ORIENTAL JOURNAL OF CHEMISTRY
An International Open Access, Peer Reviewed Research Journal
www.orientjchem.org

ISSN: 0970-020 X
CODEN: OJCHEG
2024, Vol. 40, No.(4):
Pg. 1189-1198

Multivariate Analysis for Assessment of Vamsadhara River Water Quality, Andhra Pradesh, India

CH. V. SAIKRISHNA[1]*, L. VAIKUNTA RAO[2] and D. MALLIKARJUNA RAO[3]

*[1]Department of Chemistry, Dr.V.S. Krishna GDC(A), Visakhapatnam, India.
[2]Department of Chemistry, GITAM (Deemed to be University), Visakhapatnam, India.
[3]Scientist, Akshaya Innotech, Visakhapatnam, India.
*Corresponding author E-mail: saisrikar.ch@gmail.com

http://dx.doi.org/10.13005/ojc/400435

(Received: February 13, 2024; Accepted: July 27, 2024)

ABSTRACT

Vamsadhara is a prominent river in north-western Andhra Pradesh. Without enough and reliable knowledge on the quality of the water, people utilize it for home and agricultural purposes quite a lot. This study aims to evaluate the quality of river water for agricultural and domestic consumption. Water samples from 10 sampling stations were collected during the pre and post-monsoon seasons of 2021, and the water quality index and agricultural indices were computed. The Water Quality Index was found to be satisfactory in both the seasons. Correlation and regression analyses are performed to understand the relationship between various hydrochemical parameters. The pre-season and post-season principal components were found to explain 81.3% and 78.9% of the total variance, respectively. The variables in both seasons are solely hydro-chemical and are believed to result from geological processes, suggesting geogenic sources. Water quality parameters for irrigation are within the limits. In irrigated soils, a higher growth of exchangeable Na is typically encouraged by elevated Mg levels. Water with a magnesium hazard level below fifty is considered suitable for irrigation. The Mg hazard was slightly excessive in most of the examined locations of the Vamsadhara River. The river water quality for irrigation is good to excellent, with exemptions from MH. Prioritizing effective sewage water treatment facilities before release into rivers.

Keywords: Vamsadhara river, Hydrochemical parameters, Magnesium hazard, Principal components, WQI.

INTRODUCTION

Water is a vital natural resource for life as we know it. The utmost prerequisite for life is water, and ever since the very start of time, individuals have made efforts to make use of the resources that are accessible. The unregulated use of water for industrial, drinking, and agricultural reasons has resulted in a considerable decline in both water quality and availability. Rivers serve a variety of purposes, such as producing energy, irrigation, drinking water, and fishing[1]. The physicochemical properties of water determine its quality. Water quality is classified and assessed using physical and chemical factors. The unrestricted use of water for industrial, drinking, and agricultural activities has led to a significant decrease in both water quality and availability. Pesticides, fertilizer usage, pollution movement from highland to lowland, unplanned urbanization, rapidly rising population, and increasing industries reduce water quality and pose a water supply hazard. Water quality drastically declines as pollutants from sewage and agricultural drainage enter the rivers. River streams are contaminated due to both natural and man-made causes. Natural processes, including erosion, the weathering of rocks and minerals, and changes in the geology, are a few of the causes of river pollution[2,3]. The main human activities that contribute to pollution are mining, smelting, oil refining, pesticide and fertilizer use, petrochemical manufacture, mining, raw sewage silt, etc.[4,5]. The level of soluble salts is an essential criterion for irrigation water quality. The categorization of water quality for effective management alternatives is becoming a problem as people become more aware of the importance of fresh water systems for public benefit and aquatic life6. Pollution in aquatic environments occurs due to the introduction of various nutrients from runoff water and sewage discharge[7]. The impact of water quality on product quality and soil properties is taken into consideration to assess its suitability for irrigation. Irrigation water contains a negligible, but discernible, amount of salt. These are developed due to the degradation of lime stone, gypsum, and fertilizers, conveyed by water, and settled in the land due to the usage of water by-products or the evaporation of surface waters[8]. Agriculture is a primary sector for most dwellers of the river basin; hence, the socio-economic growth of the people is influenced by the river water quality and water resources[9]. This study uses multivariate analysis such as correlation, linear regression, and principal component analysis to discover hydro-geochemical elements that are thought to be responsible for declining river water quality[10]. The Vamsadhara River basin is rich in biodiversity, with diverse flora and fauna inhabiting its riparian zones and surrounding forests. The river is known for its seasonal variability in flow. During the monsoon season, it experiences significant increases in water volume, leading to occasional flooding in the surrounding areas. However, during the dry season, the water levels recede substantially. However, like many rivers in India, the Vamsadhara is facing environmental challenges due to pollution, deforestation, and unsustainable agricultural practices. Efforts are being made to mitigate these issues through conservation measures and sustainable development initiatives; thus, the purpose of this research was to perform multivariate analysis to elucidate the quality of Vamsadhara water for drinking and irrigation.

