Irrigation Water Quality Assessment and Identification of River Pollution Sources in Bangladesh: Implications in Policy and Management

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***Abstract*-Due to uncontrolled rapid industrialization and the lack of decisive and effective policy framework, river water pollution is posing an increasing threat to surface water irrigation in Bangladesh. In this paper, irrigation water quality and possible sources of pollution in the watershed of the Khiru River have been assessed. Results indicate severe degradation in water quality likely to cause serious damage to crop production. The presence of severe alkali hazards and heavy metals pose further threats to the future. Multivariate analysis suggests that industrial and municipal wastewater may be a possible cause of such degradation. The immediate formulation and implementation of water pollution prevention policies and strategies are therefore recommended to minimize farming threats to 7000 ha of land and 20,000 families depending on the river for survival.**

Keywords-River Water Quality; Irrigation; Industrial Pollution; Heavy metal; Policy; Management

I. INTRODUCTION

Farmers are vulnerable to water pollution, particularly in the developing nations where rapid industrialization is taking place. Traditionally, farmers rely on surface water irrigation due to its availability and cost effectiveness, which is likely to be deteriorated from industrial discharge and result in declining crop production and increased food insecurity. This places immense pressure on the policy makers who seek to develop a sound strategy for sustainable resource development.

Developing countries like Bangladesh, where environmental policies and their implementations often lack coordination and alignment, water pollution due to rapid industrialization is very common in areas where polluting industries such as textile dying, leather tanning, pulp and paper processing and sugar manufacturing are located. The effluents discharged by the industrial manufacturers lead to severe pollution of surface and groundwater sources and soils, which ultimately affects the livelihood of the poor by minimizing available water resources. Agricultural practices with untreated industrial effluents, the dumping of domestic wastes and flow of sewage effluents into waterways lead to water and soil pollution [1]. However, these practices are not uncommon in Bangladesh [2], therefore requiring special attention to the details of the problem.

In Bangladesh, one of the next eleven developing countries in the world [3], agriculture is the single largest producing sector in the economy which comprises18.6% of the country's GDP and employs approximately 47% of the total labour force, as of data released in 2010 [4]. The agricultural sector is known as the largest user of water as irrigation, which currently consumes 70% of the world's developed fresh water supplies. This percentage is much higher in developing countries as irrigation consumes 95% of all water uses [5]. Industrial wastewater is primarily used for the irrigation of crops due to its easy availability, disposal problems and the scarcity of fresh water. Wastewater irrigation has long been used in developing countries like Bangladesh due to its high fertility [2] and is also considered the best substitute for freshwater shortages [6]. The use of industrial wastewater for irrigation has been associated with a number of advantages such as increases in the C, N, P, K and Mg contents of the soil as compared to clean groundwater irrigation [7]. However, irrigation with wastewater has both beneficial and harmful effects [8].

In the Khiru River watershed, lying in the north-eastern district of Mymensingh, Bangladesh, with 7000 ha of farming land and 20,000 farmer families depending on it for survival [9], water pollution is associated with the lack of proper strategies to control the industrial growth and placement of industries. The situation is further complicated by the absence of proper policy,

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attention from authority and economic opportunity and disparity in resource distribution. The area produced an estimated 270,000 MT of Boro[1] rice in 2013.Riceproduction has declined by approximately 10% over the last five years, although farming in the area has grown [9]. Over the last ten years, there has been an increasing trend among the people living in the region that are transforming their occupation to non-river related occupations [10]. Many of the farmers have also taken non-farming occupations as a secondary living while others are migrating to other places to seek seasonal or permanent jobs [11]. These communities are neither skilled with these new occupations nor adapted to these new working environments. Therefore, the trend is creating a detrimental effect to the traditional lifestyle, cultural values and socioeconomic conditions.

Despite the area's importance as a farming and fishing resource along with its rapid industrialization, studies addressing such issues are scarce. Such studies may prove to be essential for the formulation of any formal policy to ensure sustainable growth in the region. This study finds the only currently available literature reporting high amounts of dissolved metals in the river [12]. For a baseline database to address the environmental issues of the area, collecting information on river water quality, soil quality, crop content, industrial discharge and types, and basic livelihoods are of top priority. Taking these into consideration, this study explores the current state of water quality in the Khiru River, analyses its suitability for irrigation practices, investigates possible sources of pollution and reviews the current policy and strategic issues regarding proper water management. Results from this study provide important information that might be useful to government agencies and responsible industries to plan feasible industrial management and water pollution abatement programmes for the region that might revive the river and its people.

II. POLLUTION CONTEXT AND CURRENT MANAGEMENT STRATEGIES

The study area reported in this paper is Bhaluka Upazila[2] in the district of Mymensingh, located on the banks of the great Brahmaputra River in Bangladesh (Fig. 1). The region is currently treated as one of the fastest growing industrialized areas due to the frequent establishment of factories, textile mills, dying mills, ceramic industries, spinning mills, fish feed mills and cottage industries. Due to easy access to water and cost effectiveness, most of the industries were established along the bank of Khiru River, which is considered to be the only reliable agricultural water source in the area. Unfortunately, all of these industries discharge their contaminated effluents directly into this river. Moreover, the municipality of Bhaluka Upazila is also dumping its waste directly into the river system. In the dry season, the river water turns dark and causes severe odour problems. In the wet season, the untreated sewage water gets mixed with elevated upstream flow and additional water flow from ephemeral water bodies which seems to reduce the pollution, but still poses a threat to the environment [11].

Fig. 1. Google Earth image of the study area indicating exposed and control sites in the study area. Site IDs beginning with"c" indicate control sites and"e" indicates exposed sites (Image courtesy: Google Eye, 2014).

The Khiru River originates from a beel[3] formation called Kalamukha Beel in the Mymensingh district and runs an estimated 23 km to join the Brahmaputra-Sitalakkhya system in Bhalukaupazila. The River plays a significant role in irrigating over 7,000 ha of cultivatable land (6,000 ha for rice cultivation and 1,000 ha for vegetables). A very small number of deep tube wells provide a supplementary source of water [13]. Two types of rice are primarily cultivated in the surrounding agricultural lands of the river, locally known as Aman and Boro[4]. In addition to rice production, the river used to be a place to fish, though the presence of fish is now rare.

In the late 1980s, the Khiru River began to grow into a base of industrial establishment in the region. In the mid-1990s, the impact of untreated industrial effluent started to become more visible to local people involved in agricultural activities around the river. Farmers in the region have been reporting difficulty in irrigating their lands with the polluted water for decades [14]. Not only does the river affect farming lands, the river pollution also affects a vast area of fish culture in Bangladesh. According

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to the local officials from the Department of Fisheries (DoF), 329 beels in this area is under aquaculture (white fish), which cover about 16,000 ha of land. Approximately 5,350 ha of this land is directly connected to the river and adjoining canals, thus polluting the water bodies and hampering fish production. Currently, although government organizations like the Department of Agriculture (DoA), Department of Fisheries (DoF), etc., are quite concerned about the magnitude of the pollution and its impact on local agriculture and aquaculture, strategies and initiatives to tackle the situation are still non-existent [11]. According to the officials of the Upazila administration, the Bhaluka Municipality along with the Department of Environment (DoE) can play a major role. Although, there is a lack of synergy among all the laws and regulations regarding river water pollution in peri-urban areas, the effective implementation of existing laws like the Natural Waterbodies Conservation Law (2000) could prevent further damage.

