopur wetland

The pH was determined to be 6.68 during the pre-monsoon season and 7.47 during the post-monsoon season. The wetland exhibited unusually high levels of magnesium (54 mg/l & 50 mg/l), total hardness (321 mg/l & 298 mg/l), electrical conductivity (958 S & 714 S), and turbidity (62 NTU & 55 NTU) during the pre-monsoon and post-monsoon seasons, respectively. Similarly, compared to the post-monsoon season, chlorine, fluorine, nitrate, and sulphate levels were greater during the pre-monsoon season, with values of 56 mg/l, 0.51 mg/l, 33 mg/l, and 22.25 mg/l, respectively. Turbidity was twelve times higher in the pre-monsoon season and eleven times higher in the post-monsoon season (Table 2).

4.1.10 Salona wetland

The pH in this marsh was within the BIS range (6.5-8.5). The pre-monsoon value was 6.6, and the post-monsoon value was 7.3. TDS levels were detected at 160 mg/l and 149 mg/l during the pre- and post-monsoon seasons, respectively. These levels were lower than the BIS standard of 500 mg/l. Pre-monsoon calcium concentration was 44 mg/l and post-monsoon calcium concentration was 42 mg/l. During the pre-monsoon and post-monsoon seasons, magnesium concentrations were found to be greater, with values of 51 mg/l and 37 mg/l, respectively. The magnesium levels exceeded the BIS limit of 30 mg/l. Fluorine (pre-monsoon = 0.43 mg/l & post-monsoon = 0.42 mg/l), chlorine (35 mg/l & 29 mg/l), nitrate (15 mg/l & 19 mg/l), and sulphate (11.6 mg/l & 8.9 mg/l) were discovered to be less than the BIS levels (Table 2). Electrical conductivity was twice the BIS standard of 300 S for both seasons.

4.1.11 Suraha wetland

During the pre-monsoon and post-monsoon seasons, the pH in this wetland was 6.23 and 7.14, respectively. All other physio-chemical metrics for the Suraha wetland were lower than for the other wetland. TDS levels were very low, with pre-monsoon values of 61 mg/l and post-monsoon values of 70 mg/l. Similarly, pre-monsoon calcium concentrations were 59 mg/l and post-monsoon calcium concentrations were 67 mg/l. The magnesium concentration (34 mg/l) was higher than the BIS limit of 30 mg/l during the pre-monsoon season. During the post-monsoon, however, it was at 28 mg/l. The total hardness was close to the BIS threshold of 200 mg/l. During both seasons, the water in the Suraha wetland contained extremely little fluorine, chlorine, nitrate, and sulphate (Table 2). Electrical conductivity and turbidity were found to be relatively low. Pre-monsoon electrical conductivity was 456 S, with a slight improvement to 420 S during the post-monsoon season. Lower

EC values are most likely owing to enhanced plant nitrogen absorption in the control watershed. Similarly, greater fertilisation in suburban areas could be a significant cause (Henderson, L., 2014). During the pre- and post-monsoon periods, the turbidity levels were 15 NTU and 11 NTU, respectively.

4.1.12Fatehpur Narja wetland

The concentrations of TDS, calcium, fluorine, chlorine, nitrate, and sulphate were all within the BIS value range (Table 2). TDS was less than 200 mg/l over both seasons (far below the BIS of 500 mg/l). During the pre-monsoon and post-monsoon seasons, calcium levels were 39 mg/l and 25 mg/l, respectively. Pre- and post-monsoon magnesium levels, electrical conductivity, and turbidity were all quite high. However, their concentration was higher during the pre-monsoon season. The magnesium concentration fluctuated from 59 mg/l before the monsoon to 55 mg/l after the monsoon. Electrical conductivity was 536 S during the pre-monsoon season and 451 S after the monsoon season. Similarly, in the pre- and post-monsoon seasons, turbidity was 24 NTU (BIS = 5 NTU) and 17 NTU, respectively. Total hardness concentration was found to be high during both seasons, measuring 295 mg/l (BIS = 200 mg/l) in pre-monsoon and 264 mg/l in post-monsoon.

Figures 3 (pre-monsoon) and 5 summarise the range of all parameters for all wetlands (post-monsoon). Following the measurement of all physio-chemical parameters in the wetland, interpolation was performed in the Ton-Ghaghara Interfluve to determine the impact of water quality in the surrounding area (figure 5). In addition, the distribution density of all the selected parameters was calculated by integrating the data from all the wetlands to examine its distribution pattern during pre-monsoon (figure 6) and post-monsoon (figure 7).

4.2 Water Quality of Wetlands (WQI)

There was also a variation in the water quality of wetlands throughout the pre- and post-monsoon seasons (Table 3 and Fig 10). During the pre-monsoon season, the wetlands were discovered to be in very poor and unfit for consumption condition. Three wetlands, Bukiya, Suraha, and Fatehpur Narja, were classified as very poor, with WQIs of 90.02, 74.70, and 95.34, respectively. The WQI for these three wetlands was less than 100. Wetlands in Darwan, Garha, Gaira, Darulaman, Banaul, Sheotara, Hanumangari, Radopur, and Salona were unfit for consumption, with WQIs surpassing 100 as 137.15, 122.58, 136.71, 149.14, 122.88, 188.31, 213.65, 218.06 and 122.84, respectively (Table 3). Radopur Wetland has the poorest water quality (WQI of 218.06). Suraha wetland had the best water quality (WQI of 74.70). Hanumangari and Radopur had the worst WQI, which was higher than 200 in both cases. During the pre-monsoon season, seven wetlands had WQIs ranging from 100 to 200. 137.15, 122.53, 136.71, 149.14, 122.88, 188.31, and 122.84.