MATERIALS AND METHODS

Study Area: The Vamsadhara River begins its journey in the Eastern Ghats, a mountain range located along India's eastern coast. It specifically rises from the hills close to Thuamul Rampur in Odisha's Kalahandi district. Flowing southwards, the river traverses the districts of Kalahandi, Rayagada, Gajapati, and Ganjam within Odisha. It covers approximately 254 kilometers of distance and eventually merging with the Bay of Bengal at Kalingapatnam in Srikakulam district of Andhra Pradesh state. Rice and cane sugar are the major vegetation in the river basin. The river's catchment basin covers an area of 10,830 square kilometers. The famous tourist sites of Srikakulam district and the river hold cultural significance for the people living in the regions through which it flows. It has been mentioned in various ancient texts and folklore. Several temples and religious sites are located along its banks, attracting pilgrims and tourists. The catchment area's primary uses of Vamsadhara Water are agriculture and household use. The ecological significance of the Vamsadhara River makes it remarkable. Like many other rivers in India, the Vamsadhara encounters environmental issues from both natural and man-made sources. The ongoing study's primary focus is on the Vamsadhara River in North Andhra Pradesh's suitability for drinking and irrigation water quality assessment at 10 sampling locations.

Sampling and Analysis

Samples were collected from the Vamsadhara River from up to downstream along the river throughout two seasons (pre-monsoon and post-monsoon) and tested for different physicochemical characteristics of water qualities according to the standard methods[11]. In the study area, samples were analyzed in this investigation from ten different locations. For the qualitative study, water samples were collected before and after the monsoon period of 2021 in Vamsadhara. Clean 2-L plastic bottles cleaned with nitric acid and distilled water were used to collect the samples. During the sample examination, hydro-chemical parameters like pH, electrical conductivity, total dissolved solids, dissolved oxygen, COD, BOD, total organic carbon, salinity, alkalinity, anions, and cations were measured[12]. Water samples were analyzed according to standard APHA procedures[13]. Titrimetric methods and UV-Visible spectrophotometric methods were used to determine the parameters such as total hardness, alkalinity, nitrates, sulphates and phosphates etc. WQI, multivariate statistical analysis like correlation analysis, linear regression analysis, and principal component analysis are performed by using SPSS and water quality parameters for irrigation and agriculture such as sodium absorption ratio, permeability index, sodium percentage, residual sodium carbonate, residual sodium bicarbonate, magnesium hazard, and Kelly's index[14] are determined by using hydrochemical parameters to assess the suitability of Vamsadhara River water for irrigation in the current study region.

RESULTS AND DISCUSSION

Hydrochemical parameters: The mean, minimum, maximum, and standard deviation values of hydrochemical parameters for assessing water quality are shown in Table 1. All the samples' pH levels were verified to be inside the permissible limit. and in many locations, the water is slightly alkaline. The ability of water to conduct electric current is known as its electrical conductivity (EC), and it is correlated with both the amount of dissolved ionized compounds. As it comes to drinking water, the suggested value of EC is 500µS/cm; in pre-monsoon, EC values are slightly greater than post-monsoon. Alkalinity is a measure of water's resistance to changes in pH. The suggested alkalinity in drinking water is 20–200 mg/L; the average TA in pre-monsoon is 148.9 mg/L and 148.6 mg/L in post-monsoon. The hardness of water is within the permissible level; according to WHO international standards (2011), the acceptable limit of hardness for potable water is 500ppm and the desirable limit is 100ppm. The salinity of river water is influenced by the low and high tide effects; the range of salinity for the Vamsadhara river in the present study region is 0.03-0.0.09 in the preseason and 0.05-0.09 in the postseason. A certain amount of dissolved oxygen is naturally present in water since it is created by aquatic plants and algae as well as absorbed from the surrounding air. A river's or stream's dissolved oxygen content can reveal a lot about the quality of the water in it. COD and BOD are crucial for managing the water environment and regulating the overall content of pollution since they are the most extensive indicators of organic pollution[15]. The mean concentrations of cations in the current examined area are as follows: Ca^{2+} (31–62 mg/L and 33–51 mg/L)>Mg^{2+}(15-35 mg/L and 18–32 mg/L)>Na^{+} (14–28 mg/L and 11–25 mg/L)>K^{+} (5.7–9.2 mg/L and 6.9–9.8 mg/L) and anions are as follows: SO_4^{2-}(79-101 mg/L & 74-97 mg/L)>Cl-(22-39 mg/L & 21-36 mg/L)>PO_4^{3-} (1.2-2.5 mg/L & 1.6-2.8 mg/L)>NO_3^{-} (9-21mg/L & 8–19mg/L)>F-(0.3–0.6mg/L). Surface water naturally contains calcium and magnesium. The concentrations of these elements can be influenced by several factors, primarily the catchment area's geological structure, land relief, soil type and class, plant cover, and weathering. seasonal variations, and the type and intensity of water supply[16]. As long as the amount of sodium in food and drink is not above standard limits, it poses no health risks to humans. The companion of sodium is potassium. Potassium remains within the cells; potassium is regarded as an electrolyte that does not allow free circulation. Potassium concentration is necessary to withstand both the pressure created by water movement and the sodium gate pressure[17]. SO_4^{2-} in river water may be attributed to the dissolution of sulfate minerals, atmospheric deposition, and agricultural and industrial discharges[18]. Establishing timely management plans is crucial despite the difficulty of differentiating between sources of SO_4^{2-} and NO_3^{-} in coastal areas, as both can have detrimental effects on human health[19]. As fluoride is found in many natural settings and is thought to be essential for human health, it is recommended that people consume a modest dose of fluoride[20]. The water's higher HCO_3^{-} concentration signifies that mineral dissolution is prevalent. Phosphates can be tested for their impact on water quality indicators, particularly those that rely on weight, as they are not harmful to humans or animals unless they are present in extremely high concentrations. Recently, the significance of TOC determination has been acknowledged, and measuring it has become standard procedure in environmental investigations[21]. The TOC values in both seasons are 27-61 mg/L and 33–62 mg/L.

