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Irrigation Water Quality Assessment of Chitra River, Southwest Bangladesh

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Abstract

Narail Sadar Upazilla is a major agricultural productive region of Narail District, Bangladesh. The crop production here significantly depends on the Chitra River water for irrigation. The present study was undertaken with an aim to evaluate the usability of this river water for irrigation purpose during pre-monsoon, monsoon and post-monsoon. Sampling was conducted three times in each season both in high tide and low tide. The collected samples were analyzed for some physicochemical parameters including pH, electrical conductivity (EC), total dissolved solid (TDS), major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and major anions (HCO_3^-, PO_4^{3-}, SO_4^{2-}, Cl^- and NO_3^-). The calculated chemical indices' values for the collected water samples during pre-monsoon indicate that this river water is chemically suitable for irrigation during pre-monsoon with respect to sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and permeability index (PI). The values of all chemical indices declare this river water fitness for use in irrigation both in monsoon and post-monsoon. According to Wilcox diagram, all of the water samples irrespective of tide and sampling stations fall within "permissible to doubtful" category during pre-monsoon while the water samples collected in both tide from all stations fall within "excellent to good" category during monsoon and post-monsoon. The United States Salinity Laboratory (USSL) diagram certifies this river water as C1-S1 (low salinity along with low sodium level) type during monsoon and post-monsoon which makes the river water suitable for use in irrigation in these two seasons while the water is mostly C3-S1, C3-S2 and C3-S3 (high salinity along with low to high sodium level) type in pre-monsoon which makes the river water restricted for use in irrigation in this season.

Keywords

Chitra, Irrigation, Suitability, USSL, Wilcox

1. Introduction

Water quality is one of the major environmental determinants that affect the ecosystem, agricultural production and socio economic development of a country (Dang et al., 2014; Islam et al., 2016). Bangladesh possess about 5,049,785 ha irrigation based agricultural land which demands sufficient water supply from ground water (80.60%) and surface water (19.40%) for irrigation to defend the crop's growth and agricultural yield (Shahid et al., 2006; Hasan et al., 2007; Rahman et al., 2014; Vyas & Jetho, 2015; FAO, 2011). Irrigation water obtained from different sources including springs, streams or wells which contain some chemical substances that may reduce soil fertility and crop yield (Mahmud et al., 2007). Major concern for crop cultivation is the presence of excess salts in water and soils which degrade water and soil quality and decrease crop yields in turn (Tsado et al., 2014). Carbonate, bicarbonate, magnesium, calcium, sulphate, and hardness are significant ions which at high concentration can alter suitability of irrigation water for use (Choudhary et al., 2007). Cations including sodium, calcium and magnesium mainly affect the groundwater quality for use in irrigation and other purposes. At low concentrations some cations are beneficial for crop while at high concentration they can alter the irrigation water quality and soil which exerts toxic effects to plants and thus the management task becomes more difficult (Mitra et al., 2007). Water quality is mainly altered in dry climates because of high evaporation rate and deficient leaching of deposited salts (Qayyum, 1970). The useable irrigation water quality is not identical all over the world but also depends on crops type and permeability of climate and soils. Hence irrigation water quality criteria developed by US salinity laboratory have followed in many countries to evaluate the usability of water in agricultural production (Khalil & Arther, 2010; Richards, 1954). The river water quality is mainly affected by anthropogenic process like industrial wastewater discharge, agricultural runoffs etc. and natural processes like precipitation, erosion etc (Bricker & Jones, 1995; Carpenter et al., 1998; Jarvie et al., 1998). Industrial wastewater discharge into water bodies is one of the constant anthropogenic polluting sources while surface runoff is one of the non-point polluting sources which is mainly influenced by climate and topography of the area (Shrestha & Kazama, 2007; Singh et al., 2004). The lack of irrigation water resources of sustainable quality due to population growth and water quality degradation is becoming a major challenge for agricultural production (Winpenny et al., 2010; Hoekstra & Mekonnen, 2012). Because of availability and cost effectiveness Chitra River is readily used as a major source of irrigation water around it. But no relevant study was conducted on Chitra River concerning this issue. Hence this study was conducted with an aim to assess the irrigation water quality of Chitra River that will support the crop production here and help to enlarge the local and national economy in turn.

2. Materials and Methods

2.1. Study Area

The present study was conducted on Chitra River located at southwestern Bangladesh. After originating from the downcast of Chuadanga and Darsana, this river flows about 170 km in southeast and joins with Nabaganga River in Gazirhat of Narail district (**Figure 1**). Under the study water samples were collected along the Chitra River that covered only Narail Sadar Upazila of Narail District.

The study area possesses a tropical monsoon climate. It experiences pre-monsoon from March to May, which is characterized by highest temperatures; Monsoon from June to September, which is characterized by heavy rainfall when about 80% rainfall occurs and Post-monsoon from October to November, which is characterized by lesser rainfall and tropical cyclones on coastal region (FAO, 2011).

