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Evaluation of Wastewater Quality Using Multivariate Analysis and Water Quality Index for its Sustainable Management in Urban Area

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ABSTRACT

In present study, wastewater quality was evaluated applying multivariate analysis (PCA) and water quality index with respect to the Indian standards in the selected urban areas of Jaipur region, Rajasthan, India. Maximum average values of BOD5, TDS, chloride and fluoride were recorded as 21 mg/L, 1501 mg/L, 285.0 mg/L and 1.8 mg/L, respectively, along with metal concentration in order of Zn (6.31 mg/L)> Fe (0.52 mg/L)> Mn (0.25 mg/L), Cu (0.16 mg/L)> Pb (0.11 mg/L)> Ni (0.02 mg/L). PCA indicates four components extracted with a total variance of 78.48% from the water quality parameters. Wastewater Quality Index (WWQI) analysis emphasis level of pollution load at different sites which revealed 40% of the selected sites were inappropriate for reuse without treatment, however, 60% of the sites with moderate pollution load could be suitably reuse in agricultural and aquaculture. Findings of the present study conclude that multivariate analysis and wastewater quality index could be used as an effective tool for environmental monitoring, assessing, and categorizing wastewater to opt appropriate treatment, reuse and recycling options for sustainable wastewater management.

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INTRODUCTION

Water contamination with urban wastewater become a global concern due to depletion of water quality of aquatic ecosystem leading to environmental and health hazardous (Bhateria and Jain, 2016; Wen et al., 2017; Akhtar et al., 2021). More often, waste water discharged directly into rivers, lakes, and coastal waters without treatment in developing countries (Ullah Bhatt and Qayoom, 2022). During past few decades, rapidly increasing human population and urbanization leads to increase direct discharge wastewater into the aquatic environment in the developing countries (Preisner, 2020). In India, over 40,000 MLD (million litres of sewage daily) is being generated across the country, and only 20% of sewage is being treated by conventional treatment facility available (Shah and Kulkarni, 2020). Most of the Asian rivers are being getting polluted due to unregulated wastewater discharge (Shan et al., 2020; Sathre et al., 2022). Waste water discharge into the rivers and lakes causes enrichment of nutrients leads to overgrowth of aquatic weed and algae, depletion of dissolved oxygen and water quality,

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bioaccumulation of persist elements into the aquatic biota (Agarwal, 2011; Okereafor et al., 2020; Mozafari et al., 2023; Naderian et al. 2024). For ensuring environmental and health safety, water quality parameters must be within the permissible limits for safe disposal, reuse and recycling of wastewater (Pandey et al., 2014). It is crucial to monitor, collect reliable information on water quality, assess spatial variations in the water quality parameters, identify prime sources of contamination, quantify level of contamination for effective wastewater management and water conservation (Tian et al., 2019; Strobl and Robillard, 2008). Multivariate statistical techniques and the water quality index (WQI) are frequently being used in the assessing the wastewater quality for wastewater management and conservation of water resources (Mishra and Patel, 2001; Naik and Purohit, 2001). Wastewater Quality Index (WWQI) is a single numerical value used to rationally convey the data and assist in assessing the overall wastewater quality for reuse and safe disposal as a feasible assessment method with minimum sampling size, energy and resources (Sarkheil et al., 2021). Principle Component Analysis (PCA) analysis identifies the factors that have the largest impacts on wastewater quality and provides crucial inputs and information for operators and decision-makers to adapt treatment operations (Mostafaei, 2014; Muangthong and Shrestha, 2015; Abbaa et al., 2021). Geographic information system (GIS) basically utilized to produce, manage, analyse and map different data sets to show the spatial variations in wastewater quality parameters that aids in identifying the crucial zones in the area of wastewater quality evaluations and locate main sources of pollution (Khan et al., 2020). WQI, along with multivariate statistical approaches have gained prominence in recent years since due to unbiased presentation of connections among the variables (Taloor et al., 2020; Rahmat et al., 2022). However, there is scarcity of data on assessing waste water quality by applying multivariate analysis, combined analysis of water quality parameters with geostatistical and geographical information system (GIS) tools for wastewater management. Further, limited studies have been conducted on availability, distribution and propagation of metals in the aquatic environment and related health risk (Nodefarahani et al., 2020; Aradpour et al., 2021). Therefore, present study carried out with objective to assess waste water quality by applying geographical and statistical techniques particularly GIS and PCA and emphasis the spatial variations of water quality of sewage for its treatment, reuse, and safe disposal.