Table 1: Descriptive statistics of Hydro chemical parameters

Hydrochemical Parameters	Dry Season				Wet Season			
	Low	High	Aveg.	S.D	Low	High	Aveg.	S.D
pH	6.70	8.10	7.33	0.47	7.10	8.10	7.51	0.36
E.C	144.00	288.00	217.80	47.00	131.00	268.00	198.70	46.44
TDS	244.00	388.00	309.10	46.26	225.00	355.00	281.50	47.07
TA	98.00	198.00	148.90	33.62	105.00	195.00	148.60	29.87
SALINITY	0.03	0.09	0.07	0.02	0.05	0.09	0.07	0.01
TH	198.0	310.0	242.9	39.63	181.0	288.0	224.2	37.51
DO	5.90	6.50	6.24	0.20	6.10	7.10	6.54	0.39
BOD	1.90	2.40	2.11	0.17	1.70	2.20	1.98	0.18
COD	28.00	38.00	33.10	3.54	21.00	31.00	26.90	3.07
CO_3^{2-}	6.00	19.00	13.80	4.18	6.00	18.00	13.00	3.80
HCO_3^-	16.00	56.00	30.10	11.88	15.00	55.00	28.50	11.88
Cl^-	22.00	39.00	31.00	5.48	21.00	36.00	27.10	4.56
F^-	0.30	0.60	0.43	0.12	0.30	0.70	0.45	0.12
NO_3^-	9.00	21.00	12.80	3.74	8.00	19.00	12.50	3.66
SO_4^{2-}	79.00	101.00	90.90	6.72	74.00	97.00	86.50	7.65
PO_4^{3-}	1.20	2.50	1.89	0.47	1.60	2.80	2.20	0.41
Na^+	14.00	28.00	21.30	4.76	11.00	25.00	18.20	4.73
K^+	5.70	9.20	7.34	1.41	6.90	9.80	8.46	0.99
Mg^{2+}	15.00	35.00	28.20	6.27	18.00	33.00	26.90	5.38
Ca^{2+}	31.00	62.00	43.80	10.62	33.00	51.00	41.50	6.15
TOC	27.00	61.00	44.10	11.33	33.00	62.00	45.90	9.01

Water quality Index: A unitless single number obtained by uniting various water quality parameters is termed WQI. A distinctive type of quantitative averaging function that combines various values and units into one value evaluates the various hydrochemical parameters[22]. The water quality index is determined by the Pesce and Wunderlin (2000) approach shown below[23].

$$WQI = k \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i}$$

C_i is the normalized value of a parameter; P_i is the relative weight; and k is a constant. The quality of water is categorized based on WQI values[24]. If the WQI value is above 90, it is considered very good, and if it is below 25, it is very poor. Water quality is good if it is between 71 and 90. The wqi values in the study region ranged from 69.5 to 73 in the pre-monsoon and 72 to 78 in the post-monsoon season. The wqi values at all locations are given in Table 2.

Table 2: Water quality index in both the seasons

Sampling Location	Longitude	Latitude	Pre-Monsoon(%)	Post-Monsoon(%)
S-1	18.79866°N	83.92986°E	69.5	77.5
S-2	18.69277°N	83.96816°E	72.0	76
S-3	18.63050°N	83.95956°E	73.0	73.7
S-4	18.59000°N	83.96406°E	69.0	73.1
S-5	18.53964°N	83.971760°E	72.2	74.2
S-6	18.45068°N	83.94959°E	72.6	77.9
S-7	18.37153°N	83.99312°E	71.0	73.7
S-8	18.34895°N	84.00594°E	73.7	75.7
S-9	18.3330°N	84.05364°E	71.0	75.2
S-10	18.35109°N	84.09499°E	72.1	72.1

Principal component analysis: A multivariate statistical technique that is intended to reduce a complex set of variable inputs with a vast amount of data into new, uncorrelated variables that are linear combinations of the original variables[25]. The suitability of the current dataset for PCA was assessed using the Kaiser-Meyer-Olkin (KMO) and Bartlett's tests of sphericity. The factor loadings are classified as'strong,''moderate,' 'weak' based on absolute loading values greater than 0.75, 0.75-0.50, and 0.50-0.30, respectively[26]. The PCA of study locations in two seasons is given in Table 3. In premonsoon, the three PCs explained 72.53% of the total variance, in post monsoon, 68.5% of the total variance was explained. In preseason, PC_1 explains 39.7% of variance in preseason with strong factor loadings of EC, Cl^-, Na^+, SO_4^{2-}(m), PC_2 explains 20.9% with strong loadings of Mg^{2+}, TH, Ca^{2+}, TOC, HCO_3^-(m), PC_3 explains 12.01% with strong loadings of Na^+, SO_4^{2-}. On the other hand, in postseason, PC_1 explains 30.54% of variance in preseason with strong factor loadings of EC, Na^+, Mg^{2+}, Cl^-, PC_2 explains 24.1% with strong loadings of TH, Mg^{2+}, Ca^{2+}, TOC, and PC_3 explains 13.8% with strong loadings of NO_3^-, PO_4^{3-}, which indicates geogenic process and dissolution sediment nutrient effluents are responsible. The scree plots and biplots to understand the data structure are given in Figures 1 and 2.