2.2. Sampling and Preservation

Water samples were collected in three seasons namely pre-monsoon (April to May, 2017), monsoon (July to August, 2017) and post-monsoon (October to November, 2017) from five selected sampling stations (**Table 1**) maintaining about four km distance between two successive stations along the Chitra River both in high tide and low tide following the standard methods (APHA, 1999). Coordinates of the sampling spots were measured using a GPS device. The water sampling was conducted three times in each season maintaining 12 - 15 days interval and in total 90 samples were collected throughout the study period. For the analysis of cation and anion, samples were collected in two separate PET (polyethylene terephthalate) bottles. HCl acid was added (to pH ~2) into the samples for cationic analysis. Then the collected samples were reserved at 4˚C before to analysis.

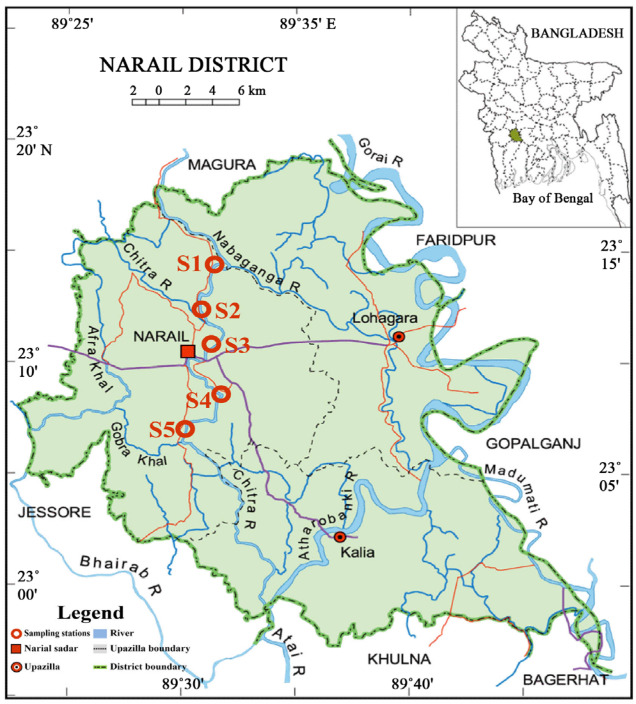

Figure 1. Location map of the sampling spots along the Chitra River (Source: http://narail.amardesh.com/).

Table 1. Description of the sampling locations.

St. No.	Dominant features of the stations	Sample ID	Co-ordinates	
			Longitude (E)	**Latitude (N)**
S1	Agriculture, Boating station, Commercial	S1HT, S1LT	89˚31'4.98"	23˚14'15.11"
S2	Agriculture, Boating station	S2HT, S2LT	89˚30'51.37"	23˚11'50.97"
S3	Commercial	S3HT, S3LT	89˚30'48.95"	23˚10'8.75"
S4	Commercial, Agriculture	S4HT, S4LT	89˚31'35.2"	23˚8'34.8"
S5	Agriculture, Boating station, Commercial	S5HT, S5LT	89˚29'51.53"	23˚6'30.62"

2.3. *In-Situ* and Laboratory Measurements

Under physical parameters pH, EC and TDS was measured in situ using pH meter (Model No. pH-5011) and EC/TDS meter (Model No. COND5022). Under major cations Na^+ and K^+ was measured using flame photometer (Model No. PEP 7 and PEP 7/C) while Ca^{2+} and Mg^{2+} was measured by complexometric titration using $AgNO_3$ solution following the guideline of standard procedure (Ramesh & Anbu, 1996). Potentiometric titration and Argentometric titration were adopted to determine HCO_3^- and Cl^- respectively (APHA, 1992). UV-Visible spectrophotometer (Model No. UVD-3200) was used to determine PO_4^{3-}, NO_3^- and SO_4^{2-} concentration in water samples (Ramesh & Anbu, 1996; APHA, 1992).

2.4. Methods for Irrigation Water Quality Assessment

For the evaluation of usability of Chitra River water in irrigation, some common water quality indices available for irrigation water quality assessment including total hardness, sodium percentage (Na%), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), Kelly's index (KI), permeability index (PI) and magnesium ratio (MR) were calculated using the standard equations (**Table 2**) and studied. Wilcox diagram and USSL diagram were also studied for the evaluation of this river water quality with respect to irrigational use.

3. Results and Discussion

3.1. General Hydrochemistry

The results obtained from the investigation showed a significant variation in general hydrochemistry among the three seasons under the study period. Summary of general hydrochemistry of the Chitra River is organized in **Table 3**. The minimum pH was found 7.33 in low tide during monsoon whereas the maximum pH was found 7.97 in low tide during pre-monsoon. The lower pH in monsoon is due to jute retting on Chitra River because during fiber-separation process various organic acids from the jute plant diffuse into water which affects the water pH (Roy & Hassan, 2016). Electrical conductivity (EC) of all sampling station during both of high tide and low tide varies from 1028.67 ± 320.81 $\mu S \cdot cm^{-1}$ and 941.47 ± 300.87 $\mu S \cdot cm^{-1}$ in pre-monsoon, 166.20 ± 0.87 $\mu S \cdot cm^{-1}$ and

Table 2. Common water quality indices for the irrigation water quality assessment.