MATERIAL AND METHODS

For the present study, the Sanganer urbanised area located in the Jaipur district of Rajasthan, India, between 26° 49° and 26° 51° N and 75° 46° and 75° 51° E was selected as study area (Fig. 1).

Following steps were followed to carry out the study: (1) Sampling and analysis of waste water samples from the Sanganer urban area in Jaipur, Rajasthan, India for water quality parameters (2) Determination of WWQI of waste water samples (3) analysis of water quality parameters using PCA and GIS. Composite waste water samples were collected using polyethylene plastic bottles with a one litter capacity and stored at 4^0 C and brough to laboratory for analysis. Samples and each collection site have been precisely geo-tagged and labelled from WW1 to WW14 and STP1 to STP4 using a Garmin GPS unit (model 68s), enabling the retrieval of a range of location-specific data (Luo et al., 2011). Description of site coordinates and more details are depicted in the Table 1.

Collected samples from various sites from the study area were analysed for different physio-chemical parameters to assess water quality in triplicates. pH meter used to determine hydrogen ion concentration (pH) in the water samples. Similarity, electrical conductivity meter (an EC probe and equipment that had been calibrated) used to determine the electrical conductivity (Mc Neill, 1992). Digital water quality test kit was used to estimate Total Dissolved Solids (TDS) in the collected wastewater samples. Chloride content, total hardness, and alkalinity of water