Table 3: Factor loadings of Principal Components

Principal components	Pre monsoon				Post monsoon			
	1	2	3	4	1	2	3	4
pH	-0.96	-0.03	-0.07	0.02	-0.87	0.03	-0.37	0.13
EC	0.86	0.04	0.43	0.02	0.99	0.03	0.05	0.07
TDS	0.44	0.32	0.79	0.07	0.04	0.5	0.08	0.32
TA	-0.95	-0.17	-0.07	-0.01	-0.88	-0.08	-0.21	0.07
SALINITY	0.38	0.58	0.51	0.03	-0.10	0.52	-0.09	0.25
TH	-0.06	0.89	0.41	0.06	0.09	0.96	0.10	-0.02
DO	0.16	0.04	-0.13	0.31	0.04	-0.33	0.21	-0.86
BOD	0.14	-0.40	0.05	0.79	0.02	-0.22	0.54	0.18
COD	0.22	0.11	0.22	-0.07	0.49	0.13	-0.35	-0.50
CO_3	-0.74	0.27	-0.22	-0.05	-0.61	0.30	-0.11	0.12
HCO_3	-0.54	0.59	-0.08	0.28	-0.56	0.70	0.19	0.34
Cl	0.84	0.11	0.47	0.08	0.92	0.06	-0.08	0.26
F	0.29	0.00	0.88	0.09	0.22	-0.06	0.08	0.78
NO_3	-0.07	-0.05	0.02	0.98	0.04	0.01	0.94	-0.08
SO_4	0.55	0.18	0.48	0.23	0.65	0.12	0.07	-0.08
PO_4	0.20	0.03	0.49	0.71	0.48	0.13	0.79	0.07
Na	0.86	0.02	0.42	0.01	0.99	-0.02	0.01	0.05
K	-0.67	-0.40	0.29	-0.31	-0.26	-0.41	0.12	0.01
Mg	0.06	0.91	-0.07	-0.07	0.04	0.89	0.26	-0.26
Ca	0.03	0.80	0.32	-0.43	0.36	0.82	-0.26	0.16
TOC	0.20	0.86	-0.11	-0.31	-0.16	0.82	-0.27	0.20
Eigen Values	8.33	4.38	2.52	1.85	6.406	5.070	2.907	2.188
Cumulative% of Variance	39.67	60.52	72.53	81.33	30.505	54.648	68.490	78.908

