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The Status of Surface Water in West Tripura District, India: An Approach by Using Water Quality Index and Multivariate Statistical Technique

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Abstract: The present investigation provides a better interpretation of surface water (rivers, ponds, bills, lakes, etc.) quality utilising entropy weighted water quality index (EWWQI) and different multivariate statistical techniques. Eleven physicochemical parameters including alkalinity, dissolved oxygen (DO), pH, total dissolved solids (TDS), electrical conductivity (EC), calcium (Ca), turbidity, magnesium (Mg), total hardness (TH), chloride (Cl^-), and iron (Fe) were analysed and monitored at 23 sampling sites (in December 2018) of West Tripura district. Experimental outcomes of turbidity followed by Fe contamination exceeded recommended WHO standard limit. The maximum values of Fe and turbidity were estimated as 8.745 mg/L and 797.7 NTU, respectively. WQI values confirmed that most of the monitoring locations had poor water quality except three reported areas (S7, S14, and S15) but without Fe and turbidity, estimated WQI confirmed drinkable water condition for entire samples. Multivariate statistical approaches like correlation analysis, principal component analysis (PCA) and cluster analysis (CA) were applied to explore water quality. PCA outcomes recognised three principal factors explaining almost 85% of the total variance. CA investigated three major clusters of 23 sampling sites namely less polluted, highly polluted and moderately polluted zone. Confirming all above, the surface water at the monitoring locations is a major concern which may lead to serious health issues in local people.

Key words: Water quality index, Pearson's correlation coefficient, principal component analysis, cluster analysis.

Introduction

River water, a key source of groundwater and surface water, is used for human consumption and agricultural purposes. Anthropogenic activities (unnecessary urbanisation, agricultural activities) and natural factors (surface overflow, precipitation and groundwater level) deteriorate water quality, making it inappropriate for different purposes (Carpenter et al., 1998). Therefore, to obtain precise information on the physicochemical properties of water and for better management of renewable water resources, reliable monitoring of water quality is suggested (Singh et al., 2005).

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To manage the depletion of water quality, researchers have developed several WQI methods for the demonstration of a universal outlook of water quality (Zeinalzadeh and Rezaei, 2017). Horton (1965) first developed WQI to achieve the level of water quality. WQI, a numerical mechanism, summarises environmental parameters into a single number revealing the status of water pollution (Bordalo et al., 2006; Sánchez et al., 2007). Some WQIs being used worldwide are EWWQI (Amiri et al., 2014), Canadian Council of Ministers of the Environment water quality index (CCMEWQI) (Lumb et al., 2006), weighted arithmetic water quality index (WAWQI) (Horton, 1965), National Sanitation Foundation water quality index (NSFWQI) (Brown et al., 1970) and Oregon water quality index (OWQI) (Cude, 2001). Among these, EWWQI provides a comprehensive understanding of water quality to researchers as it neglects any personal judgment on the weightage factor.

Applications of different multivariate statistical approaches (Pearson's correlation coefficient [*r*], PCA, CA) were implemented to judge underlying pollution sources influencing water quality and to categorise monitored sampling sites (Boyacioglu, 2006).

Research studies related to surface water quality in Tripura state are scanty (Lodh et al., 2014; Singh et al., 2016). Lodh et al. (2014) studied 17 physicochemical and biological parameters from four lakes situated in Udaipur city of Tripura state. They observed only two parameters (BOD and ammoniacal nitrogen) were accountable for deteriorating lake's water. Singh et al. (2016) investigated water status after Durga idol immersion from a single sampling site (Dashamighat, Haora River, Agartala, Tripura) and reported 17 environmental parameters. They investigated that the values of lead, iron, and chromium metals exceeded the BIS permissible limit indicating they were unfit for utilisation in general purpose. This study demonstrates the estimation of the EWWQI technique to represent the current status of water and utilisation of different multivariate statistical tools to recognize major pollution factors in water. In addition, water quality on the Haora River is highlighted in this article. Therefore, the present article is aimed to attain the following objectives: (1) to analyse 11 environmental parameters of 23 water samples using standard protocol, (2) to estimate WQI using EWWQI technique considering evaluated parameters to justify the appropriateness of water for drinking and (3) application of multivariate statistical tools (PCA, r and CA) to determine pollution sources and grouping of samples.