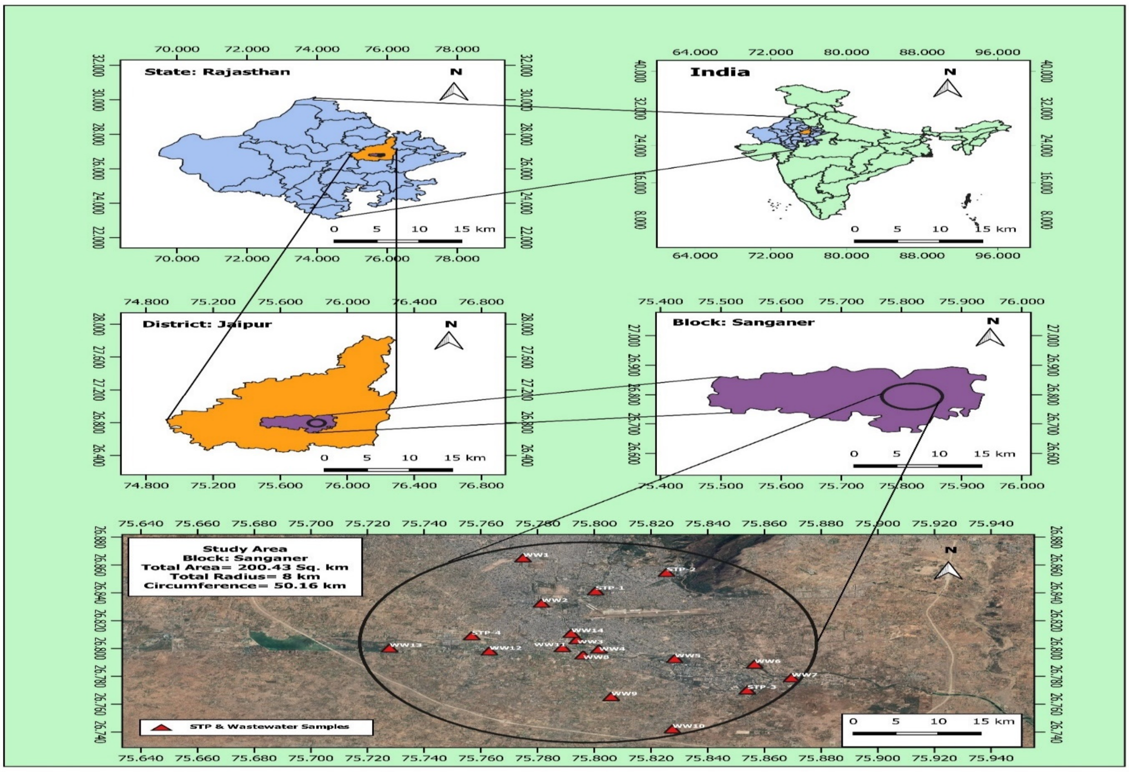


Fig. 1. Wastewater sampling collection sites at study area, Jaipur region, Rajasthan (India).

Table 1. Description of waste water samples collection site of study area of Jaipur region, Rajasthan (India).

Wastewater sample	Longitude	Latitude
WW1	75.7749	26.8651
WW2	75.7814	26.8326
WW3	75.8005	26.8414
WW4	75.8255	26.8547
WW5	75.7940	26.8064
WW6	75.8017	26.7997
WW7	75.8284	26.7928
WW8	75.8566	26.7888
WW9	75.8696	26.7790
WW10	75.8540	26.7702
WW11	75.7961	26.7954
WW12	75.8060	26.7655
WW13	75.8276	26.7422
WW14	75.7888	26.8007
STP1	75.7630	26.7983
STP2	75.7278	26.8004
STP3	75.7568	26.8092
STP4	75.7919	26.8109

samples determined by the titration method using the standard procedure for examining water and wastewater (APHA, 1992). Fluoride content determined in collected water sample using the UV-visible spectrophotometer (Barghouthi and Amereih, 2017). Dissolved Oxygen (DO) and five -days biological oxygen demand (BOD_5) estimated following Winkler titration method (Aniyikaiye et al., 2019). For estimation of sulphate in wastewater, SO_4 ions replaced with $CaCl_2$ ions by extraction process and SO_4 extract turbulence approximation is performed using a spectrophotometer. Metal content in wastewater samples estimated after complete digestion of water samples with $HNO_3/HClO_4$ (3:1, v/v) at 80^0 C and absorbance was recorded in diluted samples by using atomic absorption spectrophotometer (AAS, Shimadzu). An extensive evaluation of the various wastewater quality indicators has done to accurately access the overall quality of wastewater by multivariate analysis using the SPSS programme (version 22 for Windows) and GIS. Different statistical techniques and models including MV, SD, and CV used for data analysis (Zhu et al., 2019). Principal component analysis (PCA) was used to reduce the dataset into new variables, create a minimum data set (MDS), and analysed relationships between metal contents and other parameters along with factor analysis (FA) to identify specific factor weight of each metal (Weissmannová and Pavlovský, 2017) by using SAS Systems for Windows 10 platform and Statistica 12.5® software and varimax rotation was used to rotate each PCA component. WWQI maps, spatial distribution maps, Area maps, Thematic maps, and other maps for the region were created for the GIS-based evaluation utilising Sentinel 2 Satellite data (March 2021) in bands: 3, 4, 8, and built on ArcGIS software 10.8. (2020). Wastewater quality index (WWQI) determined using the weighted arithmetic index approach following the method of Bora & Goswami (2016).

RESULTS AND DISCUSSION

Extensive surveys were conducted in the selected urban area of the Jaipur region of Rajasthan, India for monitoring and collection of wastewater samples. Waste water samples collected analysed for water quality parameters and their variations. Maximum values of water quality parameters in the waste water samples were recorded as pH ,7.90; Electrical Conductivity, 1.93 µS/cm; TDS, 1501 mg/L; Fluoride, 1.8 mg/L; Total Hardness, 281 mg/L; TSS, 62.0 mg/L; DO, 7.00 mg/L; BOD_5, 21.0 mg/L; Cl , 285.0 mg/L; Total Alkalinity, 301 mg/L; SO_4, 158 mg/L and along with metals concentration as Zn, 6.31 mg/L; Fe, 0.52 mg/L; Cu, 0.16 mg/L; Mn, 0.25 mg/L; Ni, 0.02 mg/L and Pb, 0.11 mg/L. Variation pattern of wastewater quality parameters of collected samples shown as mean, Standard deviation, and minimum and maximum values (Fig 2).