During the post-monsoon season, four wetlands, Bukiya, Gaira, Banaul, and Fatehpur Narja, were assigned a WQI of 82.66, 97.93, 96.66, and 76.79, respectively. Suraha Wetland was the only one in the poor category, with a WQI of 60.20 and the best water quality. Seven wetlands were identified as unfit for consumption because their WQI value exceeded 100. (Table 3). WQIs for Darwan, Garha, Darulaman, Sheotara, Hanumangari, Radopur, and Salona were 111.30, 107.72, 118.39, 154.86, 189.60, 199.12, and 119.23, respectively. Radopur wetland has the highest WQI value of 199.12, indicating the poorest water quality.

Pre-Monsoon

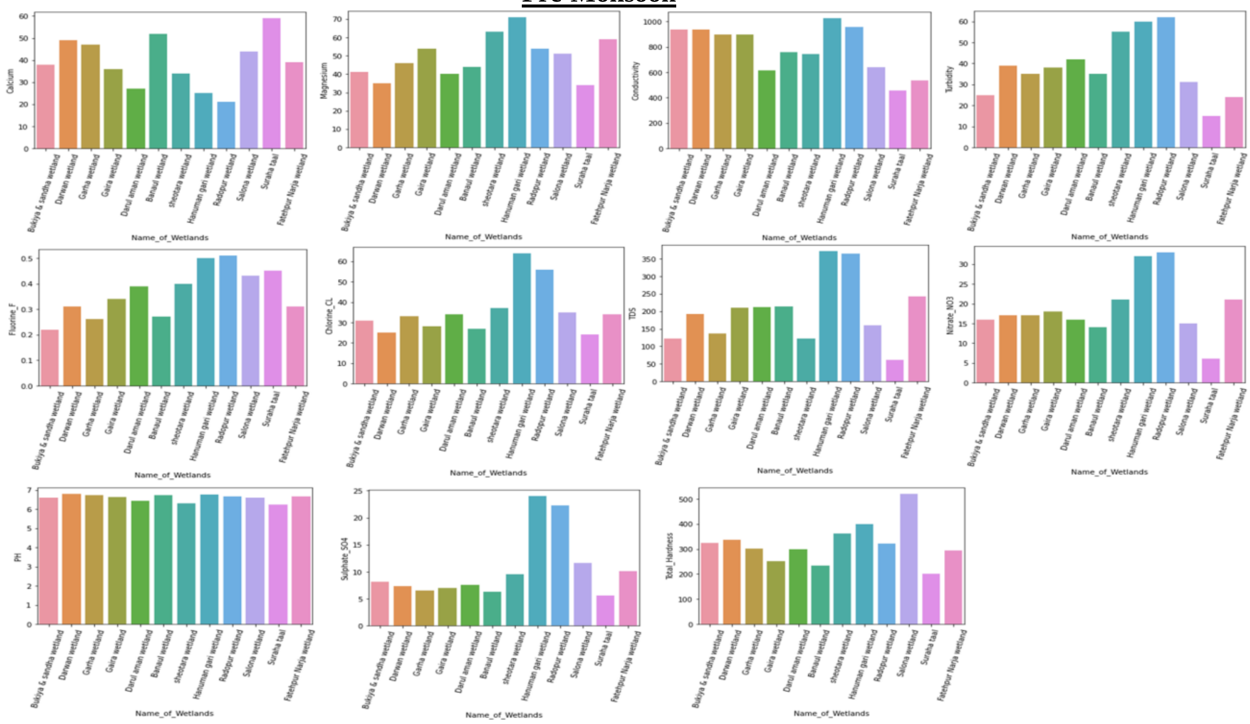

Figure 3Status of physio-chemical parametersin wetlands during pre-monsoon season