Study Area

Tripura, a geographically important territory of the North East region, is located between boundary areas of Bangladesh, Mizoram and Assam. The reported study stations mostly enclosed under Agartala city (capital of Tripura state) with the latitude of 23° 45′ N and longitude of 91° 25′ E. 23 sampling sites (Table 1; Figure 1) were chosen from West Tripura district to obtain the present status of surface water. The condition behind the selection of sampling spots considering gigantic population density, household water supply points, municipal and industrial dumping destinations, market places and other community rules. The research area also consists of the Haora River, sub-basin of Titas river, Bangladesh (Das and Chakraborty, 2013).

Table 1: Location of sampling stations

Sample No.	*Locations*	*Latitude*	*Longitude*
S1	Kamarpukur, Math chowmuhani	23.83146	91.28678
S2	M.B.B. College Lake	23.82387	91.29648
S3	Golbazar	23.82656	91.28557
S4	Bodhjung Dighi	23.83656	91.28956
S5	Ginger Hotel Surrounding	23.86232	91.28237
S6	Fishery college	23.90358	91.30743
S7	ICFAI college surrounding	23.93405	91.33816
S8	Airport area	23.89147	91.24390
S9	T.I.T. Narsingarh	23.90556	91.25222
S10	Durga chowmuhani	23.83441	91.28173
S11	Melarmath	23.82983	91.27255
S12	Haora river, Battala	23.82525	91.25293
S13	Arundhuti nagar	23.81052	91.26961
S14	Badarghat Railway station	23.79000	91.28000
S15	14 Goddess Temple, Khayerpur	23.84535	91.34353
S16	Bodhjungnagar	23.88100	91.36079
S17	Ranirbazar	23.83000	91.37000
S18	Khumlung Park	23.79000	91.43000
S19	Haora River, Champaknagar	23.80000	91.49000
S20	Lakshminarayan Bari lake	23.83000	91.28000
S21	Mandai TSR camp	23.85000	91.47000
S22	Jagannath Bari Lake	23.83000	91.28000
S23	Haora River, Kalyani	23.83000	91.30000

Materials and Methods

Sampling and Analytical Procedure

Water samples were stored in 1 L HDPE containers (flush completely with distilled water and HNO_3) from 23 reported inspecting sites (rivers, bills, ponds, lakes, etc.) of West Tripura district and 11 parameters were investigated to test its fitness for drinking. To