III. METHODS

A. Sampling framework

This research employed the comparison of exposed and control site approach. Control sites were taken in the upper reaches of the river which are relatively free from the large industrial establishments assuming lesser water pollution. In contrast, exposed sites were taken in the lower reaches of the river, therefore expected to be higher in pollution. All the sites used in this study are on the bank of the Khiru River where farmers are dependent on the river to large extents for their irrigation. All the 16 sites were chosen a kilometre and half apart from each other to maintain uniformity and monitor the span of pollution. Of them 4 sites were considered as control sites and the rest 12 sites were marked as exposed sites. The sampling sites were designed to represent the water quality of the river system accounting for tributary and inputs from wastewater drains that have impact on downstream water quality. It is logical to assume that, from upstream to downstream; Khiru River receives additional water from several connected water bodies, therefore dilution effect may be useful to take in account. However, the samples were taken during Boro growth season (February-March), which considered to be dry season in Bangladesh. As a consequence, availability of additional water from external water bodies might be limited, and it is safe to assume that pollution load might increase from upstream to downstream due to additional input of industrial discharge on the way.

1) Water sampling and laboratory techniques:

The study was conducted during the dry season (February and March) of 2014. The reason forchoosing this specific time is the plantation of Boro rice. Boro ricerequire significant irrigation, and constitute the major contribution to total rice production in the area. Water sampling was done twice: during the vegetative stage (34 days after transplantation) and the reproductive state (75 days after transplantation). Water quality parameters such as pH, Dissolved Oxygen(DO) content, Electrical Conductivity (EC), Total Dissolved Solids (TDS), chloride, calcium, potassium, magnesium, sodium, boron, copper, zinc, manganese, iron, cadmium, lead and nickel were analysed in the laboratory for overall water quality assessment.

Water samples were collected at the approximate mid-section of the river at all 16 sites in February and March, 2014. Sampling, preservation and transportation of the water samples to the laboratory was done as per standard methods [15]. Water temperature was measured onsite using a mercury thermometer. The pH value was measured electronically by a Microprocessor pH meter (Hanna instrument, Hi 8424, microcomputer pH meter), EC and TDS was measured by portable waterproof multi-range conductivity/TDS meter (Model No: H1-9635) [16]. All other parameters were determined in the laboratory following the standard protocols described in APHA (1998) [15]. The analytical data quality was ensured through careful standardization, procedural blank measurements, spiked and duplicate samples. Samples were analysed for the presence of nine major ions and eight metals. Preserved aqueous samples were analysed for metal cation concentrations using a Varian ICP Model 720-ES ICP-OES at the laboratory of Bangladesh Council of Scientific & Industrial Research (BCSIR). The ionic charge balance stayed within ±5% for the samples taken from control sites. However, the charge balance showed erratic results (±30%) in some cases from the exposed sites, which may represent an unusual concentration of metallic ions in water discharged by the industrial complexes.

B. Multivariate Analysis

The application of multivariate analyses such as Cluster Analysis (CA), Factor Analysis (FA)/Principal Component Analysis (PCA) are well-known tools to examine data structure and identify relatively important variables in hydrochemical studies [17]. These tools help to simplify and organize data sets in order to make useful generalizations and insights to hydrochemical composition.

1) Cluster Analysis:

Cluster Analysis (CA) is an exploratory data analysis tool which aims to sort different objects into groups so that the degree of association between two objects is maximal if they belong to the same group, and minimal otherwise. It is a useful multivariate technique to understand and explore the grouping operations, and identifysimilar elemental compositions in water. In this study, hierarchical CA was performed on the normalized dataset using Ward's method with Euclidean distances as a measure of similarity. Ward's method uses an analysis of variance (ANOVA) to evaluate the distance between clusters to minimize the sum of squares of any two clusters at each step. The aim of this analysis was to validate the correct identification

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of control and exposed sites, and to determine if the hydrochemical parameters demonstrate any significant spatial grouping.

2) Factor Analysis

Factor Analysis (FA) is also a multivariate technique that has been used to explain water types and behaviours in numerous studies [18, 19, 20]. Generally, the purpose of an FA is to summarize the data covariance structure in fewer dimensions. However, the primary emphasis of factor analysis is the identification of underlying factors that might explain the dimensions associated with large data variability, i.e., possible association with hydrochemical sources. A varimax rotated FA was performed to extract the factors governing water chemistry in the Khiru River. The data matrix includes 20 variables with 32 observations.

C. Interpretation of Irrigation Water Quality

In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of water. The suitability of surface water for irrigation is determined by concentrations of various ions. Irrigation water quality is often measured by indicators such as Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC), and Electrical Conductance (EC). Along with the aforementioned indicators, some additional indices are used to categorize surface water for irrigation: Total Hardness (TH) and Total Dissolved Solids (TDS). The use of the USA Salinity Laboratory Diagram [21] and the Wilcox Diagram [22] are also popular in irrigation water quality interpretation. Total Hardness (TH) of water samples is calculated using the formula proposed by Hem in 1985[23] and Ragunath in 1987[24], and water hardness classification is accomplished according to Sawyer and McMcartly, 1967[26].

D. Theoretical Framework for Interpretation

The suitability of water for irrigation is dependent on the effects of mineral constituents of water on both the plants and soil [27, 28]. Excessive amounts of dissolved ions in irrigation water physically and chemically affect plants and agricultural soil, and reduces their productivity. Water quality, soil types and cropping practices play an important role in suitable irrigation practices [29].The physical effects of these ions are to lower the osmotic pressure in the structural cells of plants, thus preventing water from reaching the branches and leaves. The chemical effects disrupt plant metabolism. It is the quantity of certain ions, such as sodium and boron, rather than the total salt concentration that affects plant development [30]. Hence, the Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC), Electrical Conductance (EC), Total Hardness (TH) and Total Dissolved Solids (TDS) are often used as indicators of irrigation water suitability.

There is a significant relationship between SAR values of irrigation water and the extent to which Na^+ is absorbed by the soil. If water used for irrigation is high in Na^+ and low in calcium, the cation change complex may become saturated with sodium. This can destroy the soil structure due to dispersion of the clay particles in the soil [31]. Additionally, soils containing large proportions of Na^+ with carbonate and chloride or sulphate are termed as alkali or saline water, respectively [32].

The presence of Na^+ in irrigation water reacts with soil to reduce permeability [33] and repeated use makes the soil impermeable, eventually resulting in soil with poor internal drainage [34], while high sodium content leads to the development of alkali soil. Frequent irrigation with high Na^+ water for a considerable duration makes the soil plastic and sticky in wet conditions, and forms clods and crust in dry conditions [35]. High sodium saturation also causes a direct calcium deficiency by combining with carbonate, leading to the formation of alkaline soils. Alternatively, in the presence of Cl^-, saline soils are formed; neither type of soil will support plant growth [36]. Thus, the Soluble Sodium Percentage (SSP) is an important criterion to assess irrigation water quality for agriculture, as it reflects the potential of deterioration of the physical properties of the soil which can affect plant growth [37].

Nitrogen is an essential plant nutrient which stimulates crop growth. Natural soil nitrogen or added fertilizers are the most common sources of nitrogen in water. However, nitrogen in irrigation water has much the same effect as soil-applied fertilizer nitrogen, and an excess will cause problems just as too much fertilizer is detrimental [27]. The presence of excess nitrogen in irrigation water may cause over-stimulation of growth, delayed maturity or poor quality in crops. Threshold limits for nitrogen in irrigation water vary from crop to crop. Some plants are sensitive to nitrogen (> 5 mg/L, e.g., sugarbeet) while others are unaffected until > 30mg/L NO_3-N.