Post-Monsoon

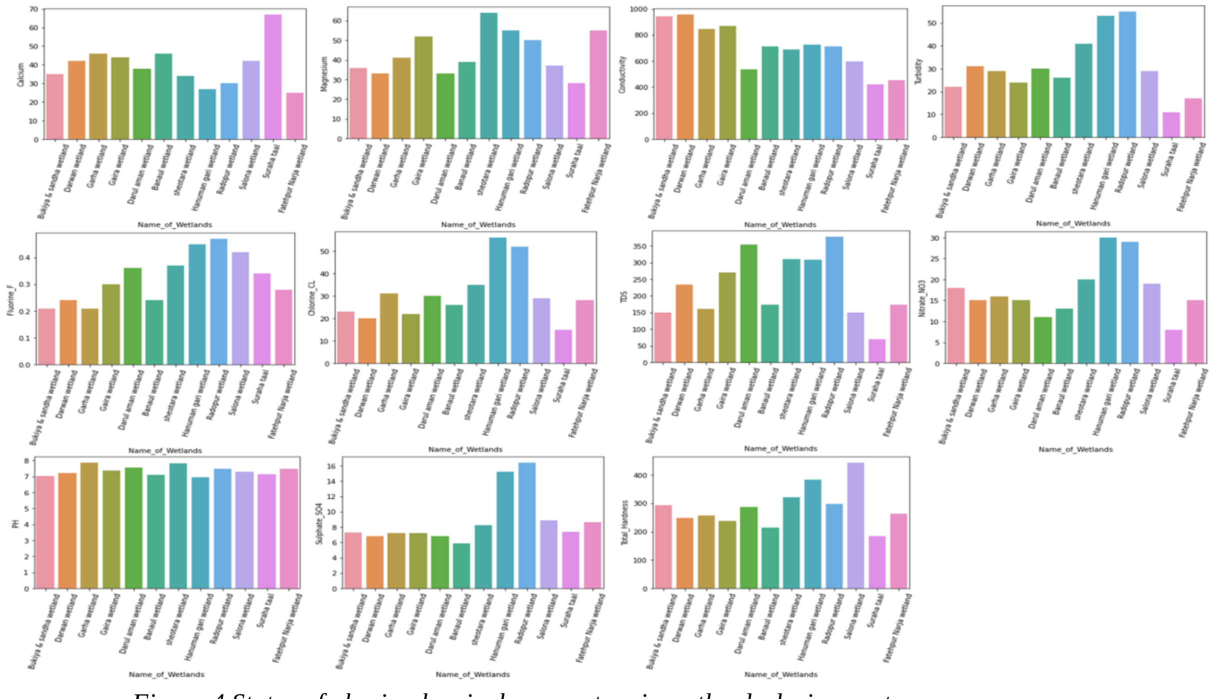

Figure 4 Status of physio-chemical parameters in wetlands during post-monsoon season