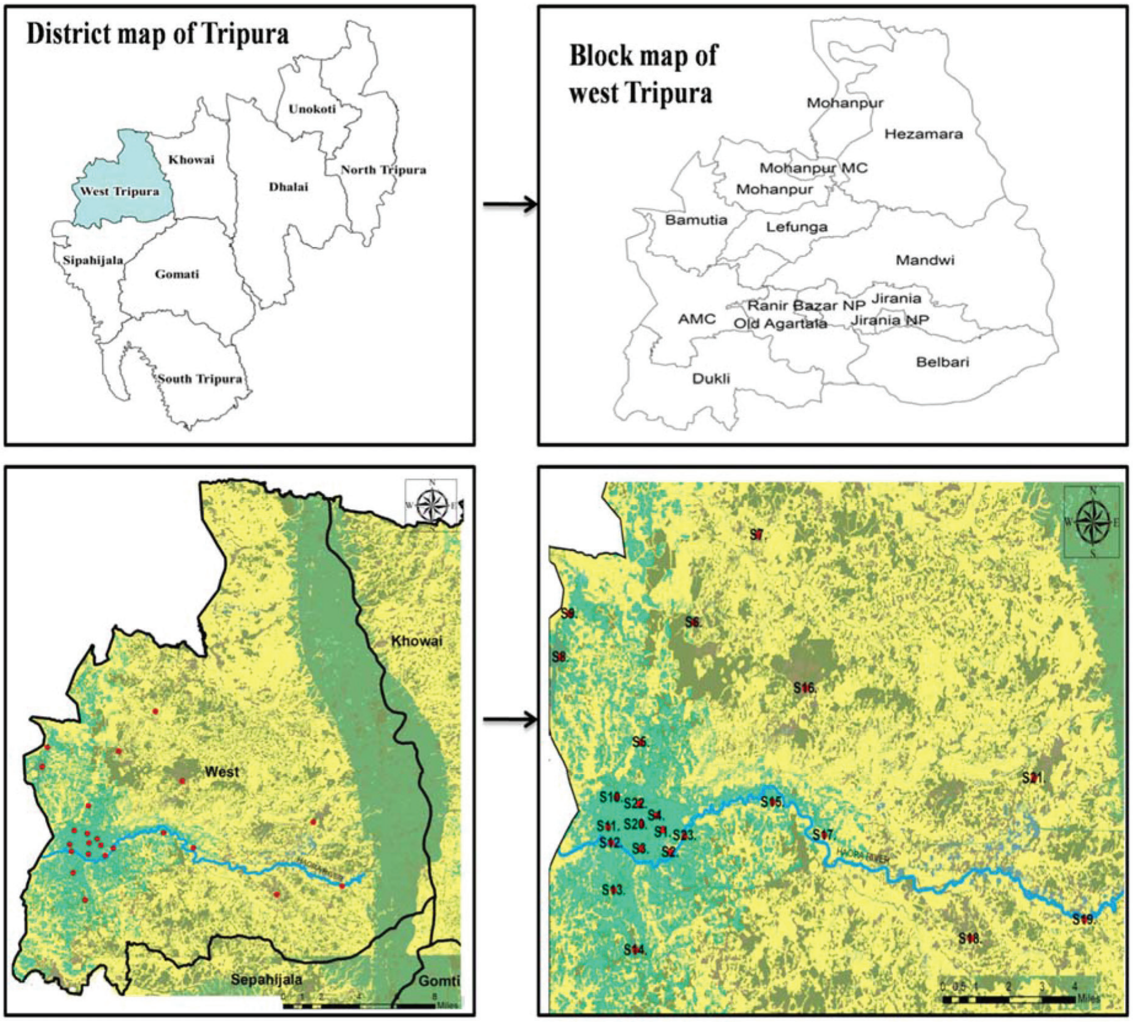

Figure 1: Sampling locations of study area.

obtain accurately analysed data, it is mandatory to characterise these physical parameters within 5 minutes after sampling. Physical parameters (pH, TDS, DO, EC and turbidity) were characterised using water analysis kit (Table 2). To characterise the remaining chemical parameters, samples were conserved adding 1:1 HNO_3. Chemical parameters including alkalinity, Ca, Cl^-, TH, Mg, and Fe were characterised in the laboratory by using the American Public Health Association (APHA, 2012) method (Table 2).

Calculation of EWWQI

Shannon (1948) first created a thought of information entropy describing disorders and uncertainty within a system and later on various researchers utilised this idea to estimate WQI. The following steps are essential to estimate WQI:

- Development of a matrix taking analysed values of parameters of each sample.
- Construction of normalization matrix considering normalised values of each analyzed parameter to eradicate errors caused by different units and dimensions.
- Estimation of information entropy (e_j) based on these normalised values which are formulated by Shannon (1948):

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ij} \ln P_{ij} \quad (1)$$

Where m is no of samples and P_{ij} (ratio-index value) can be formulated by the following equation

$$P_{ij} = y_{ij} \Big/ \sum_{i=1}^{m} y_{ij} \quad (2)$$

Table 2: Methods of analysis and WHO standard limits of physicochemical parameters

Parameters (units)	*Determination Methods*	*WHO standard limits (WHO, 2011)*
pH (unitless)	pH meter	7.5
Turbidity (NTU)	Turbidity meter	5
Electrical Conductivity (µmho/cm)	Horiba meter	250
Chloride (mg/L)	Titration by silver nitrate (APHA)	350
Calcium (mg/L)	EDTA titration (APHA method)	200
Magnesium (mg/L)	EDTA titration (APHA method)	50
Alkalinity (mg/L)	Titration method (APHA method)	200
Total Hardness (mg/L)	EDTA titration (APHA method)	500
Dissolved Oxygen (mg/L)	Horiba meter	5
Total Dissolved Solids (mg/L)	Horiba meter	1000
Iron (mg/L)	Phenanthroline method (APHA method)	0.3-1

Where y_{ij} is the construction function of normalisation (efficiency type).

From the e_j value, entropy weight (w_j) can be estimated as

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n} 1-e_j} \quad (3)$$

- The quality rating q_j for each parameter can be formulated as

$$q_j = \frac{C_j}{S_j} \times 100 \quad (4)$$

Here C_j is evaluated experimental values of environmental parameters in mg/L (except pH, turbidity and EC); S_j is standard WHO (2011) prescribed limit (Table 2).

- WQI is estimated by multiplication of w_j and q_j followed by addition of each parameter as expressed by the following formula

$$EWWQI = \sum_{j=1}^{n} w_j \times q_j \quad (5)$$

Several researchers (Amiri et al., 2014; Ding and Shi, 2005; Singh et al., 2019) have applied this technique to establish WQI. After obtainingWQI, water quality can be categorised (Table 3) into five levels from "excellent to extremely poor" (Jianhua et al., 2011).