Discharge of waste water into water leads to release of CO_2 from the breakdown of organic matter which effects pH and DO level in the aquatic bodies (Kaur, 2018) and affects aquatic organisms (Popa et al., 2012). Several other processes including re-aeration, transport, photosynthesis, respiration, nitrification, and the decay of organic matter, also impacted by the amount of DO in aquatic environment. Similarly, an average higher BOD_5 values reported in polluted water (Lokeshwari and Chandrappa, 2006; Nihalani and Meeruty, 2021). Waste water typically has higher BOD value reveals high organic matter which requires effective treatment before its discharge into the aquatic bodies for environmental and health safety (Noori et al., 2013; Saidulu et al., 2021). Waste water containing higher concentration of pollution loads may contaminate water resources including groundwater (Baruah et al., 2008; Jeevanandam et al., 2012) leads to human health hazards (Suthar et al., 2009; Boateng et al., 2016). Wastewater quality variables scaled and transformed in the score plot to demonstrate the relationships among different sewage sample. PC variables used in principal component analysis (PCA) to show how the two components relate to one another and scores and loadings plots of all the samples collectively display the chemical and physical properties that influence each order on

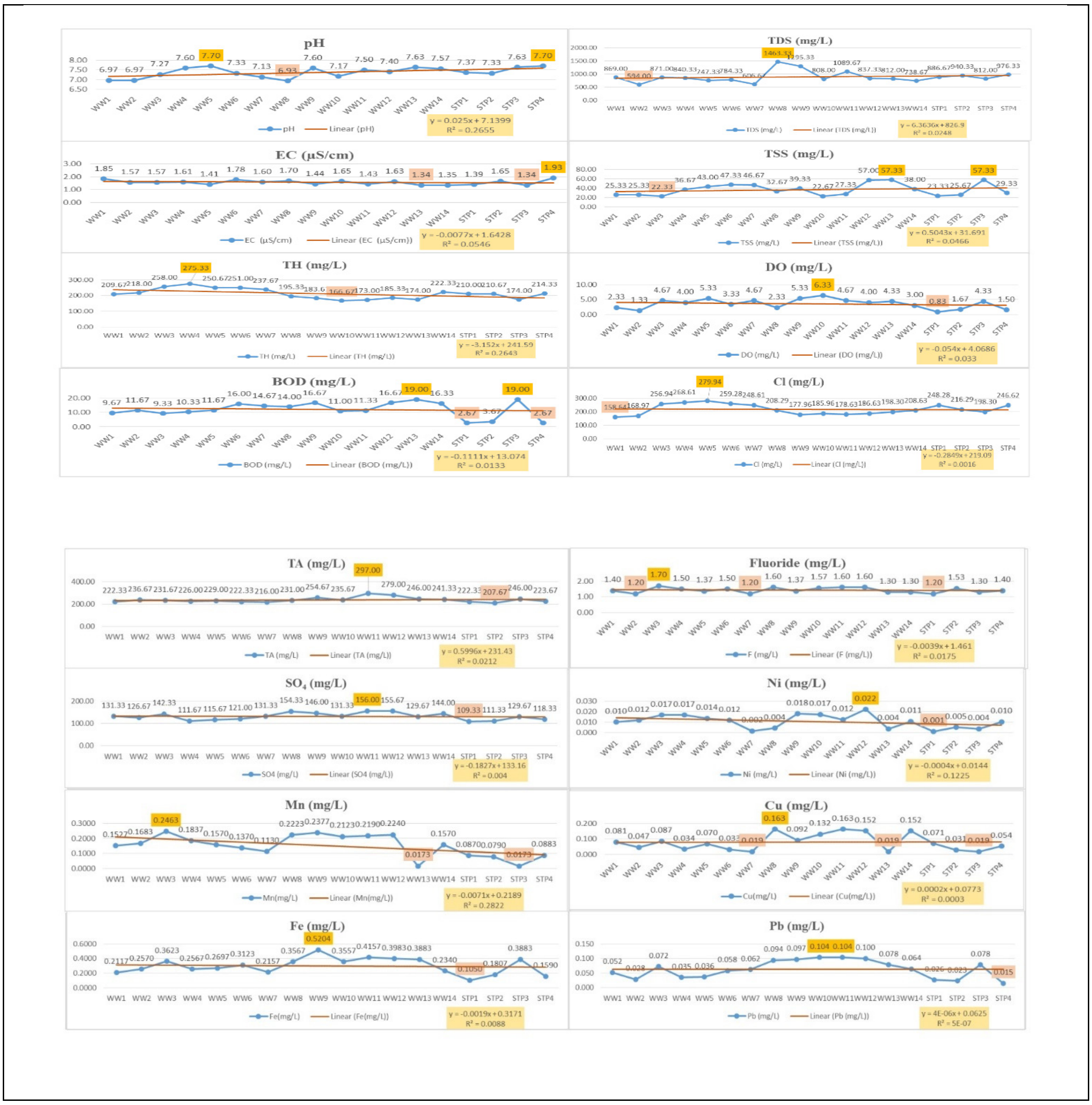


Fig. 2. Wastewater quality parameters in different wastewater samples from selected sites of Jaipur region, Rajasthan (India).

the score plots and retained variables separated into groups based on their statistical factors and correlation matrix (Table 2). Jolliffe's criterion (Jolliffe, 1972) enables a graphic representation of the factor loading through a dipole utilising the first three components, as depicted fig. 3.

Percentage of variance for wastewater recorded as 78.48% of the total variance of the data expanded using the PCA method, and the three components out of the four PC ranges placed first when accounting for the percentage (%) of variance. Principal component analysis (PCA) used to analyse 17 physico-chemical characteristics from 18 waste water samples collected from 18 sampling sites along with the Varimax rotation approach (Table 3).

An eigenvalue provides a measure of the significance of the factor with the highest eigenvalues are the most significant (Shrestha and Kazama, 2007) as Eigenvalues of 1.0 or higher are regarded as significant (Noori, et al., 2012). Liu et. al. (2003) reported that the classification of main components is "strong," "moderate," and "weak," with absolute loading values of >0.75, "0.75-0.50," and "0.50-0.30," respectively. PCA and FA analysis of wastewater shows that,

Table 2. Correlation Matrix[a] of different waste water samples from selected sites of Jaipur region (Rajasthan), India.