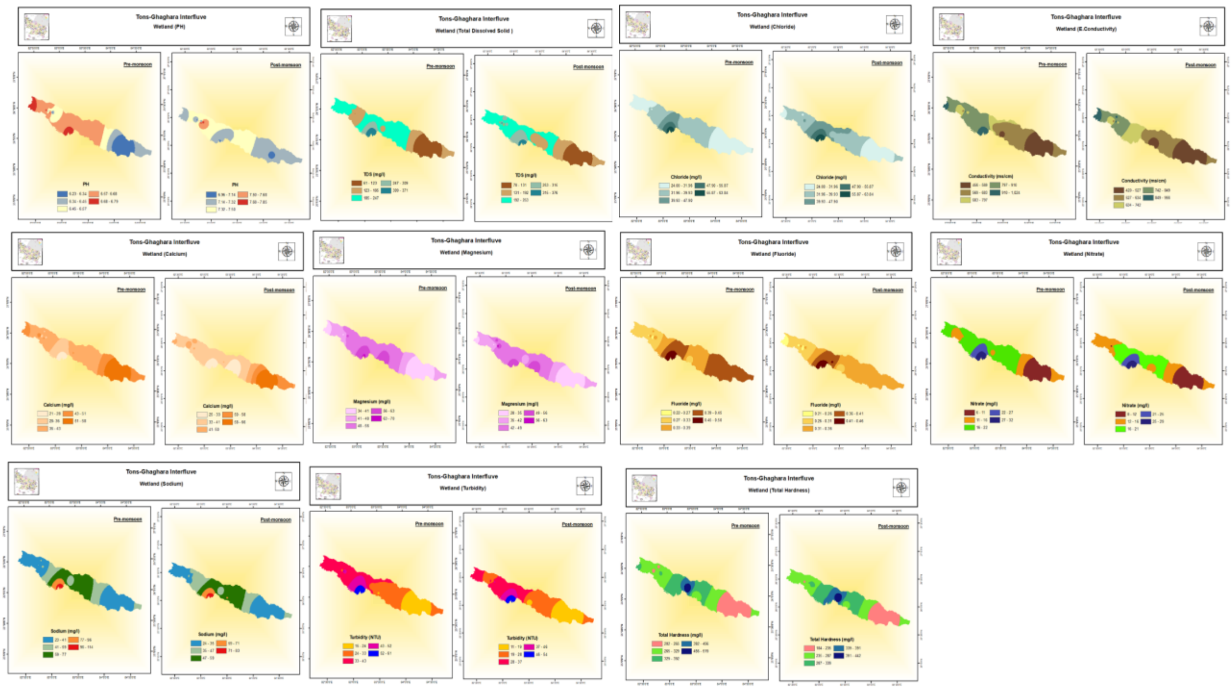

Figure 5 Interpolation of physio-chemical parameters in Tons-Ghaghara Interfluve

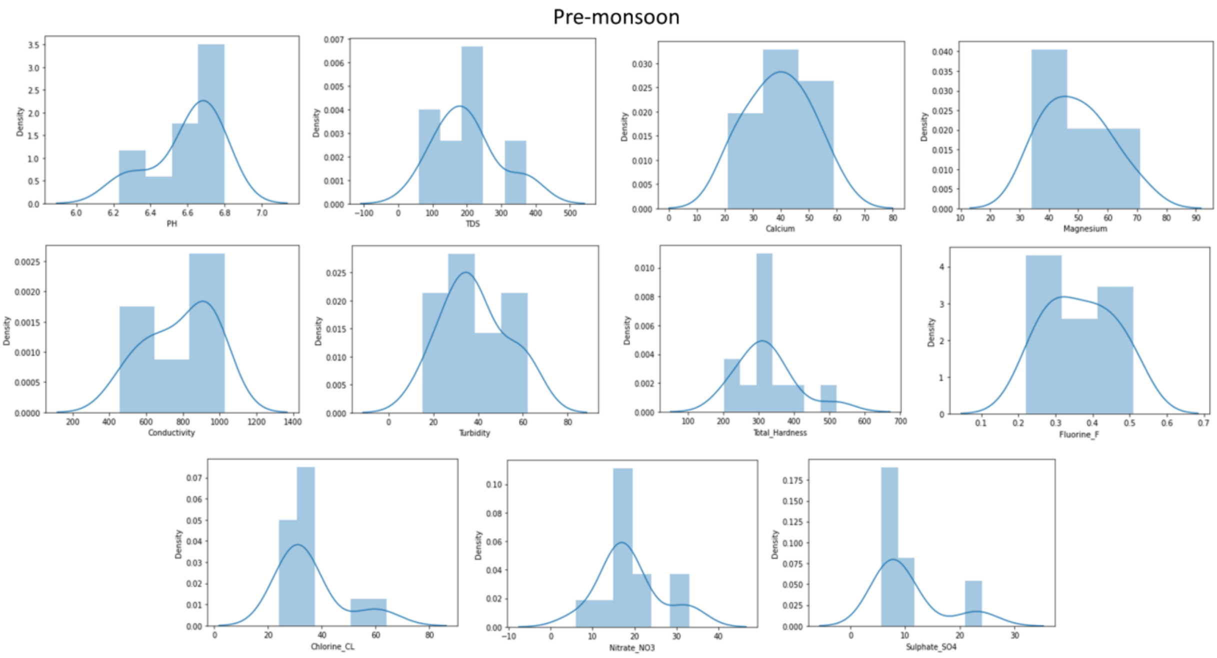

Figure 6 Density distribution of Physio-chemical parameters in all wetlands in pre-monsoon

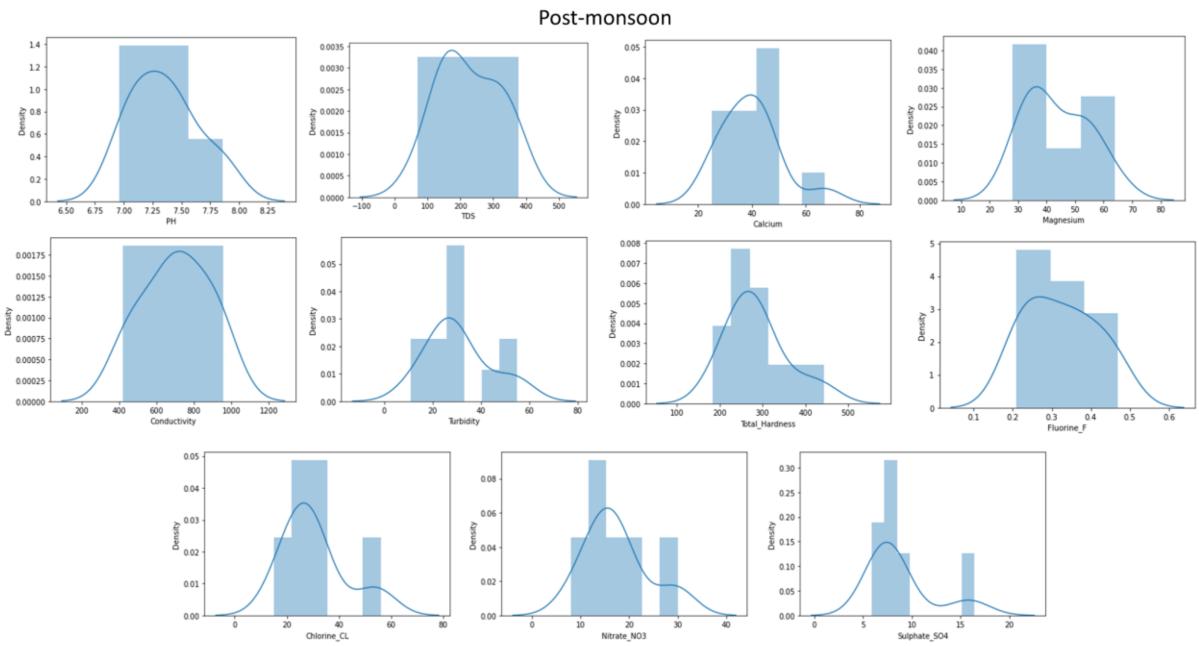

Figure 7 Density distribution of Physio-chemical parameters in all wetlands in post-monsoon

Table 3 WQI of wetlands during pre-monsoon & post-monsoon season

Sl. No.	Name of Wetlands	latitude	longitude	Pre-Monsoon		Post-Monsoon	
				WQI	Water Quality Status	WQI	Water Quality Status
1	Bukiya& Sandha wetland	26.4283816	82.81070708	90.02	Very Poor	82.66	Very Poor
2	Darwan wetland	26.53233705	82.4317937	137.15	Unfit for Consumption	111.30	Unfit for Consumption
3	Garha wetland	26.40827375	82.8079847	122.58	Unfit for Consumption	107.72	Unfit for Consumption
4	Gaira wetland	26.51429871	82.82096928	136.71	Unfit for Consumption	97.93	Very Poor
5	Darul Aman wetland	26.44028343	82.76754548	149.14	Unfit for Consumption	118.39	Unfit for Consumption
6	Banaul wetland	26.45251468	82.73256114	122.88	Unfit for Consumption	96.66	Very Poor
7	Sheotara wetland	26.41707629	82.84379514	188.31	Unfit for Consumption	154.86	Unfit for Consumption
8	Hanumangari wetland	26.06819625	83.17727255	213.65	Unfit for Consumption	189.60	Unfit for Consumption
9	Radopur wetland	26.06042325	83.18950548	218.06	Unfit for Consumption	199.12	Unfit for Consumption
10	Salona wetland	26.15669917	83.37155596	122.84	Unfit for Consumption	119.23	Unfit for Consumption
11	Suraha wetland	25.82540474	84.15904389	74.70	Very Poor	60.20	Poor
12	Fatehpur Narja wetland	26.05074259	83.5039865	95.34	Very Poor	76.79	Very Poor