Table 3: Categorization of surface water quality based on WQI value (Jianhua et al., 2011)

EWWQI value	*Rank*	*Water quality*
< 50	1	Excellent
50-100	2	Good
100-150	3	Medium
150-200	4	Poor
> 200	5	Extremely poor

Multivariate Statistical Methods

Multivariate statistical assessments are comprehensively utilised for better understanding and management of gigantic complex datasets by reducing dimensionality without influencing original information (Massart and Kaufman, 1983).

To comprehend Pearson's coefficients' (r) correlation, parameters must obey consistent distribution and similar behaviour criteria (Hamzaoui-Azaza et al., 2011). The r values closest to +1 and -1 denote the strongest proportional and inverse relationship, respectively, between parameters.

PCA alters original variables into a set of new variables (uncorrelated in character) termed as principal components (PCs). Kaiser's principle (Kaiser, 1960) is applied to detect no. of PCs reliant on eigenvalues >1. Two approaches must be satisfied to execute PCA- Kaiser Meyer Orkalin (KMO) index (>0.5) and Bartlett's Sphericity test.

To examine the similarity between reported investigation sites, CA is performed using Ward's technique based on transformed experimented datasets with squared Euclidean distance (Massart and Kaufman, 1983; Zhao et al., 2011). The outcomes are depicted in Dendrogram plot, displaying a visual image of clusters with their proximity after reducing the dimensionality of the input dataset.

Table 4: Analyzed value of physico-chemical parameters and their association as per r value

Parameters	*Min. value*	*Max. value*	*WHO standard value*	*No of samples above WHO limit*	*No of samples below WHO limit*	*Association as per r value according to Table 5*	*Remarks/Results*
pH	6.68	7.85	6.5-8	0	23	moderately +(ve) with TH (0.411)	17 samples were in alkaline condition
Turbidity	1.092	797.7	5	22	1	moderately +(ve) with Fe (0.329)	Dissolution of suspended particles, enormous inorganic materials, metal ions and other natural materials causes turbidity
EC	60.86	478.6	250	7	16	strongly +(ve) with TDS (0.999), Ca (0.822), alkalinity (0.862) and moderately positive with Mg (0.640) and Cl^-(0.674)	Increases salt and ion concentration thereby produces saline water
Cl^-	2	172	350	0	23	moderately +(ve) with Ca (0.645), TDS (0.622), Mg (0.377) and alkalinity (0.636)	Outcomes confirmed existence of soluble salts in water
Ca	3.27	53.96	200	0	23	strongly +(ve) with Mg (0.851), alkalinity (0.895), TH (0.920) and TDS (0.824)	
Mg	19.89	183.6	50	12	11	strongly +(ve) with TH (0.989) and alkalinity (0.759)	
Alkalinity	58	384	200	7	16	strongly +(ve) with TH (0.822) and TDS (0.889)	Salts of strong base and weak acids causes alkalinity
TH	29.70	237.6	500	0	23	strongly +(ve) with Ca (0.920) and Mg (0.989)	Increases heavy metal solubility in water and scale deposition in pipes
DO	1.4	6.7	5	12	11	strongly +(ve) with Cl- (0.732) but moderately –(ve) with Fe (-0.344)	Lower value indicates decomposition and die off of submerged plants
TDS	29.25	206.1	1000	0	23	strongly +(ve) with EC (0.983), Ca (0.824) and alkalinity (0.889)	TDS identifies EC and colour of water body
Fe	0.352	8.745	0.3-1	18	5	moderately+(ve) with pH (0.456) Mg (0.448) and turbidity (0.329)	Flow conditions, pH and dissolved organic matter in water mainly control Fe

Both these statistical tools (PCA and CA) are performed using SPSS version 21 software.

Results and Discussions

The proposed EWWQI has been estimated from 23 monitoring sites of the West Tripura district analysing 11 environmental parameters to describe the current situation of drinkable surface water. The analysed parameters along with their association as per *r* value are given in Table 4.

To understand two parameters' (Fe and turbidity) effect, EWWQI was first determined without either iron or turbidity considering 10 parameters. Then, excluding Fe and turbidity, nine parameters were incorporated to perform the EWWQI calculation.

After estimating EWWQI, surface water quality was categorised for drinking as per Table 3. From outcomes of EWWQI (Table 6; Figure 2) considering 11 parameters, three, seven and the rest 13 samples covered "good", "medium", and "poor" qualities. Again including 10 parameters (excluding turbidity), 20, two and only one samples fell into "good", "medium" and "poor" categories. Calculated EWWQI (excluding iron) showed "good" (two samples), "medium" (9 samples) and "poor" (12 samples) qualities. Lastly, without Fe and turbidity, 22 and only one samples covered the "good" and "medium" categories. From the above findings, it was determined that turbidity and Fe were mainly accountable for water quality deterioration and the former was more influential than the latter. This finding was clearly noticeable from Table 5 where Fe was positively associated with turbidity ($r = 0.329$).