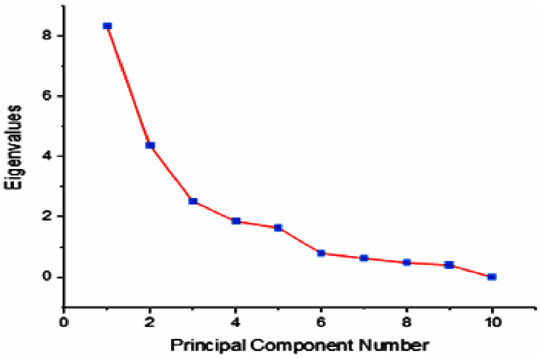

Fig. 1(a). Scree plot of dry season

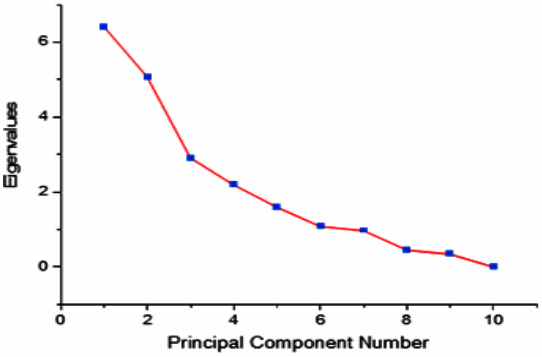

Fig. 1(b). Scree plot of wet season

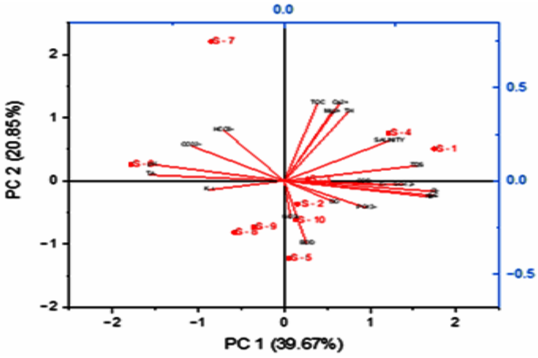

Fig. 2(a). Bi plot of dry season

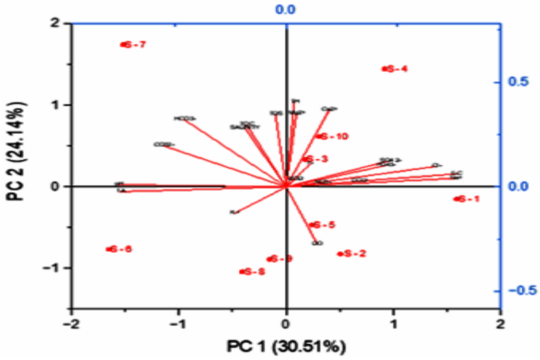

Fig. 2(b). Bi plot of wet season

Correlation analysis: It is a statistical technique used to evaluate the strength and direction of the linear relationship between two quantitative variables. The goal is to determine whether and to what extent changes in one variable are associated with changes in another variable. The most common correlation coefficient is Pearson's correlation coefficient (denoted by "r"). It ranges from -1 to 1. In general, r values > 0.7 are regarded as strong correlations, and 0.5 to 0.7 considered as moderate. Strong correlations were observed between all the measures in both seasons, suggesting that physico-chemical factors had an impact on the quality of the water in the Vamsadhara River, negative correlation was observed between dissolved oxygen and BOD due to the rise in organic and inorganic pollutants[27], strong positive correlation between magnesium and other parameters was observed, which indicates the cause of domestic and agricultural pollutants present in surface water. The correlation matrix for both seasons is shown in Tables 4 & 5.

Table 4: Correlation matrix of pre-monsoon

	pH	E.C	TDS	TA	SALINITY	TH	DO	BOD	COD	CO_3^{2-}	HCO_3^-
pH	1										
E.C	-0.92	1									
TDS	-0.54	0.78	1								
TA	0.98	-0.89	-0.59	1							
SALINITY	-0.39	0.55	0.67	-0.42	1						
TH	-0.04	0.2	0.6	-0.15	0.69	1					
DO	-0.29	0.31	0.14	-0.23	0.10	0.13	1				
BOD	-0.17	0.22	0.04	-0.09	-0.09	-0.26	-0.38	1			
COD	-0.34	0.49	0.41	-0.30	0.16	0.3	0.72	0	1		
CO_3^{2-}	0.67	-0.65	-0.3	0.62	-0.3	0.18	0.04	-0.18	-0.13	1	
HCO_3^-	0.56	-0.53	-0.17	0.47	0.19	0.48	-0.28	0	-0.49	0.58	1
Cl^-	-0.89	0.99	0.81	-0.88	0.62	0.27	0.27	0.25	0.41	-0.62	-0.43
F^-	-0.3	0.62	0.82	-0.31	0.47	0.32	-0.16	0.15	0.29	-0.38	-0.19
NO_3^-	0.1	-0.05	0.03	0.06	-0.06	0.03	0.26	0.73	-0.06	-0.07	0.23
SO_4^{2-}	-0.57	0.69	0.75	-0.6	0.7	0.33	0.32	0.11	0.24	-0.38	-0.27
PO_4^{3-}	-0.25	0.42	0.58	-0.3	0.23	0.31	0.29	0.5	0.34	-0.39	-0.13
Na^+	-0.92	1.00	0.76	-0.89	0.53	0.18	0.31	0.24	0.47	-0.65	-0.53
K^+	0.54	-0.42	-0.17	0.62	-0.32	-0.15	-0.06	-0.1	-0.07	0.33	-0.02
Mg^{2+}	-0.16	0.11	0.34	-0.29	0.4	0.83	0.24	-0.44	0.34	0.22	0.32
Ca^{2+}	-0.12	0.22	0.46	-0.19	0.62	0.85	-0.05	-0.57	0.33	0.08	0.3
TOC	-0.15	0.07	0.2	-0.29	0.48	0.63	-0.32	-0.62	-0.09	0.09	0.42
	Cl^-	F^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	TOC	
Cl^-	1										
F^-	0.65	1									
NO_3^-	-0.01	0.09	1								
$SO_4 2^-$	0.73	0.47	0.18	1							
PO_4^{3-}	0.44	0.55	0.75	0.5	1						
Na^+	0.99	0.61	-0.07	0.66	0.39	1					
K^+	-0.44	-0.1	-0.26	-0.31	-0.19	-0.4	1				
Mg^{2+}	0.14	-0.09	-0.09	0.19	0.12	0.09	-0.31	1			
Ca^{2+}	0.25	0.26	-0.46	0.1	-0.09	0.22	-0.09	0.76	1		
TOC	0.12	0	-0.35	0.07	-0.25	0.06	-0.52	0.73	0.76	1	