IV. RESULTS AND SOURCE IDENTIFICATION

A. Spatio-Temporal Variation of Physical Parameters

The pH, EC and TDS values of the river water were found varying significantly over time (Table I). The pH results indicate two facts: first, exposed sites were found to be more alkaline (6.852 $\pm$0.309 in February, 6.893 $\pm$0.342 in March) than control sites (6.265 $\pm$0.108 in February, 5.953 $\pm$0.190 in March), and second, control sites turned from slightly acidic to more acidic with time while the exposed sites remained neutral by nature and varied little over time. The EC and TDS values reveal a clear and distinct indication of additional input in river water in the exposed sites which are ~10x higher than that in control sites. Overall, physical measures depict a distinct spatial pattern in the study sites, particularly between the control and exposed sites,

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although temporal variation is not as distinctive. This is also a likely indication of additional input of industrial and municipal effluent in the exposed sites.

TABLE I. SUMMARY OF HYDROCHEMICAL COMPOSITION OF KHIRU RIVER WATER SAMPLES.

Time and Stage		Physical parameters					Cations				Anions				
		Temp	**DO**	**pH**	**EC**	**TDS**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**NO_3^{-}**	**Cl^{-}**	**SO_4^{2-}**	**HCO_3^{-}**	**PO_4^{3-}**
		^{0}C	-	-	µs/cm	ppm	Meq/L	Meq/L	Meq/L	Meq/L	Meq/L	Meq/L	Meq/L	Meq/L	Meq/L
February (Control sites)	Mean	31.25	5.45	6.26	150.1	105.3	0.47	0.85	0.86	0.07	0.13	0.90	0.94	0.73	0.05
	Stdev	2.33	0.31	0.11	5.89	3.971	0.05	0.17	0.16	0.02	0.05	0.81	0.21	0.20	0.06
	Max	33.30	5.90	6.36	157	110.1	0.50	1.10	1.02	0.10	0.19	2.00	1.17	0.95	0.13
	Min	28.00	5.20	6.11	145	101.7	0.40	0.70	0.70	0.05	0.08	0.20	0.68	0.52	0.00
February (Exposed sites)	Mean	32.15	2.51	6.85	1541	1231	0.87	1.03	19.8	0.26	0.52	8.17	3.26	4.64	0.15
	Stdev	1.29	0.63	0.30	54.74	67.35	0.07	0.12	3.13	0.07	0.27	4.26	1.91	0.53	0.04
	Max	33.60	3.20	7.45	1650	1342	1.00	1.30	23.0	0.40	1.34	16.0	6.90	5.54	0.25
	Min	29.30	1.20	6.50	1500	1132	0.80	0.90	14.3	0.17	0.37	2.00	0.23	4.01	0.11
March (Control sites)	Mean	31.45	4.82	5.95	86.95	61.32	0.20	0.57	0.52	0.02	0.06	0.25	2.06	0.41	0.00
	Stdev	0.21	1.31	0.19	4.685	3.615	0.00	0.09	0.06	0.01	0.02	0.06	1.82	0.09	0.00
	Max	31.70	5.80	6.21	92.40	65.70	0.20	0.70	0.59	0.03	0.08	0.30	4.69	0.52	0.01
	Min	31.20	2.90	5.80	81.30	57.10	0.20	0.50	0.46	0.02	0.05	0.20	0.49	0.30	0.00
March (Exposed sites)	Mean	33.11	1.55	6.89	1486.	1130	0.59	0.83	15.6	0.26	0.23	6.00	4.91	3.83	0.1
	Stdev	1.29	0.53	0.34	163.1	175.5	0.12	0.14	2.53	0.08	0.07	2.59	2.14	0.59	0.03
	Max	34.50	2.50	7.34	1840	1424	0.80	1.10	18.9	0.34	0.40	13.0	8.98	4.34	0.14
	Min	31.10	0.80	6.22	1238	857	0.40	0.60	11.0	0.09	0.16	3.50	2.34	2.92	0.03

B. Major Ion Chemistry

The spatial variation of dissolved ion concentrations in the Khiru River shows remarkable differences in concentrations of major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^- and SO_4^{2-}) and nutrients (NO_3^- and PO_4^{3-}). The variations are reported in Table II. Among the major cations, Na^+ constitutes 35 to 90% of the total cationic load of the samples, which varies from 35.3 to 91.8% in February and 35.6 to 92.3% in March. Sodium ion (Na^+) contribution to the total cationic load is almost double in the exposed sites (86 – 92%) than in the control sites (35 – 42%). The excessive Na^+ observed in the exposed sites indicates the additional input of sodium as waste discharge from the textile and dying industries. The Contribution of magnesium ions (Mg^{2+}) to the total cationic load ranges from 4.77 to 43%. Like sodium, the contribution of magnesium ions to the total cationic load is very high in the control sites (35 – 44%) when compared to the exposed sites (3– 6.5%). Among the major anions, sulphate (SO_4^{2-}) constitutes 20 to 65% of the total anions in the Khiru River. The contribution of sulphate to the total anion concentration was observed to be higher in March (40 $\pm$ 19%) than in February (24 $\pm$ 14%). The sulphate load was also found to be higher in control sites (29 - 67% of the total anionic load) than in exposed sites (10 – 47% of the total anionic load) over the study period (February and March). The contribution of chloride (Cl^-) to the total anionic load ranges from 12 to 39% while the load is relatively higher in the exposed sites (23.5 – 59%) than in the control sites (5.5 – 40.5%). Unlike chloride, the bicarbonate (HCO_3^-) load does not differ much between the exposed sites (~28%) and the control sites (~24%). The contribution of NO_3^- and PO_4^{3-} to the total anionic load was found to be insignificant. Overall, the major cations were found to contribute according to the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, while the major anions were found to contribute according to the order of $SO_4^{2-} > Cl^- > HCO_3^- > NO_3^- > PO_4^{3-}$.

C. Spatial Similarity and Clustering

The result of CA is presented in Fig. 2. Results show that sites are grouped into two major clusters (defined by 80% similarity). Cluster 1 includes all the control sites while Cluster 2 includes all the exposed sites, indicating a clear distinction of character between the two groups. This concludes that the control and exposed sites were correctly identified, and therefore can be used with greater confidence while making comparative statements.