		pH	EC	TDS	TSS	TH	DO	BOD	Cl	TA	F^-	SO_4	Zn	Ni	Mn	Cu	Fe	Pb
Correlation	**pH**	1.000	-.411	.029	.319	.067	.194	-.051	.388	.198	-.086	-.232	.134	.235	-.253	-.154	.044	-.160
	EC	-.411	1.000	.026	-.129	.168	-.178	-.151	-.024	-.272	.350	-.018	-.330	.053	.101	-.026	-.130	-.102
	TDS	.029	.026	1.000	-.202	-.399	-.083	-.107	-.187	.186	.386	.336	.336	-.017	.301	.376	.333	.313
	TSS	.319	-.129	-.202	1.000	.012	.372	.741	.091	.281	-.097	.230	.226	.071	-.146	-.073	.384	.309
	TH	.067	.168	-.399	.012	1.000	-.070	-.116	.753	-.510	-.042	-.424	-.685	.057	-.004	-.427	-.366	-.523
	DO	.194	-.178	-.083	.372	-.070	1.000	.590	-.011	.422	.359	.411	.569	.477	.473	.270	.713	.686
	BOD	-.051	-.151	-.107	.741	-.116	.590	1.000	-.291	.478	.067	.629	.564	.208	.310	.303	.726	.691
	Cl	.388	-.024	-.187	.091	.753	-.011	-.291	1.000	-.505	-.031	-.550	-.537	-.118	-.243	-.443	-.407	-.487
	TA	.198	-.272	.186	.281	-.510	.422	.478	-.505	1.000	.327	.747	.770	.436	.496	.659	.705	.703
	F^-	-.086	.350	.386	-.097	-.042	.359	.067	-.031	.327	1.000	.440	.358	.477	.603	.495	.485	.496
	SO_4	-.232	-.018	.336	.230	-.424	.411	.629	-.550	.747	.440	1.000	.748	.278	.667	.796	.743	.861
	Zn	.134	-.330	.336	.226	-.685	.569	.564	-.537	.770	.358	.748	1.000	.252	.402	.684	.767	.880
	Ni	.235	.053	-.017	.071	.057	.477	.208	-.118	.436	.477	.278	.252	1.000	.674	.309	.494	.317
	Mn	-.253	.101	.301	-.146	-.004	.473	.310	-.243	.496	.603	.667	.402	.674	1.000	.695	.621	.612
	Cu	-.154	-.026	.376	-.073	-.427	.270	.303	-.443	.659	.495	.796	.684	.309	.695	1.000	.475	.695
	Fe	.044	-.130	.333	.384	-.366	.713	.726	-.407	.705	.485	.743	.767	.494	.621	.475	1.000	.860
	Pb	-.160	-.102	.313	.309	-.523	.686	.691	-.487	.703	.496	.861	.880	.317	.612	.695	.860	1.000