Three samples (out of 23) were collected from the Haora River. EWWQI was estimated to be maximum in Battala (S12) (among these three as well other 20 stations). Champaknagar (S19), upstream point of River where EWWQI was lower enough than other two sites because the adjacent area of upstream is less populated compared to S12 and S23. Then, the river passed through Kalyani (S23) where EWWQI was 71% higher than S19 because: (a) its surrounding areas are thickly populated and (b) the River flows 22 km distance from the upstream sampling point. After flowing only 3 km away from S23, EWWQI at Battala (S12) surprisingly increased by 70% due to a population of 3 km adjacent areas nearly covers capital city Agartala whereas areas of 22 km (between S19 and S23) is situated mostly in the village and hilly regions. Further investigation revealed that EWWQI at S12 showed a percentage increase by 91% after flowing a 25 km distance from S19.

The application of PCA was performed satisfactorily to describe the loading of each environmental parameter. A scree plot (Figure 3) showed eigenvalues and principal components of 11 variables. This figure demonstrated a fracture of the line after the 3rd eigenvalue. Therefore, the first three components (eigenvalue >1) were chosen for detecting pollution sources and their total variance of 85% was obtained (Table 7) (Olsen et al., 2012).

PC1 showed the highest total variance (55%) (Table 7) and contributed positive loadings for TDS, alkalinity, EC, TH, Ca, Cl^-, Mg as these parameters described a strong positive association according to r value (Table 5). This component may be influenced by natural (dissolved materials originated from biomass,

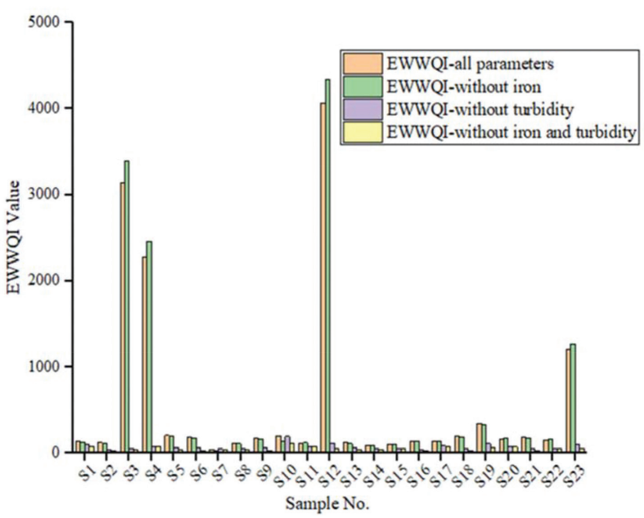

Figure 2: EWWQI value of samples.

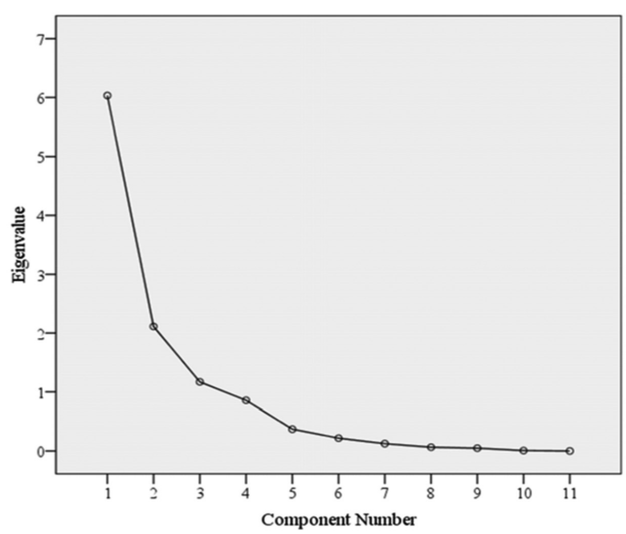

Figure 3: Scree plot of principal component.