TABLE II. CONTRIBUTION OF ION LOADS TO TOTAL ANIONIC AND CATIONIC LOAD IN THEKHIRU RIVER. SAMPLE IDS BEGINNING WITH“C” DENOTES CONTROL SITES AND “E ” DENOTES EXPOSED SITES

Time & Stage	Sample ID	Local name of the location	Cations				Anions					Sum	
			Ca^{2+}	Mg^{2+}	Na^+	K^+	NO_3^-	Cl^-	SO_4^{2-}	HCO_3^-	PO_4^{3-}	Cations	Anions
			%	%	%	%	%	%	%	%	%	meq/L	meq/L

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February (Growth Stage)	c1-1	Sonakhali	21.072	33.706	40.981	4.241	4.646	30.322	35.509	25.576	3.947	2.373	3.298
	c1-2	Sonakhali	15.361	42.230	39.308	3.102	5.622	58.088	19.652	14.979	1.660	2.604	3.443
	c1-3	Angargara	23.823	38.106	35.358	2.713	3.583	8.885	45.087	42.325	0.120	2.099	2.251
	c1-4	Angargara	25.556	35.768	35.968	2.708	4.813	19.892	44.002	31.080	0.213	1.956	2.011
	e1-1	Borta	3.482	3.916	91.333	1.269	3.549	58.539	1.523	35.335	1.053	22.973	15.375
	e1-2	Borta	5.195	5.193	88.618	0.995	4.200	40.901	8.515	45.332	1.052	17.325	12.225
	e1-3	Dairapara	3.311	4.552	91.095	1.042	2.272	60.369	14.813	22.012	0.534	24.157	23.192
	e1-4	Dairapara	3.190	3.986	91.821	1.004	2.900	53.674	15.923	26.812	0.690	25.081	18.632
	e1-5	Vandabor	3.634	4.542	90.680	1.144	5.189	62.014	14.121	18.091	0.584	22.010	25.802
	e1-6	Vandabor	4.494	4.493	89.703	1.310	2.225	47.643	23.247	25.845	1.040	22.250	16.792
	e1-7	Valuka	3.162	5.136	91.021	0.681	2.259	62.252	12.825	21.947	0.716	25.301	19.277
	e1-8	Valuka	3.753	3.752	91.776	0.719	2.581	52.971	12.062	31.630	0.757	23.978	15.103
	e1-9	Kharuali	4.690	5.210	88.016	2.084	2.262	29.844	41.163	25.252	1.478	19.188	16.754
	e1-10	Kharuali	5.425	6.027	86.385	2.163	3.185	15.590	48.687	31.275	1.262	16.588	12.829
	e1-11	Khatali	3.940	4.333	90.736	0.992	3.118	36.939	27.878	31.255	0.809	25.381	13.536
	e1-12	Khatali	4.616	6.153	87.939	1.291	3.511	35.067	23.955	36.131	1.336	19.495	11.407
March (Reproductive Stage)	c2-1	Sonakhali	13.284	46.480	39.092	1.145	2.924	11.925	64.134	20.499	0.517	1.506	2.516
	c2-2	Sonakhali	15.528	38.809	43.709	1.955	3.868	9.428	67.470	19.160	0.075	1.288	2.122
	c2-3	Angargara	15.461	46.371	35.608	2.560	4.046	23.832	39.279	32.288	0.555	1.293	1.259
	c2-4	Angargara	16.744	41.848	39.633	1.775	0.865	3.822	89.521	5.680	0.112	1.194	5.233
	e2-1	Borta	2.701	4.320	91.227	1.752	1.709	33.548	31.430	32.355	0.959	18.512	13.414
	e2-2	Borta	3.266	3.265	91.920	1.550	0.988	32.435	44.801	21.111	0.665	18.373	20.041
	e2-3	Dairapara	2.506	3.508	92.359	1.626	2.182	37.311	23.735	35.983	0.790	19.948	12.061
	e2-4	Dairapara	2.647	4.763	90.767	1.823	1.749	41.757	19.560	36.244	0.689	18.888	11.974
	e2-5	Vandabor	2.414	5.310	91.443	0.832	1.716	56.317	22.547	18.801	0.619	20.707	23.085
	e2-6	Vandabor	3.237	4.315	91.126	1.322	1.576	53.191	22.799	21.688	0.745	18.533	15.981
	e2-7	Valuka	2.246	5.615	90.540	1.599	1.497	33.764	39.540	24.422	0.777	17.805	17.771
	e2-8	Valuka	3.927	3.926	90.439	1.709	1.312	37.666	36.947	23.882	0.193	17.825	17.258
	e2-9	Kharuali	4.691	7.034	86.029	2.246	1.008	33.207	46.351	18.946	0.489	12.790	16.564
	e2-10	Kharuali	4.344	4.963	88.934	1.758	1.448	36.556	34.882	26.379	0.735	16.112	12.310
	e2-11	Khatali	5.300	6.812	87.185	0.703	1.576	39.088	27.973	30.664	0.698	13.207	10.234
	e2-12	Khatali	5.231	5.229	88.673	0.867	1.752	34.405	34.535	28.699	0.609	15.294	10.173

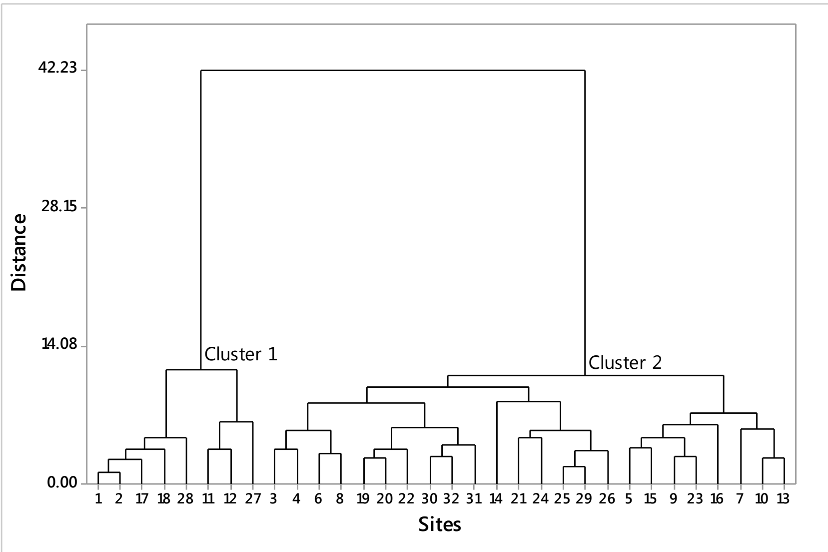

Fig. 2.Dendrogram produced from Cluster Analysis (CA) using Ward linkage and Euclidian distances, revealingtwo distinct clusters. Cluster 1 includes the samples from control sites and cluster 2 includes the samples from exposed sites over the two sampling periods.

D. Ion Combination and Correlations

A correlation matrix was performed on the physical parameters and major ion concentrations over two time periods to evaluate the associations of the analysed parameters. The results are presented in Table III (A) and III (B). It was determined that during the vegetative stage, EC is significantly correlated with TDS, Ca^{2+}, Na^{+}, K^{+}, and HCO_3^{-}($p < 0.01$). Other significantly correlated pairs are TDS with Ca^{2+}; Na^{+}, $HCO_3^{-}$with PO_4^{3-}; Ca^{2+} with Na^{+} and HCO_3^{-}; Na^{+} with HCO_3^{-}; and K^{+} with SO_4^{2-} and PO_4^{3-}. During the reproductive stage, EC was found to be significantly correlated to TDS, Na^{+}, K^{+}, NO_3^{-}, Cl^{-}, HCO_3^{-} and PO_4^{3-}. The other significantly correlated pairs were TDS with Na^{+}, K^{+}, NO_3^{-}, Cl^{-}, HCO_3^{-} and PO_4^{3-}; Mg^{2+} and Cl^{-} withPO_4^{3-}; Na^{+} with K^{+}, NO_3^{-}, Cl^{-}, HCO_3^{-} and PO_4^{3-}; K^{+} with HCO_3^{-}, NO_3^{-} and Cl^{-}; $HCO_3^{-}$with PO_4^{3-}, Cl^{-} and PO_4^{3-};and HCO_3^{-} with PO_4^{3-}. These results indicate that pre-monsoon rains during March may have played an important role in changing correlated ion pairs by diluting ion concentrations in the river as TDS drops from 949 ± 490 mg/L in February to 862 ± 485 mg/L in March. The strong correlation between Na^{+} and HCO_3^{-} in both stages with Na^{+} dominating the cationic load especially

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in the exposed sites (Table II) reveals the presence of $NaHCO_3$ residue in water, indicative of sources of domestic waste and the textile and dying industries in nearby operation.