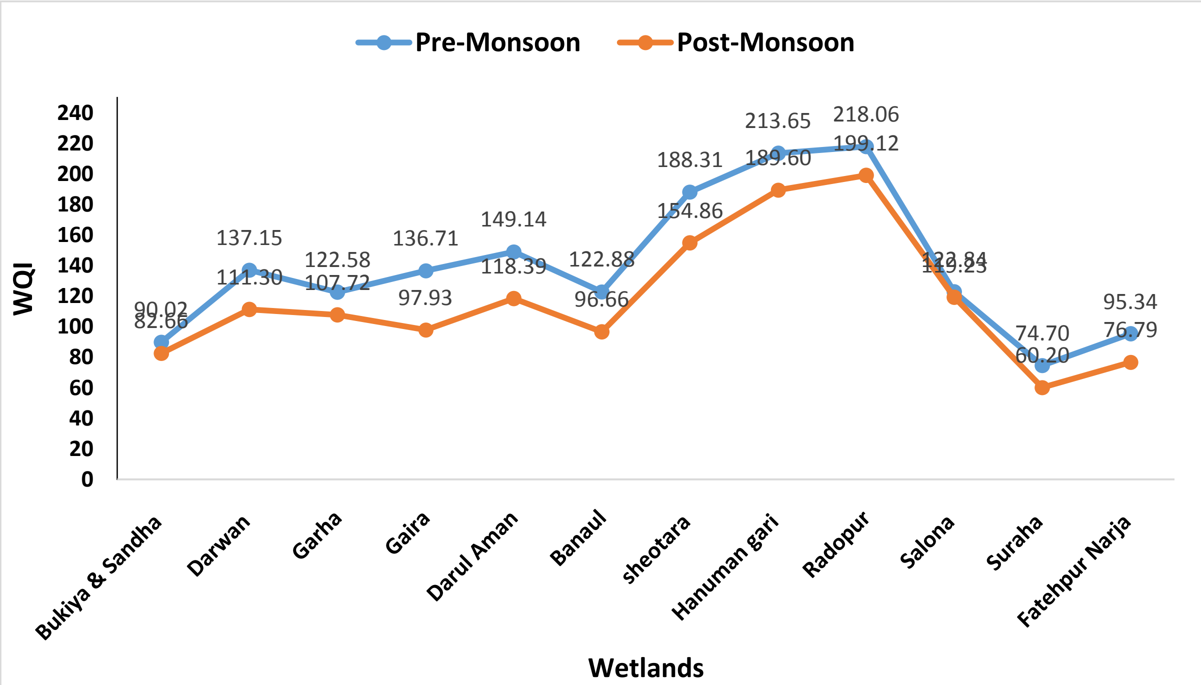

Figure 8 WQI of wetlands during pre-monsoon and post-monsoon season

The pre-monsoon WQI value ranged from 74.70 to 218.06 (WQI) while the post-monsoon WQI value ranged from 60.20 to 199.12 (WQI). The difference between the highest (218.06, Radopur wetland) and the minimum (74.70, Suraha wetland) was 143.36 in the pre-monsoon and 138.92 in the post-monsoon, as the maximum and minimum for Radopur and Suraha wetland were 199.12 and 60.20, respectively. There were no wetlands in the poor category detected during the pre-monsoon, but one (Suraha wetland with a WQI of 60.20) was located during the post-monsoon. Radopur wetland had the poorest water quality during the pre- and post-monsoon seasons, with WQIs of 218.06 and 199.12, respectively. Suraha wetland was rated as extremely bad (WQI = 74.70) during the pre-monsoon season and poor (60.20) during the post-monsoon season. As a result of the inflow of fresh water, the wetland's water quality increased throughout the post-monsoon season.

The WQI value for two wetlands was determined to be greater than 200, at 213.65 (Hanumangari) and 218.06 (Hanumangari) (Radopur). During the post-monsoon, however, WQI was never higher than 200 in the study area. Five wetlands had WQI values less than 100 in the post-monsoon period: Bukia and Sandha (WQI = 82.66), Gaira (97.93), Banaul (96.66), Suraha (60.20), and Fatehpur Narja (76.90). Three wetlands, notably Sheotara, Hanuman Gari, and Radopur, were the most degraded, having the poorest water quality for both seasons. During the post-monsoon season, their quality improved slightly.

The correlation matrix for all selected water quality measures during the pre-monsoon (Table 4) and post-monsoon (Table 5) seasons at a 0.05 confidence level revealed that the value of R2 was equal to 0.913 at p 0.05 between turbidity and WQI of wetlands during the pre-monsoon season. There was no statistically significant link found between pH and other metrics like as TDS, chlorine, magnesium, turbidity, fluorine, chlorine, and total hardness.

Table 4 Correlation among water quality parameters during pre-monsoon

					Pre-Monsoon							
	PH	*TDS*	*Calcium*	*Magnesium*	*Total Hardness*	*Fluorine(F)*	*Chlorine (CL)*	*Conductivity*	*Turbidity*	*Nitrate NO3*	*Sulphate SO4*	*WQI*
PH	1											
TDS	0.589	1										
Calcium	-0.132	-0.716	1									
Magnesium	0.173	0.573	-0.614	1								
Total Hardness	0.208	0.193	-0.319	0.412	1							
Fluorine	-0.273	0.454	-0.443	0.405	0.302	1						
Chlorine	0.275	0.805	-0.777	0.728	0.428	0.655	1					
Conductivity	0.642	0.487	-0.420	0.268	0.194	-0.073	0.466	1				
Turbidity	0.223	0.702	-0.766	0.608	0.325	0.519	0.773	0.603	1			
Nitrate NO_3	0.456	0.876	-0.830	0.745	0.347	0.455	0.904	0.614	0.841	1		
Sulphate SO_4	0.326	0.835	-0.716	0.671	0.448	0.700	0.969	0.459	0.724	0.894	1	
WQI	0.190	0.725	-0.769	0.631	0.350	0.615	0.813	0.554	0.993	0.850	0.776	1

