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Chemometric Characterization and Source Apportionment of Water Quality in Tropical Cities

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Abstract

The present study was conducted in Jhansi region for the source apportionment of water pollution and its impact on water quality. Ten sampling stations grouped into 2 categories (surface water and ground water) were selected. Surface water include, river (Betwa and Pahuj), Dam (Parichha and Pahuj Dam) and Pond (Antiya Tal and Laxmi Tal) while ground water include, Tub wells, Dug wells and Hand pumps. The water samples were analyzed for various physicochemical and microbial parameters such as pH, EC, TSS, TS,TDS, total hardness, Ca, Mg , alkalinity, acidity, Cl, DO, BOD, free CO_2, temperature and MPN. Results showed that the total hardness, TDS and acidity value are higher than the tolerance value of most of the places. PCA had generated 3 significant factors having Eigen values >1 which explain 92.78% of the variance in the dataset. Therefore, the present study revealed that mining, dumping of municipal sewage, disposal of biomedical waste and industrial solid waste (e.g fly ash) have greater negative influence on the water quality.

Keywords: Water quality, Cluster analysis, Factorial analysis, PCA, source apportionment

1. Introduction

Water pollution is the contamination of water bodies (lakes, rivers, oceans, aquifers and groundwater). Nowadays, water resource are deteriorating at a faster rate and becoming a global problem. Discharge of toxic chemicals, over pumping of aquifer and contamination of water bodies with substance that promote algae growth are some of today's major cause for water quality degradation [1]. Water with metals in discharges from mining, smelting and industrial manufacturing, is a long-standing phenomenon [2]. Almost 70% of the water in India has become polluted due to the discharge of domestic sewage and industrial effluents into natural water resources such as rivers, streams, and lakes [3]. Movement of water and dispersion within the aquifer spreads the pollutant over a wider area, its advancing boundary often called a plume edge, which can then intersect with groundwater wells or daylight into surface water such as seeps and springs, make the water supplies unsafe for humans and wildlife. India is now the biggest user of groundwater for agriculture in the world. Groundwater irrigation has been expanding at a very rapid pace in India since the 1970s. By now, tube wells have become the largest single source of irrigation water in India. The interaction of groundwater contamination with surface waters is analyzed by the use of hydrology transport models.

Bundelkhand Region of central India has always commanded an eminent place all through the Indian history. Bundelkhand is stretched between 23°35' 26'N and 78° 82' E bounded by the Yamuna in the North, the Chambal in the North West, the erupted ranges of the Vindhya plateau in the South and the Panna and Ajay Garh ranges in the South East. Jhansi falls under a semi arid climate, with two main seasons: Monsoon and Dry. It is typically monsonic with the year divisible into

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three seasons namely rainy (mid June to end October), winter (mid October to mid February) and summer (mid February to mid June).

Pollution in groundwater and surface water created health problems [4]. The quality of surface water is generally under a considerable potential of contamination especially by agriculture pesticides dumping of biomedical waste, mining and industrial waste. Thus, estimation of quality of water is extremely important for proper assessment of the associated hazards. No proper and adequate work has been done on the surface and ground water quality with duration of time in the Jhansi city in different zones. Day by day the pollution in Jhansi has been increasing, due to increasing number of mining sites, industries and biomedical waste dumping on land which affects the ground water quality and large amount of surface water is being contaminated. The objective of this research is to investigate the quality of ground water and surface water on which the large population of Jhansi depends, as well as to evaluate the water quality and source apportionment of pollution using statistical tools in this region.

2. Material and Methods

2.1. Study Area

Jhansi is located in the plateau of central Indian area dominated by rocky reliefs and minerals underneath the soil. The study area lies in southwest portion of Uttar Pradesh state in India between 25^0 30’ and 25^0 57’ N latitude and 78^0 40’ and79^0 25’ E longitudes. Being on a rocky plateau, Jhansi experiences extreme temperatures. Winter begins in October with the retreat of the Southwest Monsoon (Jhansi does not experience any rainfall from the Northeast Monsoon) and peaks in mid-December.

The study sampling stations were selected to monitor the surface and ground water quality in and around the Jhansi city. For the monitoring of surface water quality, the monitoring stations were divided into three categories as River - Pahuj (S1) and Betwa (S2) rivers, Dam - Parichha Dam (S3) and Pahuj Dam (S4), Pond - Antiya Tal (S7) and Laxmi Tal (S8), and for ground water sampling, water from tube wells & hand pumps of hospital (S6), main market area (S5) were selected. Water sampling around vegetation area (S9) was monitored as a control site.