Table 5: Person's correlation coefficient matrix

Parameters	*pH*	*Turbidity*	*EC*	*Cl⁻*	*Ca*	*Mg*	*Alkalinity*	*TH*	*DO*	*TDS*	*Fe*
pH	1.000										
Turbidity	-0.058	1.000									
EC	0.233	-0.021	1.000								
Cl^-	0.175	-0.177	0.674	1.000							
Ca	0.309	-0.115	0.798	0.645	1.000						
Mg	0.433	-0.099	0.640	0.377	0.851	1.000					
Alkalinity	0.279	0.079	0.860	0.636	0.895	0.759	1.000				
TH	0.411	-0.107	0.705	0.465	0.920	0.989	0.822	1.000			
DO	0.242	-0.303	0.258	0.732	0.392	0.283	0.171	0.323	1.000		
TDS	0.260	-0.056	0.983	0.751	0.824	0.646	0.889	0.717	0.298	1.000	
Fe	0.456	0.329	0.083	-0.342	0.249	0.448	0.274	0.405	-0.344	0.029	1

Table 6: EWWQI values of surface water samples

Sample No.	*EWWQI value*			
	All parameter	*Without iron*	*Without turbidity*	*Without iron and turbidity*
S1	134.36	124.70	92.73	74.78
S2	118.50	112.73	42.51	25.97
S3	3144.50	3388.50	52.31	35.78
S4	2274.53	2454.77	74.44	71.77
S5	201.44	199.46	61.19	42.55
S6	183.58	174.31	58.26	31.28
S7	41.87	29.48	48.60	32.32
S8	112.32	106.70	53.18	38.76
S9	163.99	153.59	56.06	29.49
S10	195.21	139.04	189.19	111.41
S11	113.77	117.03	75.43	75.53
S12	4070.96	4346.24	115.48	43.80
S13	117.69	105.05	65.41	42.13
S14	84.64	81.10	46.75	37.60
S15	99.61	102.85	46.44	44.82
S16	138.23	135.56	40.91	26.20
S17	139.05	138.10	82.99	75.28
S18	187.45	183.53	51.89	31.09
S19	339.43	327.11	105.241	61.77
S20	159.02	169.27	68.49	72.26
S21	180.81	175.03	51.69	29.08
S22	151.79	160.30	49.20	49.22
S23	1202.74	1266.31	93.87	55.13

minerals, etc.) and anthropogenic sources. PC2 (19% of total variance) accounted for positive loadings of Fe and pH. Most monitoring samples were alkaline in nature enhancing metal ion concentrations (Mikhaylov et al., 2018). Thus, PC2 indicated pollution from metal sources. PC3 (11% of total variance) was positively loaded with DO but negatively loaded with turbidity (Table 7). Again outcomes of *r* also explained the negative association between DO and turbidity (Table 5). This component may be attributed to physical pollution (ie., presence of microorganisms and organic matter) sources.

CA groups 23 monitoring stations into three different clusters. The outcomes of CA were represented in dendrogram diagram (Figure 4), showing samples under categories Cluster 1 and Cluster 2 having similar characteristics to Cluster 3. Cluster 1 was formed by grouping sites into two sub-groups (S18, S21, S16, S2, S6, S9, and S7) and (S13, S15, S14, S5, S8, S22, and S19). This group is termed the LP zone. As the S19 location is situated upstream of Haora River, less mixed streams (freshwater) and thin population areas make this location an LP zone. Cluster 2 covered sites S17, S20, S11, S10, S4, and S23. This cluster corresponds to the MP zone as estimated EWWQI values (S4 and S23) were significantly lower than cluster 3. In addition, S3 and S12 sites forming Cluster 3 correspond to the HP zone because these two stations showed higher EWWQI than the remaining 21 monitoring sites. High

Table 7: Loading values, Eigenvalues and variances of Principal Components (PCs)

Parameters	*PC1*	*PC2*	*PC3*
pH	0.129	**0.778**	0.312
Turbidity	0.092	-0.102	**-0.769**
EC	**0.932**	0.043	0.082
Cl^-	**0.745**	-0.211	0.538
Ca	**0.889**	0.318	0.125
Mg	**0.711**	0.598	0.014
Alkalinity	**0.940**	0.208	-0.048
TH	**0.784**	0.536	0.047
DO	0.427	-0.031	**0.791**
TDS	**0.949**	0.031	0.155
Fe	0.078	**0.790**	-0.500
Eigenvalue	6.033	2.112	1.169
% of Variance	54.841	19.20	10.63
% of Cummulative variance	54.841	74.041	84.671