Sl. no.	Water quality indices	References
1	$\text{Total Hardness}(\text{as } CaCO_3) = (Ca^{2+} + Mg^{2+}) \times 50$	Sawyer & McCarty, 1967
2	$Na\% = ((Na^+ + K^+) \times 100)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+)$	Wilcox, 1948
3	$SAR = Na^+/\sqrt{Ca^{2+} + Mg^{2+}}$	Richards, 1954
4	$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$	Apha et al., 1998
5	$KI = Na^+/(Ca^{2+} + Mg^{2+})$	Kelley, 1963
6	$MR = (Mg^{2+} \times 100)/(Ca^{2+} + Mg^{2+})$	Paliwal, 1972
7	$PI = ((Na^+ + \sqrt{HCO_3^-}) \times 100)/(Ca^{2+} + Mg^{2+} + Na^+)$	Doneen, 1964

For equation 1, all parameters are figured in mg/L and for equation 2 - 7, all parameters are figured in meq/L.

Table 3. Summary of water quality parameters of Chitra River during pre-monsoon, monsoon and post-monsoon.

Season	Tidal Periods	Statistical Parameters	pH	EC (μS·cm⁻¹)	TDS (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	HCO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)
Pre-moonsoon	High Tide	MIN	7.87	746.33	489.67	159.03	16.70	26.67	13.40	226.22	0.24	18.11	214.47	2.73
		MAX	7.93	1516.67	960.00	434.95	32.87	34.00	25.20	235.75	0.35	102.50	658.19	4.67
		Mean	7.91	1028.67	661.60	252.80	21.81	29.80	18.08	232.77	0.28	49.15	380.44	3.46
		Median	7.93	905.67	577.33	207.94	18.74	28.67	16.80	234.56	0.27	34.77	310.19	3.35
		SD	0.03	320.81	199.23	113.38	6.78	2.98	4.92	4.04	0.04	33.55	185.04	0.73
	Low Tide	MIN	7.77	681.33	427.33	141.80	15.66	25.33	12.20	230.98	0.24	24.11	174.30	3.13
		MAX	7.97	1402.67	895.00	383.24	28.37	32.67	23.00	244.68	0.33	112.00	579.01	4.82
		Mean	7.87	941.47	609.20	222.52	19.98	27.93	15.96	238.19	0.27	55.80	328.41	3.77
		Median	7.87	789.67	526.33	173.91	17.82	26.33	13.60	239.02	0.25	38.57	253.47	3.50
		SD	0.08	300.87	192.45	99.57	5.18	2.98	4.65	5.15	0.04	35.62	167.17	0.67
Moonsoon	High Tide	MIN	7.37	165.00	106.33	10.85	6.26	16.67	4.33	85.40	0.63	11.08	13.96	2.35
		MAX	7.43	167.00	111.67	12.72	6.83	18.67	4.93	89.34	0.67	13.17	15.06	2.65
		Mean	7.40	166.20	108.93	11.65	6.66	17.33	4.67	87.72	0.66	11.70	14.49	2.49
		Median	7.40	166.33	109.00	11.55	6.74	17.00	4.67	87.26	0.66	11.34	14.18	2.48
		SD	0.03	0.87	1.89	0.68	0.23	0.85	0.27	1.66	0.02	0.85	0.53	0.11
	Low Tide	MIN	7.33	160.00	105.33	10.04	6.09	16.67	4.07	81.47	0.64	11.08	13.29	2.38
		MAX	7.40	163.67	108.00	12.25	6.30	17.00	4.80	91.19	0.66	12.15	14.18	2.49
		Mean	7.36	162.40	106.13	11.23	6.21	16.80	4.45	85.35	0.65	11.40	14.00	2.43
		Median	7.37	163.33	105.33	11.09	6.26	16.67	4.47	83.32	0.66	11.25	14.18	2.42
		SD	0.03	1.66	1.19	0.85	0.10	0.18	0.28	4.59	0.01	0.43	0.40	0.04
Post-moonsoon	High Tide	MIN	7.60	211.00	138.00	19.02	3.70	20.33	5.33	115.79	0.26	5.90	23.93	2.01
		MAX	7.67	227.67	150.33	21.83	4.28	23.67	6.20	119.96	0.31	8.26	29.80	2.14
		Mean	7.63	216.87	143.47	20.40	3.88	21.47	5.84	118.51	0.28	6.93	26.52	2.09
		Median	7.63	214.33	142.33	20.30	3.81	21.00	6.00	119.20	0.28	6.92	25.70	2.11
		SD	0.02	6.76	4.81	1.05	0.23	1.41	0.36	1.79	0.02	0.87	2.47	0.05
	Low Tide	MIN	7.60	198.67	132.00	18.08	3.60	19.67	5.00	110.87	0.25	6.67	23.04	1.98
		MAX	7.63	217.67	145.33	21.04	3.84	22.00	5.73	119.95	0.29	8.00	26.28	2.14
		Mean	7.61	205.47	137.20	19.61	3.69	20.67	5.43	115.81	0.27	7.25	24.75	2.06
		Median	7.60	201.00	135.00	19.25	3.67	20.33	5.40	115.04	0.26	7.10	24.81	2.05
		SD	0.02	8.05	6.02	1.18	0.11	0.97	0.29	3.96	0.01	0.56	1.31	0.07

162.40 ± 1.66 μS·cm^{-1} in monsoon and 216.87 ± 6.76 μS·cm^{-1} and 205.47 ± 8.05 μS·cm^{-1} in post-monsoon respectively. Highest TDS was observed 960.00 mg/L during pre-monsoon while lowest TDS was observed 105.33 mg/L during monsoon. The average Na^+ concentrations were observed 252.80 ± 113.38 mg/L and 222.52 ± 99.57 mg/L, 11.65 ± 0.68 mg/L and 11.23 ± 0.85 mg/L, and 20.40 ± 1.05 mg/L and 19.61 ± 1.18 mg/L in pre-monsoon, monsoon and post-monsoon respectively in their respective high tide and low tide.