2.2. Sampling and Analysis

Sampling of water samples was done manually on fortnightly basis from January to June 2015 and transferred to the laboratory, preserved and stored for further analytical determinations and treatment. Biological activity such as microbial respiration, chemical activity such as precipitation or pH change, and physical activity such as aeration or high temperature must be kept to a minimum. Methods of preservation include cooling, pH control, and chemical addition. The length of time that a constituent in ground water will remain stable is related to the character of the constituent and the preservation method used [5]. For data accuracy, reagent blanks and standards were analyzed at the beginning and end of the measurement. For analytical precision, the samples were analyzed in triplicates. The reproducibility was within ±5 % in all measurements.

2.3. Statistical Analysis

Multivariate analyses were performed through hierarchical agglomerative Cluster Analysis (CA) and Principle Component Analysis (PCA). After standardization of the data (z-score transformation), CA was performed on all the six stations by single linkage method using Euclidean distance as a measure of similarity. PCA was performed to obtain significant principal components (PCs) from the data of wastewater from all the stations and groups obtained from CA with a view to assess spatial differences in ground water quality. All the statistical and mathematical calculations were conducted using SPSS 16 software.

3. Results and Discussions

3.1. Physico-chemical Parameters of Water Samples

Table 1 shows the basic quality of water of all the sampling stations. Figure 1 and Figure 2 designate the water quality parameters at different sites from January - June 2015. Observations reported that highest temperature ranged from 16.2 - 21.3 ^{0}C while pH ranged from 6.1 - 8.0. The highest temperature was recorded at site 3 and lowest at site 6. Singh *et al.* [6] has also reported the pH in ground water of Sipri area, Jhansi to range from 6.5 to 8.0.

Table 1. General Statistics of Water Quality in the City of Jhansi

Parameters	Minimum	Maximum	Mean	Std. Deviation
pH	7.10	8.0	7.5	0.33
EC	95.0	141.0	103.3	14.2
Temp (^{0}C)	16.0	21.2	16.9	1.6
Free CO_2 (mg/L)	25.7	81.3	44.8	16.6
Chloride (mg/L)	57.8	111.7	89.1	20.8
Acidity (mg/L)	14.3	60.4	31.7	16.8
Alkalinity (mg/L)	73.0	200.3	120.9	46.8
Calcium (mg/L)	18.1	40.5	28.9	8.4
Magnesium (mg/L)	34.3	112.6	78.3	23.7
Hardness (mg/L)	72.7	135.4	107.2	23.3
DO (mg/L)	3.9	7.09	5.4	1.05
BOD (mg/L)	4.95	16.2	9.2	3.82
TSS (mg/L)	10.0	30.0	18.9	7.45
TDS (mg/L)	110.0	633.3	296.7	206.0
TS (mg/L)	113.3	660.0	314.1	212.1

Electrical conductivity measures the capacity of a substance or solution to conduct electrical current. Higher values may be due to the influence of anthropogenic sources such as domestic sewage, solid waste dumping, agricultural activities and influence of rock-water interaction. In rainy season due to floods and rains, water level in the well increases, which contains more electrolytes [7].

Free CO_2 in the present study varied from 11.6 to 88 mg/L. Free CO_2 exhibited a prominent inverse relationship with the amount of DO. Present study shows that CO_2 was higher during summer season and lower during winter season. The high concentration of free CO_2 during summer may be attributed to decomposition of organic matter due to increased temperature [8] whereas low concentration of free CO_2 during winter season could be due to high photosynthetic activity. Total alkalinity ranged from 60 to 318.82 mg/L, of which maximum value (318.82 mg/L) was recorded in summer season, observed in Laxmi Tal and minimum (60 mg/L) in winter season observed in Betwa river. In fresh water samples, higher concentration of chlorides is regarded as an indicator of sewer pollution. Chlorides are found in the form of sodium chloride in the groundwater. In the present study, Cl^- varied from 37.5 - 124.53 mg/L. Chloride content was recorded higher in Hospital ground water in the month of January and 37.5 mg/L lower in Antiyataal in the month of March as shown in Figure 1. Devi *et al.* [9] reported that the minimum and maximum value of Cl is 49.3 mg/L in month of February and 59.7 mg/L in the month of June. Calcium is considered to be more important because it is an integral part of plant tissue as well as it increase the availability of other ions. In this study, the ranges of calcium hardness have been found in between 11.22-64.59 mg/L while magnesium hardness has been found in between 12.1 to 141.9 mg/L. Devi *et al.* and Gupta *et al.* [9, 10] have also reported similar results.