TABLE III CORRELATION MATRIX OF IONS DURING THE MONTH OF FEBRUARY (VEGETATIVE STAGE) (A) AND MARCH (REPRODUCTIVE STAGE) (B). **BOLD** TYPE FACE REPRESENTS SIGNIFICANT VALUES (P < 0.01).

(A)

Parameters	EC	TDS	Ca	Mg	Na	K	NO_3	Cl	SO_4	HCO_3
TDS	**0.997**									
Ca	**0.925**	**0.911**								
Mg	0.529	0.503	0.417							
Na	**0.957**	**0.954**	**0.864**	0.562						
K	**0.800**	0.786	0.786	0.384	0.695					
NO_3	0.606	0.621	0.438	0.284	0.600	0.452				
Cl	0.679	0.702	0.445	0.459	0.772	0.390	0.797			
SO_4	0.533	0.500	0.590	0.356	0.420	**0.804**	0.274	0.184		
HCO_3	**0.972**	**0.981**	**0.870**	0.404	**0.933**	0.724	0.630	0.703	0.373	
PO_4	0.723	**0.717**	0.699	0.405	0.628	**0.873**	0.438	0.411	0.660	0.671

(B)

Parameters	EC	TDS	Ca	Mg	Na	K	NO_3	Cl	SO_4	HCO_3
TDS	**0.993**									
Ca	0.782	0.730								
Mg	0.703	0.687	0.460							
Na	**0.983**	**0.987**	0.740	0.635						
K	**0.848**	**0.857**	0.582	0.434	**0.863**					
NO_3	**0.892**	**0.913**	0.519	0.741	**0.897**	0.664				
Cl	**0.862**	**0.875**	0.551	**0.717**	**0.823**	0.584	**0.931**			
SO_4	0.554	0.547	0.423	0.254	0.493	0.533	0.420	0.533		
HCO_3	**0.973**	**0.977**	0.705	0.652	**0.984**	**0.891**	**0.872**	0.790	0.543	
PO_4	**0.870**	**0.869**	0.502	**0.678**	**0.862**	0.712	**0.843**	**0.804**	0.550	**0.856**

E. Data Structure and Source Investigation

From Factor Analysis (FA), five factors with eigen values >1 were extracted from the principal factor matrix after varimax rotation explaining 77.67% of the variation in the dataset (Table IV). Factor I shows high loading (> 0.75) of EC, TDS, pH, HCO_3^-, PO_4^{3-}, Na^+ and K^+ and moderate loading (> 0.50) of Ca^{2+}, Cl^-, NO_3^- and SO_4^{2-}. Evidently, this group explaining ~37% of the total variance is indicative of the mixture of municipal waste and industrial discharge in the river. While strong positive loading of Na^+, K^+, HCO_3^- and pH along with moderate positive loading of Ca^{2+} and Cl^- indicate the presence of textile and dying industrial discharge, strong positive loading of PO_4^{3-} and moderate positive loading of NO_3^-accompanied by the weak positive loading of Cl^- and SO_4^{2-} is indicative of the municipal waste carrying domestic discharge. The second factor explains 13.59% of the total variation, and shows strong positive loading (> 0.75) of Mn, Cr and Cu and moderate positive loading (> 0.50) on Pb. This group therefore represents metallic groups and are indicative of the industrial discharge alone. The third factor explains 9.49% of the total variance showing a strong positive loading of F and Cd with a slight positive loading (< 0.50) of Fe. All of these metals may enter the river system by both soil leaching and industrial discharge. However, given the slightly negative loading of NO_3^- and SO_4^{2-}, this factor may be interpreted as industrial discharge similar to Factor III. The fourth factor reveals a strong positive loading of Mg^{2+} and explains 8.86% of the total variance. In this region, the soil is rich in Fe and Mg but lacks organic matter [38]. Mg^{2+} may enter the water from both industrial discharge and soil-runoff. However, this factor with a slightly positive loading of Ca^{2+}, PO_4^{3-} and NO_3^- might be indicative of agricultural runoff that includes fertilizer washout. The fifth and final factor explains 8% of the variance and shows a strong positive loading of Zn with a slightly positive loading of Fe, Pb, Na^+ and Cl^-. This factor is representative of the discharge offew galvanizing factories present in the region.

TABLE IV.VARIMAX ROTATED FACTOR LOADING MATRIX FROM PRINCIPAL COMPONENT ANALYSIS OF PHYSICAL PARAMETERS, MAJOR IONS AND METALS IN THE KHIRU RIVER (N = 32). FIVE COMPONENTS WERE EXTRACTED USING EIGENVALUE > 1. **BOLD** TYPE FACE INDICATES STRONG LOADING (⩾ 0.75) AND ITALIC TYPE FACE INDICATE MODERATE LOADING (0.50 ⩾, ⩽0.75).

Parameter	Factors				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
EC	**.964**	.037	-.014	.098	.097
TDS	**.969**	.067	-.007	.105	.099
pH	**.805**	.304	.193	-.153	.009
HCO_3	**.951**	.143	.006	.136	.083
Ca^{2+}	*.695*	.166	-.144	.458	-.101
Mg^{2+}	.441	.077	.060	**.792**	.178
PO_4^{3-}	**.779**	.039	.016	.373	-.143
Na^+	**.919**	.065	.003	.200	.234
K^+	**.894**	-.156	.066	-.009	-.181

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NO_3^-	*.568*	.204	-.046	.485	.111
Cl^-	*.697*	.033	-.016	.346	.384
SO_4^{2-}	*.563*	-.424	-.236	-.326	-.008
Fe	.128	.198	.483	-.257	.445
F	.017	.106	**.877**	.274	-.104
Mn	.024	**.819**	.031	.055	.183
Cr	.204	**.768**	-.067	.106	-.272
Cu	.083	**.760**	.203	-.082	.010
Cd	-.037	.106	**.828**	-.139	.154
Pb	.006	*.642*	.195	.184	.379
Zn	.070	.048	.051	.135	**.884**
Eigenvalue	8.222	3.151	1.653	1.381	1.129
% variance explained	37.72	13.59	9.49	8.86	8.01
% cumulative variance explained	37.72	51.31	60.80	69.67	77.67

F. Suitability of River Water for Irrigation

1) Sodium Hazards and Dissolved Constituents

Water quality classifications for irrigation are summarized in Table V (A) and (B). EC (μs/cm) values have already been reported in an earlier section. In the control sites, the EC values were below 250 μs/cm during both periods, which is excellent for irrigational purposes based on Ragunath's classification [24]. Similarly, exposed sites (n = 24) were designated as "permissible" (EC values between 750 and 2000 μs/cm) for irrigational purposes.