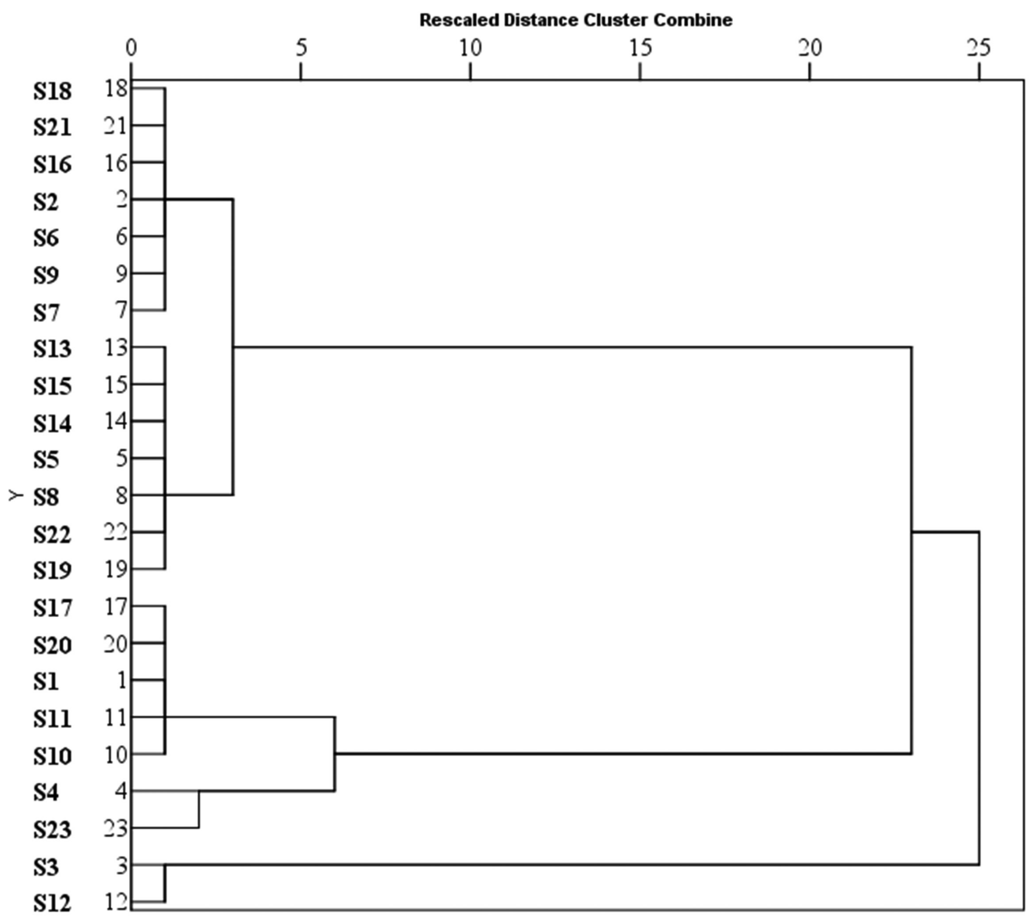

Figure 4: Cluster plot of sampling locations.

turbidity and Fe values in the S12 sample make the HP zone because it is located downstream of River Haora and its adjacent area in the densely populated capital city, Agartala.

Conclusion

The study efficiently utilises the EWWQI technique and multivariate statistical tools to reflect the current status of surface water (river, lakes, ponds, etc.) and also recognises potential contamination sources. The environmental parameters used are Fe and turbidity in most monitoring sites overstepped WHO standard guidelines. EWWQI of all monitoring sites showed medium to poor water quality (excluding S7, S14, and S15) due to Fe and turbidity contaminations. PCA identified three factors (PC1, PC2, and PC3) clubbing 11 environmental parameters. PC1 recognised natural and anthropogenic sources, PC2 attributed to metal sources, and the contribution of PC3 was physical pollution sources. Outcomes of PCA were satisfactorily compared with r values. CA grouped 23 monitoring sites into three clusters based on their inherent characteristics: cluster 1 (less polluted stations), cluster 2 (moderately contaminated zones) and cluster 3 (highly polluted sites). Outcomes of CA were successfully correlated with EWWQI results. Therefore, surface waters in affected stations need appropriate treatment and management to make potable water.

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References

Amiri, V., Rezaei, M. and N. Sohrabi (2014). Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. *Environmental Earth Sciences*, **72(9):** 3479-3490.

American Public Health Association (APHA) (2012). Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC, 27th ed.

Bordalo, A.A., Teixeira, R. and W.J. Wiebe (2006). A water quality index applied to an international shared river basin: The case of the Douro River. *Environmental Management*, **38(6):** 910-920.

Boyacioglu, H. (2006). Surface water quality assessment using factor analysis. *Water SA*, **32(3):** 389-393.

Brown, R.M., McClelland, N.I., Deininger, R.A. and R.G. Tozer (1970). A Water Quality Index: Do We Dare? *Water & Sewage Works*, **117:** 339-343.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. and V.H. Smith (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, **8(3):** 559-568.