Biological oxygen demand (BOD) is an important parameter which is widely used to determine the pollution load of waste water. The aim of BOD test is to determine the amount of bio-chemically oxidisable carbonaceous matter [11]. Values of BOD were due to higher rate of decomposition of organic matter at higher temperature, turbidity and less water current. In the present study the highest average value was recorded at site 3 (16.15 mg/L) and lowest value was recorded at site 2 (4.95 mg/L). Vega *et al.* [12] has worked on Parola Dam in Hingoli District-Maharashtra, found the BOD values were varied from 3.9 to 24.6 mg/L. The highest DO value was recorded at site 2 (7.09 mg/L) and lowest at site 6 (3.94 mg/L).

3.2. Pattern Recognition and Major Source Identification

Figure 2 revealed the characteristic features and types of pollution sources in water. Sampling stations have been classified into three groups using CA in a convincing way. CA is an unsupervised multivariate technique used to classify objects into categories or clusters based on their nearness or similarity [13]. Among all the ten stations, three significantly different groups: (1) stations having highest pollution sources (S8 and S3), (2) Moderate polluted area (S5, S6, S9 and S1), and (3) less polluted site (S4, S7 and S2) of the study stretch were formed by CA. Group 1 and 2 enumerate polluted water which may be due to thermal power plant, municipal waste, agricultural waste, hospital waste, dams, dumping of hospital waste, biomedical waste and active mining activities. Wunderlin [14] has also reported similar results in different areas.

Factor analysis provides information regarding the most meaningful parameters and a powerful technique for pattern recognition which describe whole data set rendering for data reduction with minimum loss of original information [13, 15]. CA/Factor analysis was carried out on standard data set. The PCA generated 2 significant factors having Eigen values >1. These factors, Eigen values and proportion of variance explained are presented in Table 2. These two factors explain 97.13% of the variance in the dataset. The factor scores are mapped out in Figure 3. Each water quality parameter and sites with strong correlation coefficient value was considered to be significant ($p<0.01$). Scatter plot of scores (Figure 4) for the principal components, PC1 and PC2 was obtained for water sampling sites (highest pollution, moderate pollution and