Maximum potassium ion concentration was noticed 32.87 mg/L in pre-monsoon during high tide and minimum concentration was noticed 3.60 mg/L in post-monsoon during low tide. Highest potassium concentration in the river water during pre-monsoon may be because of upward sea water movement during dry season which contains high content of potassium due to the dissolution of potassium containing sedimentary rocks in the sea water (Hem, 1970). Again under the study higher concentration of potassium was observed in monsoon season compared to post-monsoon which may be cause of potassium containing fertilizer runoff mixing with rain water during monsoon. Maximum calcium concentration was found 34.00 mg/L in pre-monsoon while minimum concentration was found 16.67 mg/L in monsoon. Also maximum magnesium concentration was found 25.20 mg/L in pre-monsoon and minimum concentration was found 4.07 mg/L in monsoon. Dissolved magnesium concentration is usually lower than dissolved calcium for a majority of the natural waters because of the high solubility of Mg salts into water than Ca salts (Ramesh & Anbu, 1996). Bicarbonate ion concentration was observed to vary 232.77 ± 4.04 mg/L for high tides and 238.19 ± 5.15 mg/L for low tides in pre-monsoon, 87.72 ± 1.66 mg/L for high tide and 85.35 ± 4.59 mg/L for low tide in monsoon and 118.51 ± 1.79 mg/L for high tide and 115.81 ± 3.96 mg/L for low tide in post-monsoon. Variation in bicarbonate concentration in river water may be due to wastewater discharge into the river and bicarbonate weathering (Datta & Subramanian, 1997; Li & Zhang, 2009). In the study area phosphate ion concentration was observed with an average value 0.28 ± 0.04 mg/L (high tide) and 0.27 ± 0.04 mg/L (low tide) in pre-monsoon, 0.66 ± 0.02 mg/L (high tide) and 0.65 ± 0.01 mg/L (low tide) in monsoon and 0.28 ± 0.02 mg/L (high tide) and 0.27 ± 0.01 mg/L (low tide) in post-monsoon. The higher concentration of phosphate in the river water during monsoon might be coming from the phosphate containing fertilizer used for jute cultivation (Roy & Hassan, 2016). Sulfate concentration was found to vary widely among the three sampling seasons. Maximum sulfate concentration was recorded 112.00 mg/L in low tide during pre-monsoon and minimum concentration was recorded 5.90 mg/L during post-monsoon in high tide. Higher concentration of sulfate in the river water during pre-monsoon may be due to wreathing coupled with erosional deposits into the river (Varol et al., 2012). Chloride ion concentration was recorded 380.44 ± 185.04 mg/L for high tide and 328.41 ± 167.17 mg/L for low tide in pre-monsoon, 14.49 ± 0.53 mg/L for high tide and 14.00 ± 0.40 mg/L for low tide in monsoon and 26.52 ± 2.47 mg/L for high tide and 24.75 ± 1.31 mg/L for low tide in post-monsoon. Maximum concentration of chloride ion was recorded 658.19 mg/L in pre-monsoon during high tide and minimum concentration was recorded 13.29 mg/L in monsoon during low tide. In the coastal water zone, the chloride concentration in water is directly proportional to its salinity (Ayers & Westcot, 1994). Since chloride ion is a major anionic constituent in sea water, higher chloride ion concentration in river water indicates a significant influence of sea water on the river hydrochemistry (Bu et al., 2010; Appelo & Postma, 2010). In the study area nitrate ion concentration varied between 3.46 ± 0.73 mg/L for high tide and 3.77 ± 0.67 mg/L for low tide in pre-monsoon, 2.49 ± 0.11 mg/L for high tide and 2.43 ± 0.04 mg/L for low tide in monsoon and 2.09 ± 0.05 mg/L for high tide and 2.06 ± 0.07 mg/L for low tide in post-monsoon. Agricultural runoff, industrial wastewater and sewage disposal are the major sources of river water contamination with nitrate ion while microbial consumption and de-nitrification are the main routes of nitrate reduction (Rahman et al., 2014; Varol et al., 2012).

3.2. Suitability for Irrigation

In order to evaluate the Chitra River water suitability for use in irrigation purpose, water quality parameters that mainly affect the crop production need to be studied. The statistical summary of calculated chemical indices related to irrigation water quality is listed in **Table 4**.