Table 5: Correlation matrix of post-monsoon

	pH	E.C	TDS	TA	SALINITY	TH	DO	BOD	COD	CO_3^{2-}	HCO_3^-
pH	1										
E.C	-0.89	1									
TDS	-0.58	0.78	1								
TA	0.96	-0.91	-0.61	1							
SALINITY	0.38	-0.10	0.40	0.29	1						
TH	-0.07	0.13	0.29	-0.11	0.46	1					
DO	-0.35	-0.01	-0.33	-0.22	-0.5	-0.21	1				
BOD	-O.13	0.08	0.14	0.02	0.04	-0.03	-0.05	1			
COD	-0.29	0.41	0.38	-0.3	0.13	0.14	0.17	-0.3	1		
CO_3^{2-}	0.66	-0.61	-0.19	0.66	0.46	0.28	-0.45	0.32	-0.14	1	
HCO_3^-	0.49	-0.5	-0.16	0.46	0.44	0.68	-0.4	0.08	-0.45	0.63	1
Cl^-	-0.7	0.91	0.86	-0.74	0.09	0.12	-0.23	-0.01	0.28	-0.52	-0.4
F^-	-0.07	0.23	0.54	-0.05	0.22	-0.04	-0.6	0.16	0.02	0.05	0.12
NO_3^-	-0.42	0.07	0.12	-0.24	-0.19	0.12	0.45	0.55	-0.16	-0.01	0.15
SO_4^{2-}	-0.48	0.58	0.71	-0.44	0.21	0.22	-0.04	0.24	0.22	-0.09	-0.22
PO_4^{3-}	-0.6	0.5	0.64	-0.5	0.24	0.22	0.25	0.42	0.04	-0.28	-0.03
Na^+	-0.88	0.99	0.76	-0.89	-0.16	0.08	0	0.06	0.45	-0.62	-0.54
K^+	0.42	-0.31	-0.04	0.54	0.39	-0.34	0.07	0.23	-0.01	0.09	-0.12
Mg^{2+}	-0.16	0.08	0.18	-0.17	0.33	0.93	0.05	0.08	0.15	0.32	0.6
Ca^{2+}	-0.14	0.39	0.47	-0.25	0.46	0.85	-0.43	-0.25	0.32	0.01	0.41
TOC	0.24	-0.13	0.08	0.03	0.48	0.64	-0.41	-0.56	-0.02	0.23	0.62
Cl^-	F^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	TOC		
Cl^-	1										
F^-	0.32	1									
NO_3^-	-0.12	0.14	1								
SO_4^{2-}	0.73	-0.02	0.07	1							
PO_4^{3-}	0.45	0.28	0.72	0.48	1						
Na^+	0.9	0.26	0.06	0.56	0.45	1					
K^+	-0.17	0.15	-0.01	0.01	0.19	-0.31	1				
Mg^{2+}	-0.01	-0.25	0.32	0.25	0.29	0.03	-0.41	1			
Ca^{2+}	0.43	0.16	-0.25	0.24	0.08	0.37	-O.33	0.63	1		
TOC	-0.02	-0.01	-0.31	-0.14	-0.17	-0.18	-0.45	0.53	0.64	1	

Linear regression analysis Linear regression is a powerful tool for understanding and predicting relationships between variables. It is a statistical technique used to find the relationship between a dependent variable and one or more independent variables by fitting a linear equation to the observed data. The aim is to find the best-fitting line that minimizes the difference between the observed values and the values predicted by the model. The equation for a simple linear regression with one independent variable is typically written as: Y=aX+b, where Y is the dependent variable and X is the independent variable. The regression plots with squared R values for hydrochemical parameters with high correlation (r>0.7) are given in Figures 3 and 4.