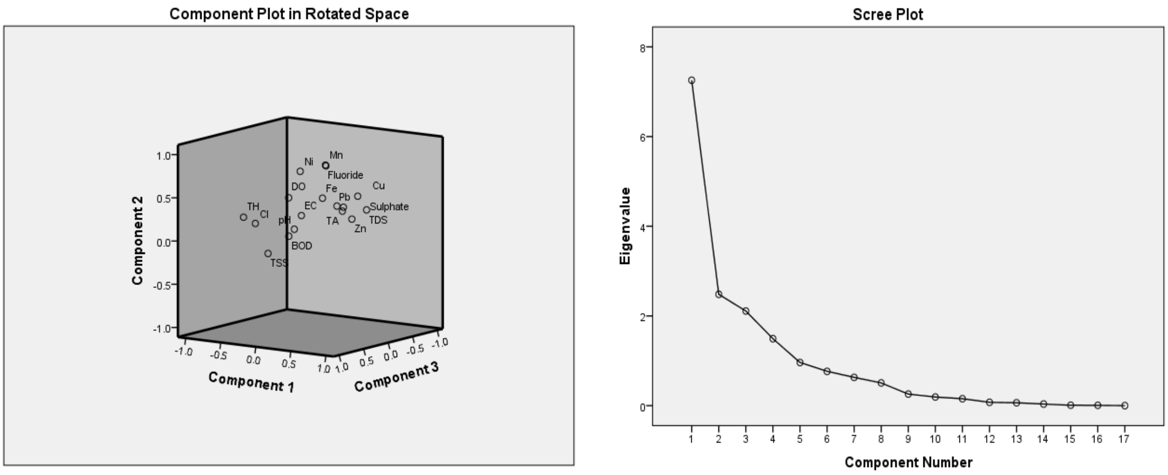
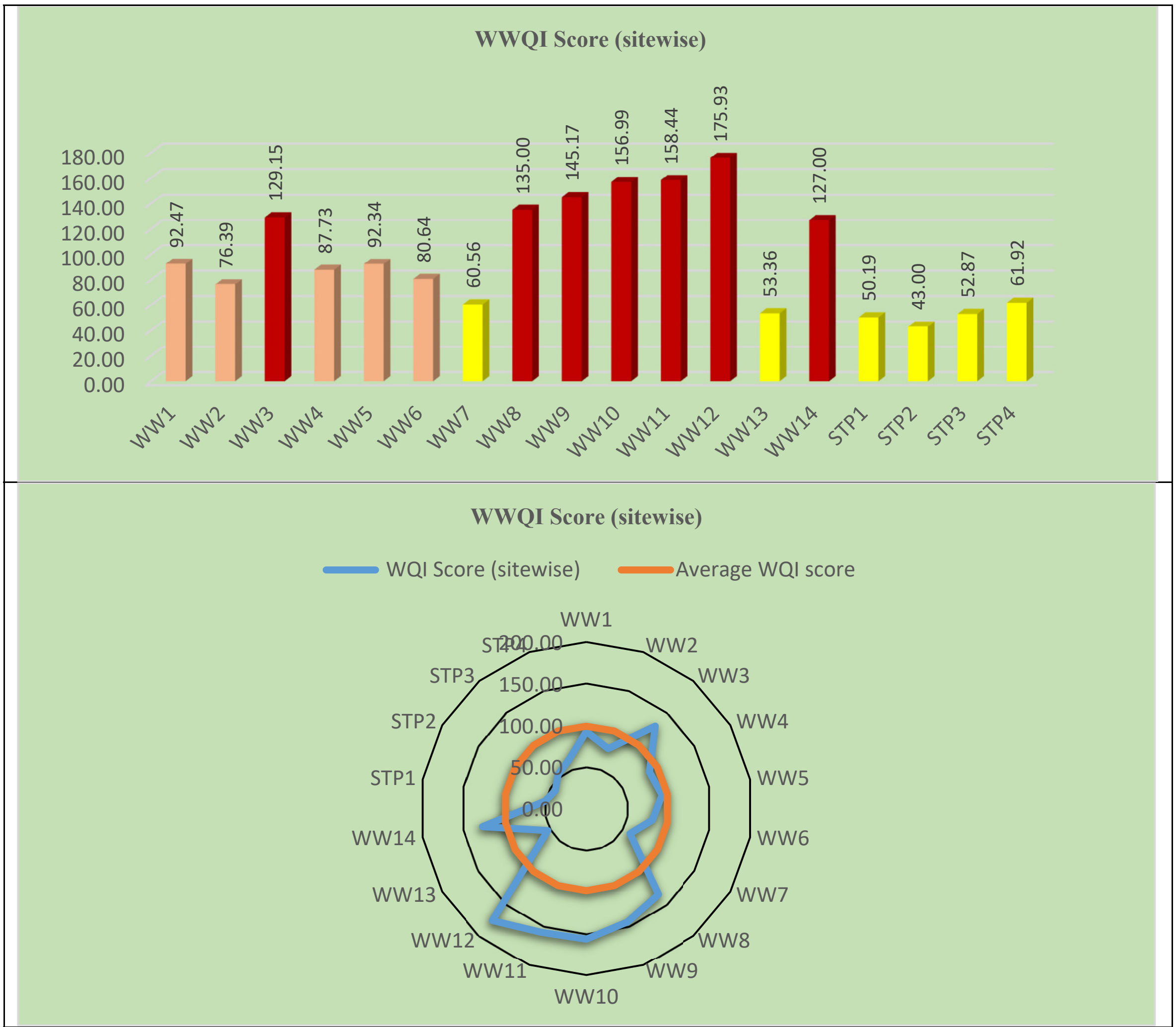


Fig. 3. Component plot of wastewater quality parameters of Jaipur region, Rajasthan (India).

the first component (PC1), which accounted for 42.68% of the total variance, and has strong positive correlation value with Pb, Fe, Sulphate, Zn, and Total alkalinity and a moderately strong positive correlation Cu, Mn, BOD_5, DO, Ni, chloride, fluoride which reflects the role of lithogeny factors in influencing the water quality. PC2 (14.60 of the total variance) has



Categary	Range	WWQI Status
Category-A	0-25	Excellent
Category-B	26-50	Good
Category-C	51-75	Poor
Category-D	76-100	Very Poor
Category-E	Above-100	Unsuitable for fish culture

Fig. 4. Wastewater Quality Index (WWQI) of the different wastewater samples from selected sites of Jaipur region, Rajasthan (India).

moderate positive correlation with TSS and pH and moderate negative correlation with BOD_5, DO, TDS and EC. PC3 was strongly correlation with total alkalinity, chloride, Mn, Ni, and fluoride accounts for 12.41%, however, PC4 demonstrates 8.78 % of the total variance observed and has moderate correlation with chloride.