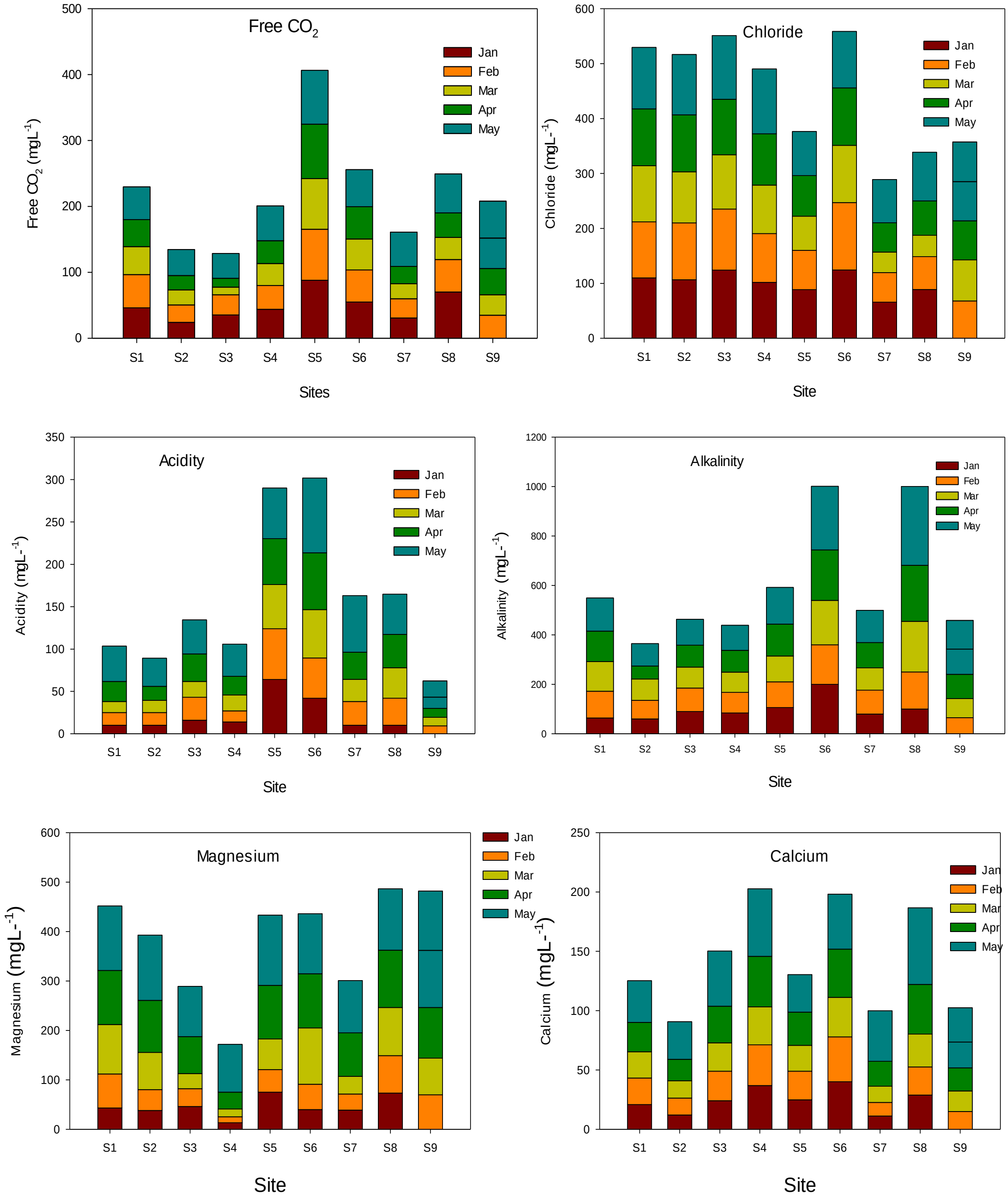

Figure1. Water Quality Parameters (Free CO_2, Cl^-, Acidity, Alkalinity, Mg and Ca) at Different Study Site in Different Months

control site). Present study revealed that a total 5 types of water pollution sources in the study area including mining waste, hospital waste, industrial waste, solid waste disposal from house hold sectors and agricultural waste are present.

The quantity of pollution may be determined by a number of variables and actual pollution levels and types [16, 17]. In addition, the different pollution types in the above results along with this work indicated that water samples of each site had unique physical and chemical characteristics due to its different natural and anthropogenic features [16].