Again, in the control sites, Sodium Absorption Ratio (SAR) values ranged from 0.90 to 1.2 with an average of 1.05 $\pm$0.16 in February, and from 0.72 to 0.95 with an average of 0.83 $\pm$0.09 in March .These values are excellent for irrigation purposes according to Richard's (1954) classification [25]. In the exposed sites, SAR values varied from 14.7 to 24.2 with an average of 20.3 $\pm$ 3.2 in February, and from 12.7 to 23.78 with an average of 18.68 $\pm$ 3.56 in March. In both cases, 66% of samples appeared to be "doubtful" for irrigation based on the classifications for SSP [22, 24, 32].All the samples (n = 8) from control sites fall in the "good" or "permissible" categories. More specifically, in February, 50% of all samples fell in the "good" category and the rest fall in the "permissible: class; in March, 25% of the samples fell in the "good" category and 75% fell in the "permissible" class. For the exposed sites, all the sample (n = 24) fall in 'unsuitable' class indicating that water is not safe for irrigation. A positive Residual Sodium Bicarbonate (RSBC) value indicates that the amount of dissolved calcium and magnesium ions in water is less than the carbonate and bicarbonate contents. Higher RSBC values indicate a lower quality of irrigation water. In control sites, all the samples showed low RSBC (< 1.25) over both periods, which is "good" for irrigation purposes. However, in exposed sites, all the samples (n = 12) in February qualify as "unsuitable" whereas in March, 83.33% were "unsuitable" and 16.66% were "doubtful" for irrigation purposes.

TABLE V. (A) SUITABILITY ANALYSIS OF KHIRU RIVER WATER FOR IRRIGATION BASED ON EC, SAR, SSP, TH, RSBC AND TDS (CONTROL SITES). SAMPLE IDS BEGINNINGWITH"C" DENOTES CONTROL SITES, AND "E" DENOTES EXPOSED SITES.

Parameter	**Range**	**Classification**	**Sample numbers**		**Number of samples**		**Percentage of samples**	
			February	March	February	March	February	March
EC[a] (μS/cm)	<250	Excellent	All	All	4	4	100	100
	250-750	Good	-	-	-	-	-	-
	750-2000	Permissible	-	-	-	-	-	-
	2000-3000	Doubtful	-	-	-	-	-	-
	>3000	Unsuitable	-	-	-	-	-	-
SAR[a]	<10	Excellent	All	All	4	4	100	100
	10-18	Good	-	-	-	-	-	-
	18-26	Doubtful	-	-	-	-	-	-
	>26	Unsuitable	-	-	-	-	-	-
SSP[a]	<20	Excellent						
	20-40	Good	c1-3, c1-4	c2-3	2	1	50	25
	40-60	Permissible	c1-1, c1-2	c2-1, c2-2, c2-4	2	3	50	75
	60-80	Doubtful	-	-	-	-	-	-
	>80	Unsuitable	-	-	-	-	-	-
RSBC[a]	<1.25	Good	All	All	4	4	100	100
	1.25-2.50	Doubtful	-	-	-	-	-	-
	>2.50	unsuitable	-	-	-	-	-	-
TH[a] as $CaCO_3$ (mg/L)	<75	Soft	-	-	-	-	-	-
	75-150	Mod. High	-	-	-	-	-	-
	150-300	Hard	-	-	-	-	-	-
	>300	Very Hard	All	All	4	4	100	100
TDS[a] (ppm)	<450	Good	All	All	4	4	100	100
	450-2000	Permissible	-	-	-	-	-	-
	>2000	Unsuitable	-	-	-	-	-	-

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TABLE V (B) SUITABILITY ANALYSIS OF KHIRU RIVER WATER FOR IRRIGATION BASED ON EC, SAR, SSP, TH, RSBC AND TDS (EXPOSED SITES). SAMPLE IDS STARTING WITH *C* DENOTES CONTROL SITES, AND STARTING *E* DENOTES EXPOSED SITES

Parameter	**Range**	**Classification**	**Sample numbers**		**Number of samples**		**Percentage of samples**	
			February	March	February	March	February	March
EC[a] (µS/cm)	<250	Excellent	-	-	-	-	-	-
	250-750	Good	-	-	-	-	-	-
	750-2000	Permissible	All	All	12	12	100	100
	2000-3000	Doubtful	-	-	-	-	-	-
	>3000	Unsuitable	-	-	-	-	-	-
SAR[a]	<10	Excellent						
	10-18	Good	e1-2, e1-9, e1-10, e1-12	e2-9, e2-10, e2-11, e2-12	4	4	33.33	33.33
	18-26	Doubtful	e1-1, e1-3, e1-4, e1-5, e1-6, e1-7, e1-8, e1-11	e2-1, e2-2, e2-3, e2-4, e2-5, e2-6, e2-7, e2-8	8	8	66.66	66.66
	>26	Unsuitable	-	-	-	-	-	-
SSP[a]	<20	Excellent	-	-	-	-	-	-
	20-40	Good	-	-	-	-	-	-
	40-60	Permissible	-	-	-	-	-	-
	60-80	Doubtful	-	-	-	-	-	-
	>80	Unsuitable	All	All	12	12	100	100
RSBC[a]	<1.25	Good	-	-	-	-	-	-
	1.25-2.50	Doubtful	-	e2-11, e2-12	-	2	-	16.66
	>2.50	unsuitable	All	All but e2-11, e2-12	12	10	100	83.33
TH[a] as $CaCO_3$ (mg/L)	<75	Soft						
	75-150	Mod. High						
	150-300	Hard						
	>300	Very Hard	All	All	12	12	100	100
TDS[a] (ppm)	<450	Good	-	-	-	-	-	-
	450-2000	Permissible	All	All	12	12	100	100
	>2000	Unsuitable	-	-	-	-	-	-

Note: [a] after Ragunath (1987), Ayers and Westcot (1985), Todd (1980), Sawyer and McMcartly (1967) Richards (1954), Eaton (1950), and Wilcox (1955).

Total Dissolved Solids (TDS) values of all the samples are found to be "good" for irrigation in control sites, whereas in the exposed sites the values fall into the "permissible" class. Analytical data plotted on the US salinity diagram [21] illustrates that all of the water samples from control sites fall into the C1S1 section, indicating low saline and sodium hazards, and revealing good water quality for irrigation (Fig. 3a). Similarly, in the exposed sites, all water samples except one sample in March fell into the C3S4 field, indicating high saline and very high sodium hazards in the water. This water is generally undesirable for irrigation. For irrigation, salinity and sodium tolerance of plants is of the utmost importance [28]. The Wilcox diagram [22] is used to determine the probabilityof the effects of water on the hydraulic properties of soil if it is used for irrigation activities in the area. The Wilcox diagram was prepared using EC vs SSP values for the water samples from the Khiru River (Fig. 3b). According to the diagram, samples collected from control sites fall in the classification "very good to good" whereas water samples from exposed sites fall in the classification "doubtful to unsuitable" for irrigation.