Depending on pH value, irrigation water is mainly classified into three classes (**Table 5**). Based on this classification all of the water samples irrespective of season and tide fall within "no problem" class. Electrical conductivity (EC) expresses the total concentration of all soluble salts and it is used widely to classify the irrigation water (Varol et al., 2012). According to Richards (1954), during pre-monsoon 20% of water samples collected in high tide and 40% of water samples collected in low tide are marked as "good" and the rest 80% water samples for high tide and 60% water samples for low tide are categorized as "permissible" for use in irrigation. Irrespective of tide during monsoon and post-monsoon 100% of the water samples were marked as "excellent" for use in irrigation. High EC bearing water used in crop production can reduce the crops growth rate, lower the crop yield and create nutritional disorders under specific condition (Eaton, 1950). TDS and EC values are interrelated and both values indicate the salinity of water when non-ionic dissolved constituents remain absent (Meybeck et al., 1992). Based on TDS values, most of the samples during pre-monsoon for both of high tide and low tide are categorized as "permissible" and all of the water samples during monsoon and post-monsoon for high tide and low tide are categorized as "good" for use in irrigation. The water bearing high sodium level can damage the structure of soil by replacing calcium ion and magnesium ion present in the soil which affects the soil fertility and crop yield capacity in turn (Ayers & Westcot, 1994; Gupta, 2005). During pre-monsoon sodium content in 60% water samples for both of high tide and low tide fall within "moderate" level and the rest 40% for both tide falls within "severe" limit while 100% of water samples irrespective of tide contain safe range of sodium

Table 4. Statistical summary of calculated indices.

Season	Tidal Cycle	Descriptive Statistics	TH (as $CaCO_3$)	Na%	SAR	RSC	PI	KI	MR
Pre-moonsoon	High Tide	MIN	2003.33	74.98	6.25	−0.09	91.47	2.82	45.58
		MAX	2960.00	83.87	13.72	1.40	94.78	4.98	55.26
		Mean	2394.00	78.27	8.79	0.82	92.89	3.54	49.66
		Median	2273.33	77.07	7.60	1.03	92.69	3.19	49.41
		SD	393.95	3.64	3.07	0.60	1.38	0.88	4.18
	Low Tide	MIN	1876.67	74.20	5.77	0.24	92.06	2.70	44.37
		MAX	2783.33	83.05	12.51	1.64	96.40	4.69	53.99
		Mean	2194.67	77.81	8.11	1.18	94.53	3.42	48.11
		Median	1996.67	76.60	6.83	1.56	95.53	3.09	46.26
		SD	380.49	3.52	2.75	0.61	1.98	0.80	4.35
Moonsoon	High Tide	MIN	1066.67	34.46	0.60	0.12	94.10	0.39	28.51
		MAX	1156.67	35.78	0.68	0.22	98.03	0.42	33.04
		Mean	1100.00	35.02	0.64	0.18	96.84	0.40	31.00
		Median	1096.67	35.12	0.64	0.19	97.23	0.40	31.82
		SD	34.40	0.53	0.03	0.04	1.57	0.01	2.09
	Low Tide	MIIN	1036.67	32.65	0.56	0.11	95.99	0.36	28.91
		MAX	1080.00	36.02	0.68	0.26	99.79	0.43	32.43
		Mean	1062.67	34.82	0.63	0.19	98.31	0.40	30.62
		Median	1073.33	35.19	0.62	0.19	98.67	0.41	30.45
		SD	18.47	1.27	0.04	0.06	1.52	0.03	1.28
Post-moonsoon	High Tide	MIN	1283.33	37.83	0.95	0.23	108.62	0.54	30.39
		MAX	1493.33	40.09	1.03	0.44	118.91	0.59	33.21
		Mean	1365.33	38.76	1.00	0.38	115.83	0.57	31.21
		Median	1330.00	38.55	1.02	0.44	118.23	0.57	30.77
		SD	83.09	0.91	0.03	0.09	4.40	0.02	1.17
	Low Tide	MIN	1233.33	37.82	0.93	0.37	115.43	0.54	29.76
		MAX	1386.67	40.06	1.03	0.49	121.72	0.60	30.77
		Mean	1304.67	38.94	0.99	0.41	117.71	0.57	30.44
		Median	1286.67	39.00	1.00	0.39	117.11	0.58	30.68
		SD	62.52	0.81	0.04	0.05	2.38	0.02	0.42

during monsoon and post-monsoon making the water suitable for use in irrigations. Irrigation water with high sulfate ion concentration limits the absorption of calcium and increases the uptake of sodium and potassium by plants (Tiwari & Manzoor, 1988). According to Eaton (1942), irrespective of season and tide Chitra River water was evaluated as suitable for use in irrigation with respect to sulphate concentration. Chloride at lower concentration is an essential nutrient

Table 5. Analysis of water quality classes of Chitra River with respect to agricultural use during pre-monsoon, monsoon and post-monsoon.