Table 5 Correlation among water quality parameters during post-monsoon

	PH	*TDS*	*Calcium*	*Magnesium*	*Total Hardness*	*Fluorine(F)*	*Chlorine (CL)*	*Conductivity*		*Turbidity*	*Nitrate NO3*	*Sulphate SO4*	*WQI*
PH	1												
TDS	0.278	1											
Calcium	-0.103	-0.597	1										
Magnesium	0.353	0.500	-0.659	1									
Total Hardness	-0.019	0.273	-0.525	0.288	1								
Fluorine	-0.010	0.541	-0.269	0.334	0.595	1							
Chlorine	0.077	0.672	-0.662	0.574	0.558	0.691	1						
Conductivity	-0.090	0.145	-0.141	0.025	-0.013	-0.419	0.005	1					
Turbidity	0.113	0.786	-0.580	0.504	0.530	0.648	0.913	0.250		1			
Nitrate NO_3	-0.066	0.553	-0.681	0.585	0.639	0.605	0.904	0.265		0.887	1		
Sulphate SO_4	-0.115	0.530	-0.520	0.450	0.474	0.771	0.895	-0.060		0.802	0.893	1	
WQI	0.142	0.793	-0.567	0.528	0.562	0.728	0.922	0.156		0.993	0.882	0.828	1

V. Impact of wetland quality on groundwater quality

After examining the water quality of the wetlands in the research area, the impact on groundwater in the surrounding region was also evaluated. Groundwater samples were taken at depths of 40 feet, 80 feet, and 120 feet from a nearby handpump. All 20 samples were collected near the wetlands during the pre-monsoon season. The same metrics used to assess wetland water quality were used to assess groundwater quality. pH, TDS, calcium, magnesium, total hardness, fluorine, chlorine, conductivity, turbidity, nitrate, and sulphate were all assessed in all of the collected samples (Table 6). The WQI of ground water was determined by analysing the content of several parameters in all of the water samples (Table 7 & Fig 11). Except for total hardness, electrical conductivity, and turbidity, all parameters for all samples at all depths were found to be within acceptable ranges. In the samples, these three metrics were determined to be extremely high. The ground water had high turbidity at 40 feet, comparably low turbidity at 80 feet, and the lowest turbidity at 120 feet.

No one was found in the category of excellent water from 20 samples of handpump water (Table 7). Only four water samples were found to be in the good category of water quality categories. In the poor and very poor categories, nine and seven water samples were detected, respectively. 45% of the samples were determined to be in the poor group, with 35% falling into the extremely poor category. This means that 80% of the water in the handpump was classified as poor or very poor (Table 7). Only 20% of the water was found to be of high quality. At a depth of 40 feet, four of six taken samples were determined to be extremely poor and two to be poor in water quality. Gaira wetland, Sheotara wetland, and Salona wetland all have very poor ground water, with WQIs of 136.71, 188.31, and 122.84, respectively (Table 7). At 80 feet depth, one of four samples was determined to be very poor, two to be poor, and one to be of fair water quality. Ten samples were obtained from a 120-foot handpump. Five of these samples were determined to be of bad quality, two were found to be very poor quality, and three were found to be of high quality. The good water quality was discovered at a depth of 120 feet near the Banaul, Sheotara, and Suraha wetland areas, which had comparatively superior water quality. The investigation discovered a link between the quality of the nearby wetland and the drinking water obtained from the handpump. The neighbouring groundwater was impacted by the Radopur wetland, which had a WQI of

218.06 during the pre-monsoon season. The WQI of the handpump water was determined to be 92.91, which falls into the category of very bad. This water sample was taken at a depth of 120 feet. The Suraha wetland, on the other hand, was deemed to have the best water quality. During the pre-monsoon season, it had a WQI of 74.70. The groundwater quality near this wetland was determined to be good, with a WQI of 37.14. It demonstrates that the water quality of the wetland has an effect on the neighbouring groundwater quality. Because of the wetland's low WQI score, ground water near the Fatehpur Narja wetland at 80 feet was found to be in the good category with a WQI of 47.20. However, ground water quality was found to be very bad and poor at the same depth, with a WQI of 90.92 around the Gaira wetland and 57.70 surrounding the Sheotara wetland, respectively. The samples collected from a long distance away from the wetlands were of quite high quality (Fig 10).

Table 6 physio-chemical characteristics of handpump water at the depth of 40ft, 80 ft and 120 ft