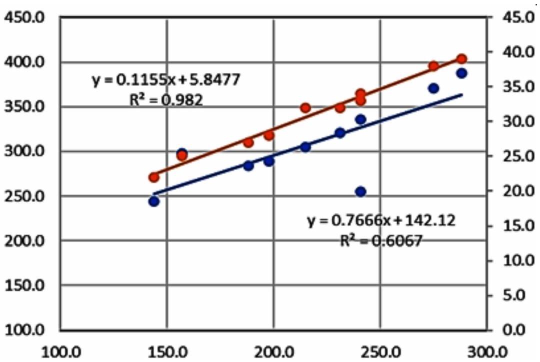

Fig. 3(i)(a). EC Vs TDS (b) EC Vs Cl⁻

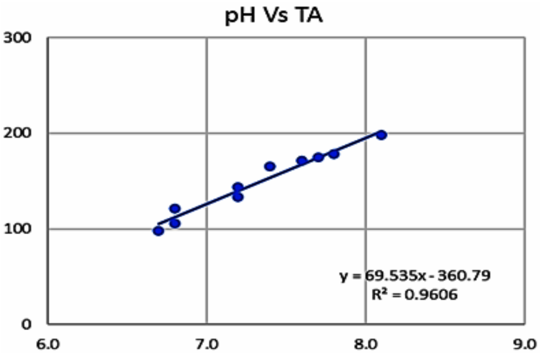

Fig. 3(ii). pH Vs TA

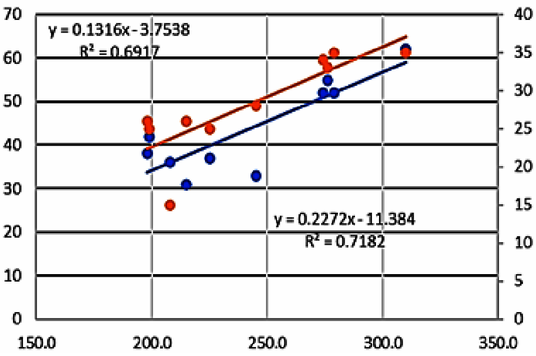

Fig. 3(iii) (a). TH Vs Ca^{2+} (b) TH Vs Mg^{2+}

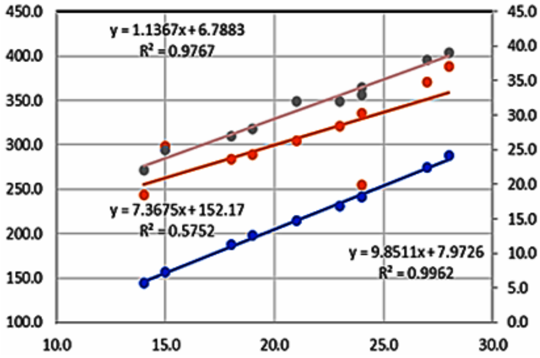

Fig. 3(iv) (a). Na^+ Vs EC (b) Na^+ Vs TDS (c) Na^+ Vs Cl

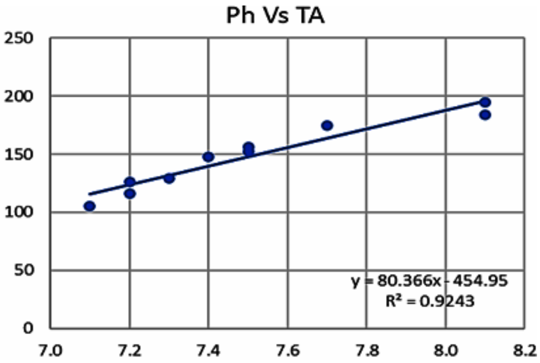

Fig. 4(i). pH Vs TA

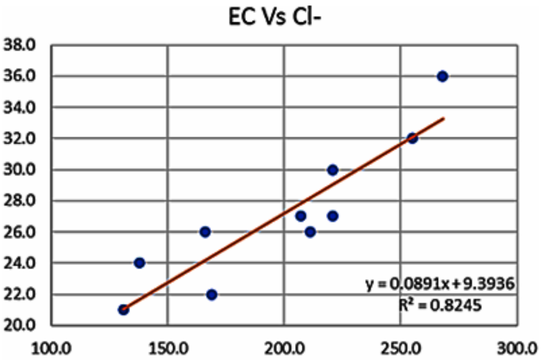

Fig. 4(ii). EC Vs Cl^-

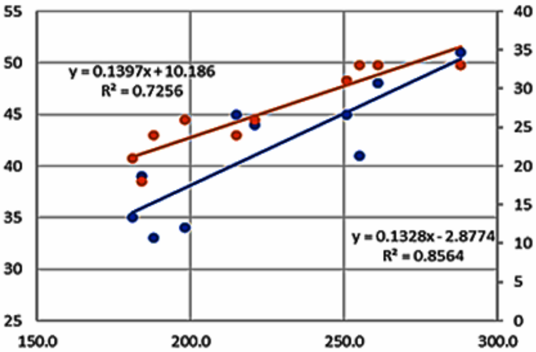

Fig. 4(iii) (a). TH Vs Ca^{2+} (b) TH Vs Mg^{2+}

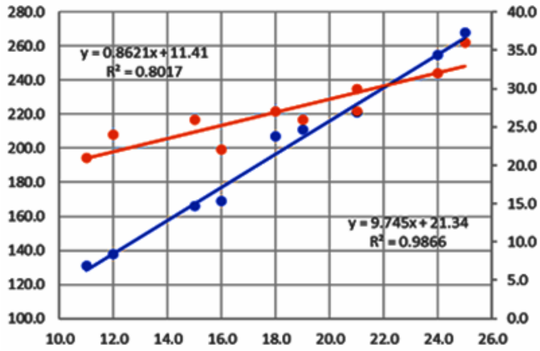

Fig. 4(iv) (a). Na^+ Vs EC (b) Na+Vs Cl^-

Water Quality parameters for Irrigation: The physical and chemical characteristics such as pH, conductivity, Na^+, Mg^{2+}, K^+, Ca^{2+}, SO_4^{2-}, Cl^-, carbonate and bicarbonate, etc. are used to establish the appropriateness of water quality for agriculture and irrigation purposes[28,29]. The assessment of water quality for irrigation is ascertained by calculating some indices such as sodium percentage, residual sodium carbonate, residual sodium bicarbonate, sodium adsorption ratio, magnesium hazard, Kelly's index, and permeability index. The formulas to calculate these parameters are in Table 6. The summary of the parameters shown in Table 7.

SAR in all stations shows less than 10 meq/L in both seasons, which indicates the water quality was very good for irrigation[30,31]. SAR is a measure of the relative portion of Na in water, Increased sodium concentrations in water have a negative impact on soil characteristics and reduce soil permeability[32]. Sodium percentage levels of Vamsadhara river water in the study region are below 60% is considered a good quality of water for irrigation[33]. Irrigation water with a Mg Hazard<50 is appropriate. In the Vamsadhara river, S-2, S-5, and S-7 locations in the dry season and locations S-1, S-2, and S-5 in the wet season were found to be less than 50. MH<50 is suitable for water used for irrigation purposes. Due to the negative effects on soil structure and nutrient imbalance, crops grown in soils with high magnesium levels may exhibit stunted growth, poor root development, and lower yields. The residual sodium carbonate and RSBC values indicate the safe levels for irrigation. RSC values range from -5.04 to -2.2 in pre-monsoon and -4.1 to -2.47 meq/L, and RSBC values are less than 1 in both seasons at all sampling stations. Kelly`s index is less than one at all sampling sites, indicating water is good for irrigation; PI values under 25% are considered not suitable for agriculture. Vamsadhara river water PI falls within the range of 25–50% in the class II category.