Parameters	Rate of hazard	Water quality classes	Pre-monsoon		Monsoon		Post-monsoon	
			High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
pH[a,b]	6.5 - 8.4	No problem	All	All	All	All	All	All
	5.1 - 6.4 and 8.5 - 9.5	Moderate						
	0-5.0 and 9.5+	Severe						
EC[c] (μS·cm^{-1})	<250	Excellent			All	All	All	All
	250 - 750	Good	S1HT	S1LT,S2LT				
	750 - 2250	Permissible	S2HT - S5HT	S3LT - S5LT				
	>2250	Unsuitable						
TDS[a,b] (mg/L)	<450	Good		S1LT	All	All	All	All
	450 - 2000	Permissible	All	S2LT-S5LT				
	>2000	Unsuitable						
Na^{+}[a,b] (meq/L)	<3	No problem			All	All	All	All
	3 - 9	Moderate	S1HT - S3HT	S1LT - S3LT				
	>9	Severe	S4HT, S5HT	S4LT, S5LT				
SO_4^{2-}[d] (meq/L)	<4	Excellent	All	All	All	All	All	All
	4 - 12	Good to injurious						
	>12	Injurious to unsuitable						
Cl^{-}[a,b] (meq/L)	<4	No problem			All	All	All	All
	4 - 10	Moderate	S1HT - S3HT	S1LT - S3LT				
	>10	severe	S4HT, S5HT	S4LT, S5LT				
NO_3^{-}[a,b] (mg/L)	<5	No problem	All	All	All	All	All	All
	5 - 30	moderate						
	>30	severe						
Na%[e]	<20	Excellent						
	20 - 40	Good			All	All	S2HT - S5HT	S2LT - S5LT
	40 - 60	Permissible					S1HT	S1LT
	60 - 80	Doubtful	S1HT - S4HT	S1LT - S4LT				
	>80	Unsuitable	S5HT	S5LT				
SAR[c]	<10	Excellent	S1HT - S4HT	S1LT - S4LT	All	All	All	All
	10 - 18	Good	S5HT	S5LT				
	18 - 26	Doubtful						
	>26	Unsuitable						
RSC[f]	<1.25	Safe	S2HT - S5HT	S4LT - S5LT	All	All	All	All
	1.25 - 2.50	Permissible	S1HT	S1LT - S3LT				
	>2.50	Unsuitable						

[a]Ayers & Westcot ,1994; [b]Sundaray et al., 2009; [c]Richards, 1954; [d]Eaton, 1942; [e]Wilcox, 1948; [f]Wilcox, 1955.

for plant but excess chloride may cause chloride toxicity to the plant. A chloride concentration of about 140 - 350 mg/L in irrigation water is injurious to plants while > 350 mg/l is fatal to plants which can cause leaf tissue drying or leaf burning (Mass, 1990). According to classification given by Ayers and Westcot (1994), Chitra River water shows moderate to severe chloride toxicity during pre-monsoon and does not show any chloride toxicity during monsoon and post-monsoon. Nitrogen is another essential nutrient for plant that stimulates plant growth but excess nitrogen can cause injury to plant. Latent soil nitrogen and supplementary nitrogen containing fertilizers are the major sources of nitrogen. Nitrogen contaminants in irrigation water possess the same effect on plant as like as latent soil and supplementary fertilizer nitrogen (Ayers & Westcot, 1994). The nitrogen concentrations in this river water are categorized under "no problem" class (**Table 5**) during the study period which reveals that the Chitra River water do not possess any nitrate hazard. Based on hardness, Durfer and Backer classified water as "soft" (0 - 60 mg/Las $CaCO_3$), "moderately hard" (60 - 150 mg/L as $CaCO_3$), "hard" (120 - 180 mg/L as $CaCO_3$) and "very hard" (>180 mg/L as $CaCO_3$) (Durfer & Backer, 1964). According to this classification Chitra River water fall within "very hard" class and assigned as unsuitable for use in irrigation. SAR and Na% indices are generally related with sodium hazard possessing in irrigation water. Based on Na%, 100% of water samples during pre-monsoon fall within "doubtful" to "unsuitable" category and marks this water unsuitable for use in irrigation during this season while 100% of water samples during monsoon and post-monsoon are categorized within "good" to "permissible" category and marks this water suitable for use in irrigation purpose during those two seasons. SAR is a expression of exchange ability of sodium ion with calcium and magnesium ions in soil which measures a water's suitability for use in irrigation purpose with respect to sodium hazard (Tiwari & Manzoor, 1988; Sundaray et al., 2009; Haritash et al., 2008). Based on SAR, All water samples irrespective of season and tide fall within "excellent" to "good" category and was assigned as suitable for irrigation (**Table 5**). In water bearing high carbonate concentration, the carbonate precipitates with calcium and magnesium as their carbonate. When all of the calcium and magnesium ions get precipitated, the remaining carbonate or bicarbonate ions precipitate with sodium forming sodium carbonate (RSC) or bicarbonate in solution (Haritash et al., 2008). Use of irrigation water having high RSC value might cause sodium carbonate accumulation in soil which turns soil into black colored (Eaton, 1950). Depending on RSC values, all of the water samples collected from Chitra River irrespective of tide and season fall within "safe" to "permissible" class making this water compatible for use in irrigation. Based on permeability index (PI), Doneen (1964) classified irrigation water into three classes namely Class I, Class II and Class III, where water of Class I and Class II are marked as "good" for irrigation having 50% - 75% or more of permeability index range and Class III is categorized as "unsuitable" for irrigation having 25% of maximum permeability index range