Overall quality of the waste water depicted by describing the WWQI with respect to five categories of wastewater quality in fig 4. Higher values of WWQI found in the sewage water sample WW3, WW8, WW9, WW10, WW11, WW12 and WW14 indicating their unsuitability for aqua culture as compared to the sample WW7, WW13, STP1, STP2, STP3 and STP4 waste water recorded with poor category, however, the samples WW1, WW2, WW4, WW5, WW6, showed very poor water quality. WWQI approach used as one of the best and most widely used techniques for assessing the quality of wastewater (Arshad and Martin, 2002). Results indicate

Table 3. PCA analysis of variance and component Matrix of different waste water samples from selected sites of Jaipur region (Rajasthan), India.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.257	42.687	42.687	7.257	42.687	42.687	4.766	28.038	28.038
2	2.483	14.606	57.293	2.483	14.606	57.293	3.854	22.673	50.711
3	2.110	12.412	69.705	2.110	12.412	69.705	2.878	16.927	67.638
4	1.493	8.783	78.487	1.493	8.783	78.487	1.844	10.850	78.487
5	.962	5.658	84.145						
6	.765	4.500	88.646						
7	.630	3.707	92.352						
8	.507	2.980	95.332						
9	.258	1.520	96.852						
10	.192	1.131	97.983						
11	.154	.907	98.890						
12	.074	.433	99.323						
13	.063	.373	99.696						
14	.036	.210	99.906						
15	.009	.053	99.959						
16	.007	.040	99.999						
17	.000	.001	100.000						

Parameter	Component			
	PC1	PC2	PC3	PC4
Pb	.952			-.130
Fe	.902	.189		
Sulphate	.899	-.139		-.182
Zn	.890		-.296	.171
TA	.832	.109	-.150	.191
Cu	.771	-.352		.101
Mn	.703	-.281	.529	
BOD	.663	.511		-.476
DO	.640	.466	.314	
Cl	-.553	.382	.504	.236
TSS	.273	.768		-.297
TDS	.349	-.469	-.104	.436
EC	-.125	-.467	.428	-.449
TH	-.522	.266	.691	-.140
Ni	.483	.104	.589	.230
Fluoride	.530	-.325	.572	.156
pH		.607		.712

Extraction Method: PCA.

that 40% of the sites of the selected areas found with high pollution loads, however, 60% sites represent moderate pollution load which indicates that water quality of category of E and C of wastewater (Fig. 4).

CONCLUSION

Wastewater quality parameters found to vary at different site in the selected areas with respect to organic load and water contaminants in wastewater emanating from urban areas. WWQI and multivariate analysis reveals that at most of selected sites, wastewater found unsuitable for reuse in aquaculture due to its poor quality and require adequate treatment for further use and safe disposal. Unregulated discharge of poor quality of wastewater into the aquatic bodies with high organic loads may cause water contamination and degradation of aquatic ecosystem. However, wastewater with moderate organic loads and trace amount of metals may be recommended for reuse in aquaculture and irrigation. Present study concludes that assessment of wastewater quality applying multivariate analysis could be new insight in evaluating wastewater treatment processes and categorizing wastewater for their further use and recycling for sustainable wastewater management and safe disposal. Further, by applying GIS and PCA in environmental monitoring for water quality could be presented in more comprehensive and effective ways for their real time variations and adapting appropriate technology for wastewater treatment, sustainable water resource utilization, environmental protection, and health safety.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INETREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

DATA AVAILABILITY

All data are provided in the manuscript.

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