Sl. No.	Parameters	Concentrated Value																			
		Sheotara wetland			Gaira wetland			Radopur wetland	Hanumangari wetland	Fatehpur Narja Wetland		Bukia & Sandha wetland			Banaul wetland		Salona wetland	Garha wetland	Darwan wetland		Suraha wetland
		40 ft	80 ft	120 ft	40 ft	80 ft	120 ft	120 ft	120 ft	80 ft	120 ft	40 ft	80 ft	120 ft	40 ft	120 ft	40 ft	120 ft	40 ft	120 ft	120 ft
1	PH	6.66	7	7.08	7.46	7.33	7.66	6.84	7.24	7.08	6.78	7.56	6.87	6.83	6.85	7.05	6.4	6.86	6.91	7.03	6.82
2	TDS	338	138	481	270	394	158	362	682	481	315	702	192	285	244	263	216	371	180	263	160
3	Calcium	41	48	59	51	54	58	28	24	59	54	38	40	44	31	46	27	56	39	45	57
4	Magnesium	35	37	29	62	53	59	61	68	29	42	41	38	33	37	32	33	34	29	28	32
5	Total Hardness	295	331	310	302	354	361	248	294	310	385	360	347	336	386	394	345	321	243	274	267
6	Fluorine	0.56	0.18	0.11	0.22	0.34	0.27	0.58	0.64	0.11	0.26	0.44	0.19	0.36	0.36	0.21	0.58	0.37	0.24	0.21	0.15
7	Chlorine	42	46	52	51	58	51	125	135	52	85	42	29	74	73	74	77	86	55	45	72
8	Conductivity	841	817	875	841	670	721	875	1241	875	842	922	475	557	685	847	758	667	587	578	684
9	Turbidity	19	14	11	23	17	10	16	13	12	10	17	15	9	15	9	13	9	12	14	8
10	Nitrate	11	13	17	16	18	14	17	14	17	17	13	15	10	15	14	13	12	14	16	15
11	Sulphate	5.6	4.8	6.7	6	6.7	7.2	6.7	4.9	6.7	5.6	4.6	11.3	9.4	7.3	5.9	5.5	8.1	7.6	7.9	9.4

Table 7 WQI of groundwater

Sl. No.	Name of Wetlands	Wetland WQI		Handpump depth	Pre-Monsoon	Water Quality Status
		Pre-Monsoon	Post-Monsoon		Handpump WQI	
1	Bukiya& Sandha wetland	90.02	82.66	40 ft	88.34	Very poor
				80 ft	60.33	Poor
				120 ft	54.73	Poor
2	Darwan wetland	137.15	111.30	40 ft	54.84	Poor
				120 ft	59.17	Poor
3	Garha wetland	122.58	107.72	120 ft	56.03	Poor
4	Gaira wetland	136.71	97.93	40 ft	90.92	Very poor
				80 ft	80.99	Very Poor
				120 ft	58.27	Poor
5	Banaul wetland	122.88	96.66	40 ft	72.39	Poor
				120 ft	45.63	Good
6	Sheotara wetland	188.31	154.86	40 ft	96.83	Very Poor
				80 ft	57.70	Poor
				120 ft	44.40	Good
7	Hanuman Gari wetland	213.65	189.60	120 ft	91.70	Very Poor
8	Radopur wetland	218.06	199.12	120 ft	92.91	Very Poor
9	Salona wetland	122.84	119.23	40 ft	79.43	Very Poor
10	Suraha taal	74.70	60.20	120 ft	37.14	Good
11	Fatehpur Narja wetland	95.34	76.79	80 ft	47.25	Good
				120 ft	51.55	Poor