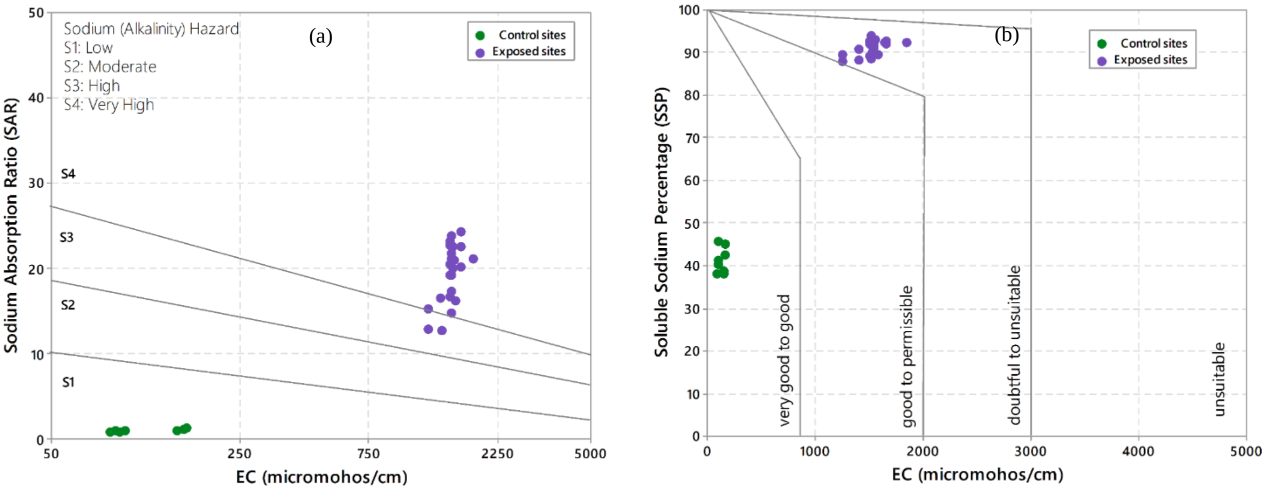

Fig. 3. (a) USSL (1954) and (b) Wilcox (1955) plot for irrigation suitability analysis showing samples from control and exposed sites in the Khiru River. In both cases, exposed samples show high sodium hazards.

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2) PH Abnormality

The pH itself is not usually problematic for water, but may create favourable conditions for toxicity in a certain range [28]. The normal pH range for irrigation water is between 6.5 and 8.4. An outlier value means the water needs further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion. Again, lower pH than in the usual range may incur accelerated irrigation system corrosion [38]. In February, two samples from control sites and two samples from exposed sites show pH values lower than 6.5; in March, two samples from control sites and three samples from exposed sites also showed pH values lower than 6.5. On average, the pH was found to be at the edge of the lower normal limit in both periods (6.7 ± 0.36 in February, 6.65 ± 0.50 in March). These findings suggest that the slightly acidic nature of the water may not have largely aggravated the sodium hazard in the area, but persistent use of such water for irrigation may incur corrosive effects on local irrigation equipment.

3) Nitrogen and Magnesium

In control sites nitrate was found to be high (~23 mg/L) in February except for the first two sites, where $NO_3$was found in lower amounts (~5 mg/L).March samples were typically low in nitrate, averaging 11.53 ± 5.53 mg/L, ranging from 2.8 to 24.5 mg/L. In the exposed sites, five of twelve samples show nitrogen in excess of 30 mg/L in February, while no such case is found in March. The rest of the samples (both in February and March) also average around ~20 mg/L, indicating a high amount of nitrate in the water. This indicates the application of N-fertilizer in February during the vegetative stage of crops, and may not be related with industrial discharge.

High levels of dissolved magnesium in irrigation water are thought be coupled with soil infiltration problems. The role of magnesium in such problems is not well understood yet, although there is a common agreement among researchers that [40, 41, 42, 43] the mechanism of magnesium acting in soil is similar to calcium rather than sodium, and its rate of absorption in soil is greater than that of sodium but lower than that of calcium. Therefore, in magnesium-dominated water (weight ratio: Ca/Mg < 1) the effect of sodium in soil may be increased. In the Khiru River, water samples show the domination of magnesium ions over calcium in March (seven sites out of sixteen in total, including both control and exposed sites) more than in February (one site out of sixteen). The excessive magnesium in river water may be the product of pre-monsoon (March-May) rainfall-runoff causing wash out of magnesium rich soil in the region, which may allow favourable conditions for accelerating the sodium hazard that already prevails in the area.

4) Chloride

Chloride is an essential element for plant growth in low concentrations, but may be toxic in higher concentration. According to Mass (1990), a chloride concentration between 140 and 350 mg/L is injurious to even moderately tolerant plants, while an excess of 350 mg/L may cause severe damage to plant life [44]. In February, seven sites (N = 16) showed Cl^- concentrations between 140 and 350 mg/L;in March, ten sites (N = 16) showed the same (Fig. 4), including both control and exposed sites. Additionally, in February three sites and in March one site showed a Cl- excess of 450 mg/L (Fig. 4). This reveals that a chloride hazard is present in the study area and may be one of the causes of apparent leaf injuries during crop cycles reported by the local farmers. However, it appears premon soon (March-May) rainfall plays an important role in creating dilution effect in Cl^- concentration.

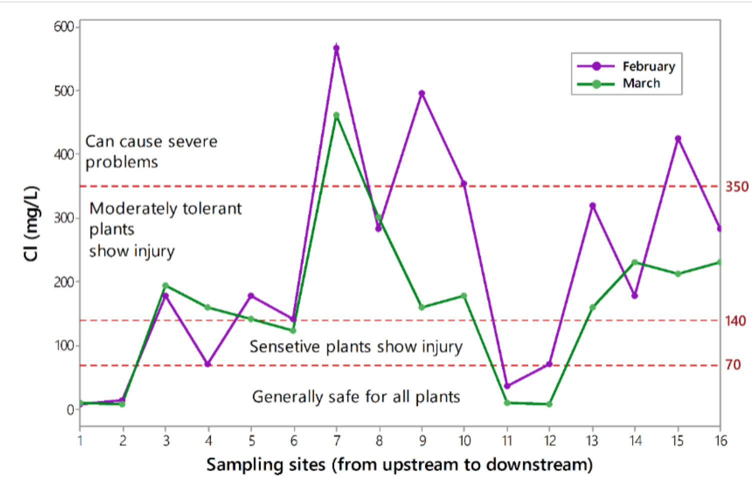

Fig. 4. Chloride concentration in Khiru River water samples. The plot indicates that most of the samples show Cl- concentrations that may cause injury to even moderately tolerant plants.

5) Dissolved trace Metals

Trace metals are essential for plant growth, but an excess of dissolved trace metals may cause bioaccumulation in plant

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tissue and result in moderate to serious injuries to plants, causing subsequent crop failure. Documentations recognize that most trace elements are readily fixed and accumulated in soils, and because this process is largely irreversible, repeated exposure of amounts in excess of plant needs eventually contaminate a soil and may either render the soil non-productive or the product unusable [28]. Eight trace metals were analysed in this study. A summary of their recommended maximum limits and possible impacts are presented in Table VI. The study area exhibits a considerable number of sites which exceed the recommended maximum limit of F, Mn, Cr. Cu, Cd and Zn. Table VII presents a summary of the trace metals found in the different sites over the time period. It is found that, with the exception of Cd, all the trace metals found in the control sites are within the maximum permissible limits, whereas the exposed sites show the opposite. This result depicts the influence of industrial discharge on water quality in the exposed sites. Cd is well known to be associated with phosphate fertilizer [45] and therefore expected to be in water in slightly higher amounts. However, Cd found in the control sites (0.24 $\pm$ 0.09 mg/L) is significantly less than that in the exposed sites (0.92 $\pm$ 0.60 mg/L), which might be explained by additional industrial input.

TABLE VI. SUMMARY OF THE MAXIMUM RECOMMENDED LIMIT OF STUDIED TRACE METALS FOR IRRIGATION PURPOSES AND THEIR EFFECTS ON PLANTS.

Trace metal	**Recommended maximum concentration (mg/L)**	**Possible effects when exposed to excess of recommended limit**
Cd	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
F	1.0	Inactivated by neutral and alkaline soils.
Fe	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Cr	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Mn	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Zn	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.
Pb	5.0	Can inhibit plant cell growth at very high concentrations.