Cude, C.G. (2001). Oregon water quality index: A tool for evaluating water quality management effectiveness. *Journal of the American Water Resources Association*, **37(1):** 125-137.

Das, N. and M. Chakraborty (2013). Flood hazard and risk assessment of the Haora River basin : A case study on Khayerpur Mouza, Tripura, North-East India. *Indian Journal of Research*, **3(4):** 193-196.

Ding, S.F. and Z.Z. Shi (2005). Studies on incidence pattern recognition based on information entropy. *Journal of Information Science*, **31(6):** 497-502.

Hamzaoui-Azaza, F., Ketata, M., Bouhlila, R., Gueddari, M. and L. Riberio (2011). Hydrogeochemical characteristics and assessment of drinking water quality in Zeuss-Koutine aquifer, Southeastern Tunisia. *Environmental Monitoring and Assessment*, **174(1-4):** 283-298.

Horton, R.K. (1965). An index number system for rating water quality. *Journal of the Water Pollution Control Federation*, **37(3):** 300-306.

Jianhua, W., Peiyue, L. and Q. Hui (2011). Groundwater Quality in Jingyuan County: A semi-humid area in Northwest China. *E-Journal of Chemistry*, **8(2):** 787-793.

Kaiser, H.F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement*, **20(1):** 141-151.

Lodh, R., Paul, R., Karmakar, B. and M.K. Das (2014). Physicochemical studies of water quality with special reference to ancient lakes of Udaipur City, Tripura, India. *International Journal of Scientific and Research Publications*, **4(6):** 1-9.

Lumb, A., Halliwell, D. and T. Sharma (2006). Application of CCME water quality index to monitor water quality: A case of the Mackenzie River Basin, Canada. *Environmental Monitoring and Assessment*, **113(1-3):** 411-429.

Massart, D. and L. Kaufman (1983). The interpretation of analytical chemical data by the use of cluster analysis, New York, Wiley, 237 p.

Mikhaylov, V.I., Maslennikova, T.P., Krivoshapkina, E.F., Tropnikov, E.M. and P.V. Krivoshapkin (2018). Express

Al/Fe oxide–oxyhydroxide sorbent systems for Cr(VI) removal from aqueous solutions. *Chemical Engineering Journal*, **350:** 344-355.

Olsen, R.L., Chappell, R.W. and J.C. Loftis (2012). Water quality sample collection, data treatment and results presentation for principal components analysis - Literature review and Illinois river watershed case study. *Water Research*, **46(9):** 3110-3122.

Sánchez, E., Colmenarejo, M.F., Vicente, J., Rubio, A., García, M.G., Travieso, L. and R. Borja (2007). Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. *Ecological Indicators*, **7(2):** 315-328.

Singh, K.P., Malik, A. and S. Sinha (2005). Water quality assessment and apportionment of pollution sources of Gomti River (India) using multivariate statistical techniques - A case study. *Analytica Chimica Acta*, **538(1):** 355-374.

Singh, K.R., Dutta, R., Kalamdhad, A.S. and B. Kumar (2019). An investigation on water quality variability and identification of ideal monitoring locations by using entropy based disorder indices. *Science of The Total Environment*, **647:** 1444-1455.

Singh, M.K., Paul, R., Karmakar, B., Jamatia, A. and M.K. Das (2016). Water quality assessment of river Haora in Agartala. *International Journal of Geology, Earth & Environmental Sciences*, **6(2):** 37-44.

Shannon, C. (1948). A Mathematical Theory of Communication. *Bell System Technology Journal*, **27:** 379-423.

Vuori, K.M. (1995). Direct and indirect effects of iron on river ecosystems, *Annales Zoologici Fennici*, **32(3):** 317-329.

World Health Organization (WHO) (2011). Guidelines for Drinking Water Quality. World Health Organization, Geneva, Switzerland, 4th ed.

Willett, J. (1987). Similarity and clustering in chemical information systems. John Wiley & Sons, New York, United States, 266 p.

Yang, H., Shen, Z., Zhang, J. and W. Wang (2007). Water quality characteristics along the course of the Huangpu River (China). *Journal of Environmental Sciences*, **19(10):** 1193-1198.

Zeinalzadeh, K. and E. Rezaei (2017). Determining spatial and temporal changes of surface water quality using principal component analysis. *Journal of Hydrology: Regional Studies*, **13:** 1-10.

Zhao, J., Fu, G., Lei, K. and Y. Li (2011). Multivariate analysis of surface water quality in the three gorges area of China and implications for water management. *Journal of Environmental Sciences*, **23(9):** 1460-1471.