(Doneen, 1964). Under the study, during pre-monsoon the permeability index values fall between 91.47 to 94.78 and 92.06 to 96.40 for high tide and low tide respectively which are categorized as Class I and Class II indicating its "suitability" for use in irrigation. PI values of the water samples collected from Chitra River during Monsoon ranges from 94.10 to 98.03 in high tide and 95.99 to 99.79 in low tide respectively while PI values in post-monsoon ranges from 108.62 to 118.91 and 115.43 to 121.72 in high tide and low tide respectively. Therefore all of the water samples collected from Chitra River during monsoon and post-monsoon fall under Class I and Class II category which certifies the "suitability" of this water for use in irrigation purpose during these two agricultural seasons. Kelly's index (KI) is another significant parameter to measure the usability of irrigation water. Waters with KI < 1 are categorized as "suitable" for crop irrigation, while waters with KI > 1 are considered as "unsuitable" (Kelley, 1963; Paliwal & Singh, 1967). The calculated KI values of all water samples collected from Chitra River irrespective of tide during pre-monsoon were >1 indicating that the water is "unsuitable" for use in crop irrigation during this season. In the monsoon and post-monsoon, the calculated KI values for all water samples collected during high tide and low tide were <1 indicating its suitability for use in irrigation purpose. According to Paliwal, irrigation water having MR value more than 50% makes the soil more alkaline and therefore adversely affects the crop yield (Paliwal, 1972). During pre-monsoon, 40% water samples for both of high tide and low tide possess a MR value more than 50% indicating its unsuitability for irrigation. The rest 60% samples in high tide and low tide were evaluated as suitable for irrigation. During monsoon and post-monsoon all of the water samples for high tide and low tide were assigned as safe for use in irrigation bearing a MR value less than 50%.

3.3. Assessment of Irrigation Water Quality with Respect to FAO and DoE Standards

The usual irrigation water quality parameters for the collected water samples from Chitra River were compared with the DoE standards (DoE, 1997) and FAO standards (Ayers & Westcot, 1985) enlisted in **Table 6**. According to DoE, 1997 and FAO, 1985 the values of all irrigation water quality parameters including pH, EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^- and SAR for the water samples collected from Chitra River fall within the acceptable limit during pre-monsoon, monsoon and post-monsoon. Thus, it can be recommended that the Chitra River water is chemically suitable for crop production during pre-monsoon, monsoon and post-monsoon.

3.4. Evaluation of Irrigation Water Quality from Graphical Representations

From the Wilcox diagram (**Figure 2**) it is observed that during pre-monsoon, irrespective of the sampling locations and tide, 100% water samples collected from Chitra River fall within "permissible to doubtful" category whereas all of

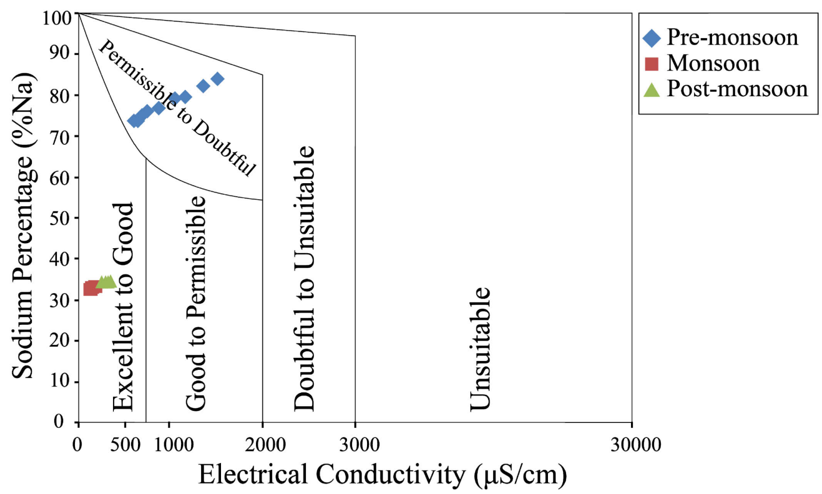

Figure 2. Wilcox diagram for the classification of Chitra River water.

Table 6. Water quality evaluation of Chitra River for irrigation purpose comparing with FAO and DoE standards.

Parameters	FAO[a]	DoE[b]	Percentage (%) of samples within the ranges		
			Pre-monsoon	Monsoon	Post-monsoon
pH	6.0 - 8.5	6.5 - 8.5	100	100	100
EC ($\mu S \cdot cm^{-1}$)	0 - 3000	2250	100	100	100
TDS (mg/L)	0 - 2000	2100	100	100	100
Na^+ (meq/L)	0 - 40	43.5	100	100	100
K^+ (meq/L)	0 - 20		100	100	100
Ca^{2+} (meq/L)	0 - 20		100	100	100
Mg^{2+} (meq/L)	0 - 05		100	100	100
HCO_3^- (meq/L)	0 - 10		100	100	100
SO_4^{2-} (meq/L)	0 - 20		100	100	100
Cl^- (meq/L)	0 - 30		100	100	100
NO_3-N (mg/L)	0 - 10	10	100	100	100
SAR (meq/L)	0 - 15	23	100	100	100

[a]Ayers & Westcot, 1985; [b](DoE, 1997).

the samples, fall within "excellent to good" category during monsoon and post-monsoon. Therefore, it can be assumed that the Chitra River water can be used in crop production during these three agricultural seasons. The USSL (US Salinity Laboratory Staff) diagram (Figure 3), a plot of EC (salinity hazard) against SAR (sodium hazard or alkalinity hazard) reflects the effect of EC and SAR (Richards, 1954). The SAR and EC values for all of the water samples collected from Chitra River were plotted in a diagram (Figure 3). Irrespective of tide all of the water samples collected during monsoon and post-monsoon fall into C1-S1 field indicating low salinity hazard along with low sodium level.