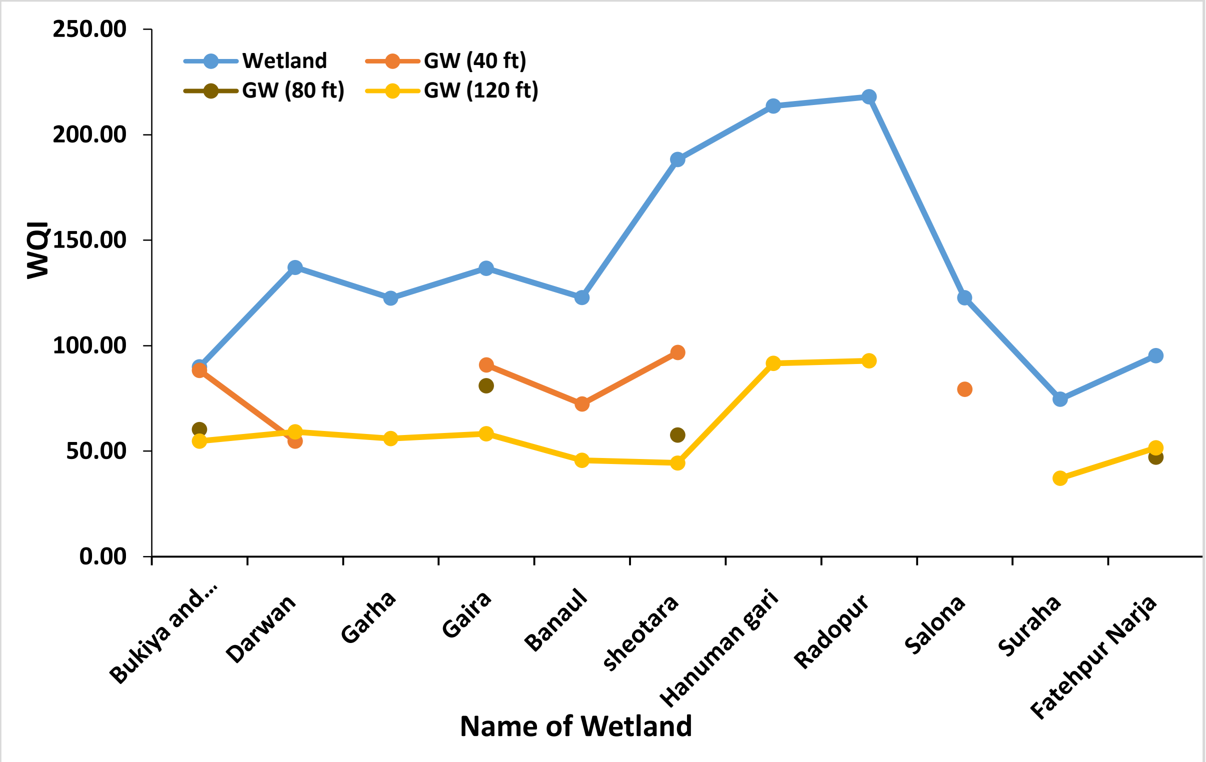

Figure 9 Wetland WQI and groundwater WQI relation

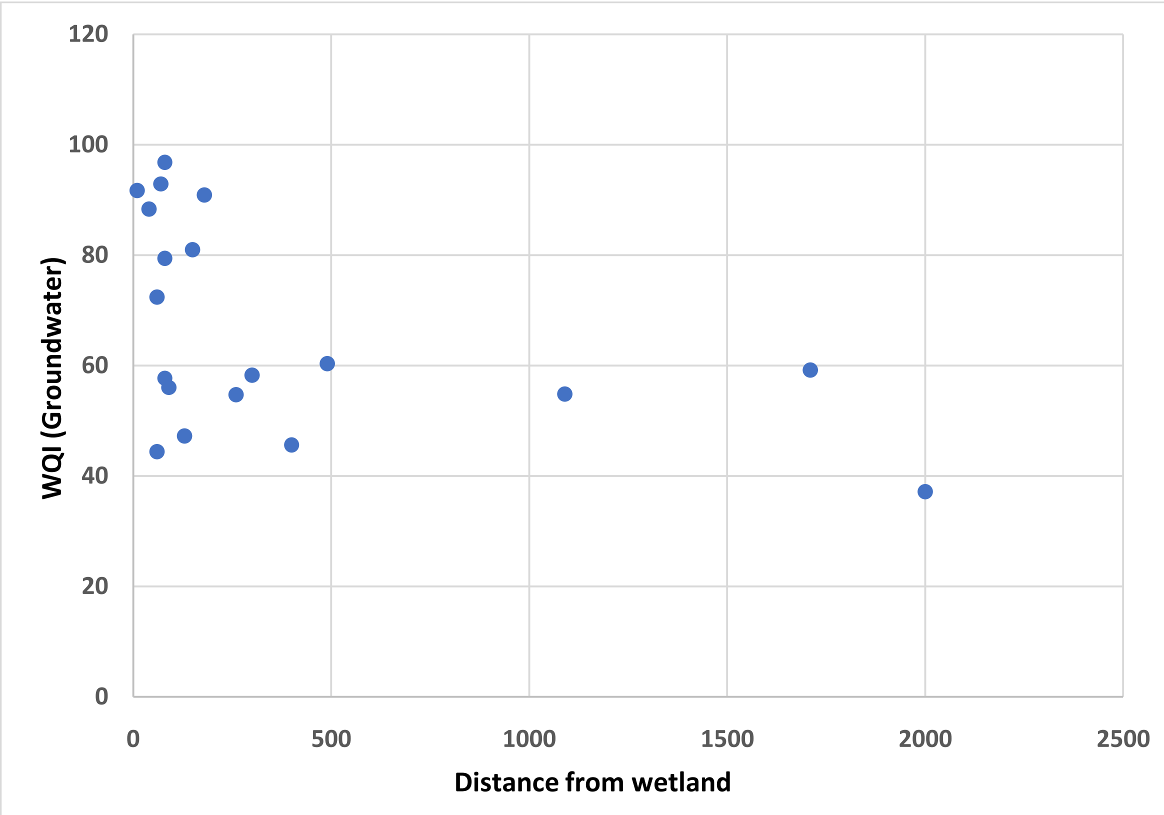

Figure 10 Groundwater WQI and its distance from wetland

VI. Conclusion

Analysis of the physio-chemical quality of wetlands found that the most significant water quality parameter was turbidity, which had a substantial impact on the wetlands' water quality. During the pre- and post-monsoon seasons, there is a strong link between turbidity and wetland quality index. The current study found that adding fresh water during the monsoon season only slightly enhances the water quality of the wetlands in the study area. WQI values ranged from 74.70 to 218.06 (WQI) before the monsoon and from 60.20 to 199.12 (WQI) after the monsoon. Nine wetlands were determined to be unsafe for drinking, and three were judged to be very poor in terms of water quality. Though most of the water in the wetlands was unfit for drinking, the water quality was the worst in three wetlands: Sheotara, Hanuman Gari, and Radopur. Following the discovery of the wetland's water quality, the impact of these high-quality wetlands on the groundwater in the surrounding region was also evaluated. It was discovered that the wetland has a substantial impact on the quality of groundwater. The poorest groundwater quality was discovered near the poorest water quality wetlands. Only three groundwater samples at a depth of 120 feet were found to have acceptable water quality. Wetlands have a great potential value, especially in stressed catchments, hence efforts should be made to manage their protection and, if possible, to provide incentives for it. Human causes have been discovered to be a key role in the degradation of wetland water quality. As a result, this study serves as the foundation for developing various management plans to ensure better wetland water quality, which eventually affects human health.

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Reviewer
1. Gopal Krishna, PhD
Scientist D
drgopal.krishan.nihr@gov.in
Expertise in Ground water and Surface water monitoring or Modelling
2. Rajneesh Singh, PhD
Postdoctoral Research Associate
sing0881@umn.edu
water quality monitoring, wastewater treatment and reuse of Agricultural/Industrial wastewater

3. JahangeerJahangeer
post-Doctoral Research Associate, University of Nebraska,
(Nebraska water center)
Jahangeer.tomar@gmail.com