Table 6: Water quality parameters for Irrigation

Sodium (Na%)	$\frac{Na^{+}\ x\ 100}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}}$
Sodium Absorbtion Ratio (SAR)	$\frac{Na^{+}}{\sqrt{\frac{Mg^{2+}+Ca^{2+}}{2}}}$
Magnesium Hazard (MH)	$\frac{Mg^{2+}\ x\ 100}{Ca^{2+}+Mg^{2+}}$
Kelly`s Ratio	$\frac{Na^{+}}{Ca^{2+}+Mg^{2+}}$
Residual Sodium Carbonate (RSC)	$(CO_3^{2-}+HCO_3^{-})-(Ca^{2+}+Mg^{2+})$
Residual Sodium Bicarbonate (RSBC)	$(HCO_3^{-}-Ca^{2+})$
Permeability Index (PI)	$\frac{(Na^{+}+\sqrt{H}CO_3^{-})\ x\ 100}{Ca^{2+}+Mg^{2+}+Na^{+}}$

Table 7: Summary of irrigation water quality parameters

Parameters	Season	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	Min	MAX	Mean
SAR	Dry	0.73	0.72	0.61	0.71	0.84	0.43	0.38	0.57	0.59	0.65	0.38	0.84	0.62
	Wet	0.75	0.62	0.53	0.65	0.70	0.36	0.32	0.48	0.50	0.51	0.32	0.75	0.54
Na%	Dry	22.86	24.77	19.52	22.54	28.50	16.20	12.51	21.48	21.74	23.95	12.51	28.50	21.41
	Wet	24.39	21.38	18.13	21.45	24.00	14.55	11.47	18.38	19.00	18.05	11.47	24.39	19.08
Mg H	Dry	50.00	49.80	52.15	52.87	40.98	53.28	48.48	58.30	52.97	58.58	40.98	58.58	51.74
	Wet	47.06	49.62	53.45	53.40	43.48	50.00	51.89	54.79	56.03	57.29	43.48	57.29	51.70
RSBC	Dry	-2.49	-1.76	-2.14	-2.09	-1.37	-1.38	-2.18	-1.21	-1.42	-0.93	-2.49	-0.93	-1.70
	Wet	-2.00	-1.89	-1.82	-1.92	-1.56	-1.26	-1.65	-1.32	-1.29	-1.36	-2.00	-1.26	-1.61
RSC	Dry	-5.04	-3.54	-4.51	-4.41	-2.22	-2.94	-4.47	-2.84	-3.04	-2.86	-5.04	-2.22	-3.59
	Wet	-3.80	-3.79	-3.97	-4.11	-2.66	-2.47	-3.80	-2.82	-3.02	-3.71	-4.11	-2.47	-3.42
PI	Dry	25.75	31.19	26.08	28.20	41.44	28.51	24.15	30.43	31.07	35.99	24.15	41.44	30.28
	Wet	29.66	27.86	26.13	27.98	35.30	29.65	25.27	28.47	29.28	28.88	25.27	35.30	28.85
KR	Dry	0.22	0.25	0.18	0.21	0.34	0.15	0.11	0.21	0.21	0.23	0.11	0.34	0.21
	Wet	0.26	0.21	0.17	0.20	0.26	0.14	0.10	0.18	0.18	0.16	0.10	0.26	0.19

CONCLUSION

The water quality of the Vamsadhara River was found to be acceptable in most areas during the research investigation in both seasons. The water quality was sufficient for consumption with little need for disinfection. It is evident from the principal component analysis of geogenic processes and dissolution sediments; nutrient effluents might be responsible for pollution of surface water. There is a good correlation between hydrochemical parameters and a perfect fit of regression with squared R values. The quality of the river water used for irrigation in the study region has been found to be good to exceptional over the study period. The irrigation water quality parameters such as SAR, Na%, RSC, RSBC, and KI values predict the good quality of river water for irrigation, PI values classify the Vamsadhara water as class II. Water for irrigation that has a magnesium hazard of less than fifty is adequate. In the Vamsadhara river, S-2, S-5, and S-7 locations in the dry season and locations S-1, S-2, and S-5 in the wet season were found to be less than 50. With the exception of the magnesium hazard, every location's irrigation quality ranged from adequate to exceptional. The relevant agency will provide water users with the necessary instruction and training such as to promote sustainable agricultural practices, such as organic farming, and the use of environmentally friendly pesticides and fertilizers, to reduce runoff and pollution, maintaining riparian buffer zones along riverbanks to filter pollutants, reduce erosion, and protect aquatic habitats, construct and maintain waste water treatment plants to ensure that industrial and domestic wastewater is treated before being discharged into rivers, by implementing these policies, can effectively reduce river water pollution, protect water resources. Lastly, it is recommended that comprehensive research with seasonal changes be carried out to evaluate the quality of water.

ACKNOWLEDGMENT

The authors would like to express sincere gratitude to Gitam University (Deemed) for providing laboratory facilities to complete this research.

Conflict of interests

We state that there are no conflicts of interest in this study.

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