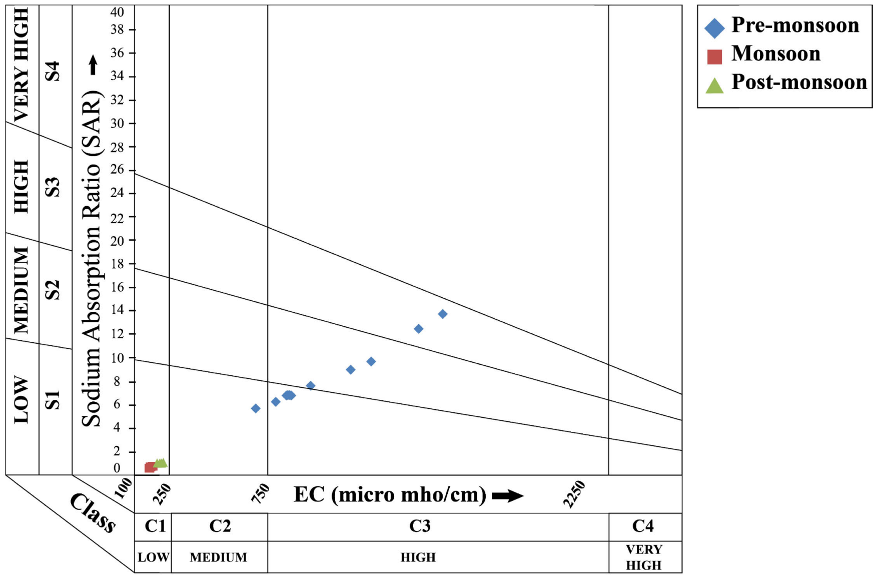

Figure 3. US salinity laboratory diagram for the classification of Chitra River water.

While during pre-monsoon 10% of the sample fall into C2-S1 (medium salinity hazard along with low sodium level), 40% of the sample fall into C3-S1 (high salinity hazard along with low sodium level) field, 30% of the sample fall within C3-S2 (high salinity hazard along with medium sodium level) and the rest 20% of the sample fall within C3-S3 (high salinity hazard along with high sodium level) field in pre-monsoon. Salinity in water reduces the water uptake rate by the plant because of osmotic effect, possesses ion specific toxic effects and also causes nutritional imbalance in plant (Natarajan et al., 2005). Sodium hazard affects the texture of soils, while high salinity content in irrigation water influences the crop growth directly. Therefore, water with high salinity is completely unsuitable for use in crop irrigation purpose (Haritash et al., 2008).

4. Conclusion

The findings of the present study on Chitra River show that the seasonal variation of the hydrochemistry of this river system is significant. In pre-monsoon Na^+ is the dominant cation with a cationic order $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ while Cl^- is the most dominant anion with a anionic order $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$. During monsoon and post-monsoon the cationic order has been found as $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$ and $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ respectively while the anionic order has been found to be $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$ both in monsoon and post-monsoon. Like major rivers, irrespective of tidal cycle, the water of Chitra River is alkaline in nature with pH 7.77 to 7.97 during pre-monsoon, 7.33 to 7.43 during monsoon and 7.60 to 7.67 during post-monsoon. In pre-monsoon EC varies with an average value of 1028.67 ± 320.81 for high tide and 941.47 ± 300.87 for low tide, in monsoon 166.20 ± 0.87 for high tide and 162.40 ± 1.66 for low tide and in post-monsoon 216.87 ± 6.76 for high tide and 205.47 ± 8.05 for low tide. The water quality parameters including pH, EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^- and SAR estimated for all of the water samples satisfy the value limit given by DoE, 1997 and FAO, 1985 for irrigation purpose during monsoon, monsoon and post-monsoon indicating its suitability for use in agriculture. During pre-monsoon the values of SAR, RSC and PI indicate that this river water is suitable for use in crop irrigation purpose while the river water is identified as "unsuitable" with respect to KI and "doubtful to unsuitable" with respect to Na%. The values of all chemical indices permit the Chitra River water for use in agricultural irrigation purpose during monsoon and post-monsoon. Based on Wilcox diagram, the water samples fall within "permissible to doubtful" category during pre-monsoon while all of the water samples fall within "excellent to good" category during monsoon and post-monsoon indicating its usability for irrigation during these agricultural seasons. Again according to USSL diagram, the river water can be used in irrigation during monsoon and post-monsoon because of low salinity with low sodium while during pre-monsoon this river water turns restricted for use in irrigation because of its high salinity coupled with low to high sodium. This river supports the regional crop production in this area. Hence, from this study it could be suggested that further studies regarding heavy metal pollution and periodic monitoring of water quality should be carried out. Awareness program and strict enforcement against domestic and municipal wastewater disposal into the river water should be adopted. Alternative sources for irrigation water and efficient irrigation methods should be found out.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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