TABLE VII SUMMARY OF THE ANALYTICAL RESULTS OF TRACE METALS IN KHIRU RIVER WATER SAMPLES (MG/L).

Time period	**Site**		**Fe**	**F^-**	**Mn^-**	**Cr^{2+}**	**Cu^{2+}**	**Cd**	**Pb**	**Zn^+**
Recommended limit			**5.0**	**1.0**	**0.2**	**0.1**	**0.2**	**0.01**	**5.0**	**2.0**
February	Control	Avg.	1.079	2.847	0.917	0.149	0.295	0.250	0.096	1.076
		Stdev.	0.308	0.523	0.169	0.145	0.114	0.085	0.044	0.613
	Exposed	Avg.	2.980	3.255	2.389	0.272	0.549	0.711	0.338	3.312
		Stdev.	1.419	1.007	1.222	0.172	0.168	0.255	0.176	1.530
March	Control	Avg.	1.195	1.620	1.140	0.112	0.276	0.237	0.145	1.382
		Stdev.	0.578	0.859	0.406	0.028	0.064	0.108	0.042	0.537
	Exposed	Avg.	3.166	3.261	1.890	0.192	0.510	1.135	0.263	3.323
		Stdev.	1.650	1.601	0.435	0.046	0.158	0.753	0.103	1.705

V. DISCUSSIONS AND POLICY OUTLOOK

This research shows that, although rapid urbanization and industrialization have generated huge quantities of industrial waste including liquid sewage, the amounts are yet unknown due to absence of monitoring activities from any responsible authority. However, the surface water of the Khiru River in Bangladesh has become the destination of those wastes, particularly the liquid waste. Deterioration of water quality used for irrigation is now a matter of serious concern in the river. The degradation of water resources can have significant effects on environmental quality, human health and even global warming [28, 46, 47]. In addition, the chemicals used in nearby agricultural fields is another important polluting agent in this region, although the recent introduction of the Integrated Pest Management (IPM) strategy hassled to diminishing use of pesticides.

This study shows that the concentration and composition of analysed chemical parameters have already exceeded the limits set by Department of Environment (DoE), the Government of Bangladesh. The increased concentrations of parameters may cause nutritional disorders in plants. The deterioration of surface water quality also leads to changes in groundwater quality. If the current trend of water quality deterioration continues, the image of agriculture as an environmentally benign practice would suffer [48]. This not only affects production prospects, but also the health of the population depending on it. Any scarcity of water in future may not be caused by physical scarcity of water [49] alone but by poor water quality as well. Managing water quality is still not receiving adequate attention, because it is significantly morecomplex, difficult and expensive compared to water quantity management [50-53].

The efforts and activities of water planners to mitigate the impacts of water utilization and development are often collectively referred to as water conservation. Generally, the goals of water conservation efforts include: sustainability, energy

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conservation and habitat conservation [54]. In this case of the Khiru River, water conservation could be a strategy to influence the usage of water in order to meet the objectives of economic efficiency, social equality, environmental protection and sustainability of water supply and services. The economic efficiency and social equality aspects of water conservation address the importance of water usage for irrigation purposes. Therefore, the findings in this study are helpful for the water planners/policy makers to approve future industrial construction or development along the Khiru River, and place attention on the discharge of effluent into the Khiru River water. Zoning regulations should be established for the location of new industries in consideration of fresh and safe water availability and effluent discharge possibilities.

The Government of Bangladesh has already provided attention to the issue of pollution by enacting a number of policies such as the National Environmental Policy 1992, Industrial Policy 1999 and National Water Policy 1999. Bangladesh Water Policy recognised that there is a growing need to provide total water quality management (checking salinity[55], deterioration of surface water and groundwater quality, and water pollution) and maintenance of the ecosystem [56]. The government's interest in protecting the rivers from pollution has also been reflected in the Environmental Conservation Act (ECA) 1995. According to the provisions made in the ECA-1995, the river water quality standards were developed by the Department of Environment (DOE), a government organisation. DOE is also responsible for monitoring the quality of the river water. Recently, the Government of Bangladesh formulated the Bangladesh Water Act 2013 [57].

For managing water resources (both quantity and quality), there are established policies in Bangladesh [58,59,60]. However, the actual implementation of these existing policies seems to be far behind what policy documents indicate [61, 62]. For actual implementation of the policies, water quality issues should be framed within existing policies and other regulatory mechanisms that may require further developments to facilitate mainstreaming. A holistic approach considering Integrated Water Resources Management (IWRM) principles [63,64] is therefore required to monitor the water quality to prevent further deterioration and to bring about improvement in the quality of water. Establishing uniform standards relating to water quality along with the establishment of an effective water quality monitoring network is integral. This monitoring system will be required by law to pay for the clean-up of water bodies polluted by any industry. Ultimately, the involvement of public and private sectors, communities, and individuals in water resources management should be ensured, and it is important to delineate the roles and responsibilities of everyone involved in the total water resource management. The principle that community resources should be managed by the community concerned [65], along with the local government institutions unless a greater national interest prevails, should guide and control water resource management in Bangladesh.

VI. CONCLUSIONS

From this study, sodium hazard is evident in the irrigation water, continuous use of which may appear to be detrimental to crop production in the region. The recent drop of production in spite of the increasing use of fertilizer likely to be related to such a sodium hazard. Farmers have also reported that the soils in the region appear plastic and not strong enough to hold plants during the ripening period, which is likely the effect of long term use of sodium rich irrigation water. However, a detailed analysis of soil chemistry is required to arrive ata definitive conclusion. In addition, given the prevailing conditions of generally low pH and significantly high concentrations of F, Mn, Cr. Cu, Cd and Zn compared to the control sites, it can be concluded that soil contamination by wastewater use presents long-term environmental and health risks. Long term use of irrigation with such high concentrations of Cd bioaccumulates in soils and plants which may end up settling in the human body and put human health in great danger. Cd is primarily toxic to the kidneys, especially to the proximal tubular cells [66]. Excess concentrations of Cu and Zn in irrigation water is also toxic to crops and eventually reduces crop production, which is a likely case in the study area.

The Khiru River is a life support system for the 7000ha of farming land in Mymensingh. Water chemistry proves to be a serious threat for this river, ultimately affecting irrigation water quality and posing a threat to the local farming communities. As deduced from the water quality of control and exposed sites, it appears that the industrial development alongside the river is the apparent source of such threats to water quality. Additionally, untreated discharge of municipal waste and poorly managed agricultural run-off may have exacerbated the situation. This calls for a rise of awareness in the community, development of policies regarding wastewater dumping and treatment, as well as the implementation of strict laws and regulations. Coordination among the state and municipal authorities in association with the farming community can enact solutions to such problems. In addition, a long-term monitoring program for water quality is required for the river to monitor and manage the situation. Otherwise, the deteriorating water quality may cause more serious damage to crop production, which may trigger occupation loss, mass migration and social unrest in the region. This is the time for the development of an integrated policy and immediate implementation

Notes: [1]Boro is local variety of winter rice that requires irrigation.

[2] Second tier of local administrative unit in Bangladesh: first tier is district, second is upazila, third is union and fourth is ward.

[3] A beel is a low-lying oxbow lake, typically inundated during monsoon flooding (wet season).

[4]Aman and Boro are local common names for seasonal varieties of rice in Bangladesh. Aman is a long life span rice variety usually harvested in December which matures through the summer rain, while Boro is a short life span rice variety that is harvested in March.

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