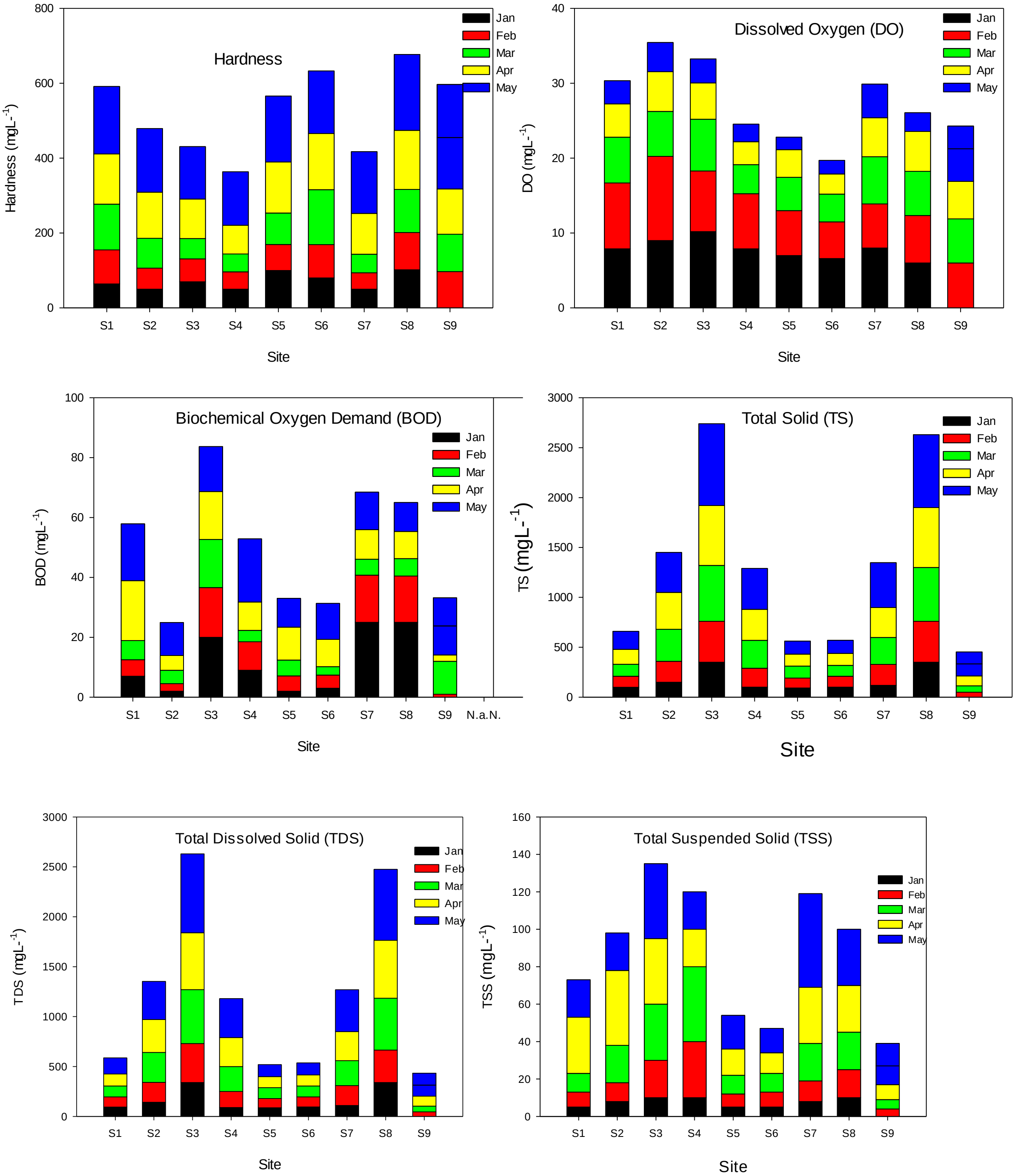

Figure 2. Water Quality Parameters (Hardness, DO, BOD,TS, TDS, TSS) at Different Study Site in Different Months

Table 2. Loading of 10 Experimental Variables on Significant Variance Factor

Sites	**PC1**	**PC2**
Pahujrive	***0.936***	0.309
Betwariver	***0.953***	-0.291
ParichaDam	***0.909***	-0.416
PahujDam	***0.946***	-0.310
City	***0.873***	0.443
Hospital	***0.769***	***0.577***
Antiyatal	***0.954***	-0.292
Dharmashala	***0.940***	-0.314
vegetation	***0.844***	0.477
% Variance	97.264	81.8
Cumulative % variance	15.491	81.1

Bold and italic indicate strong and moderate loadings, respectively

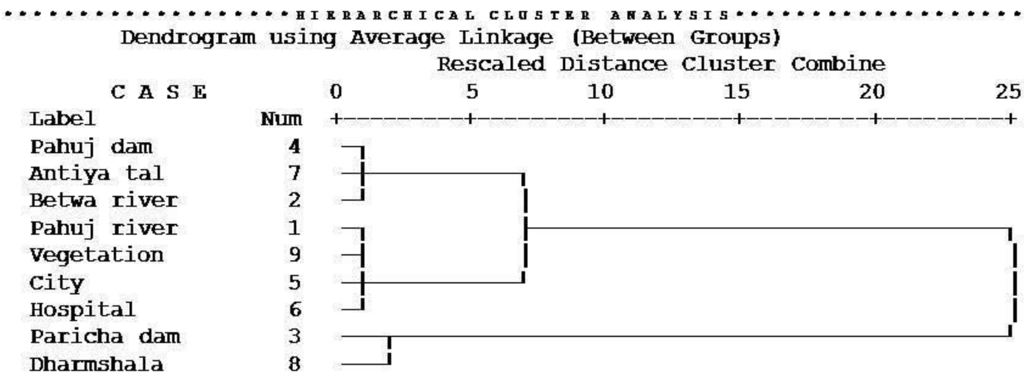

Figure 3. Dendrogram Based on Hierarchical Agglomerative Clustering of Sites

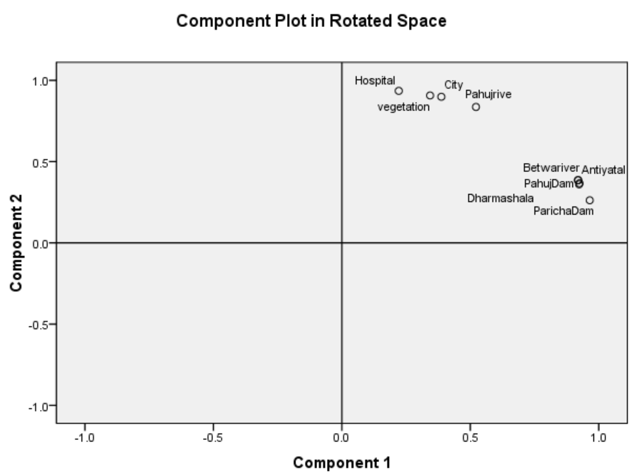

Figure 4. Scatter Plot of Loading for PC1 and PC2

5. Conclusions

The ground water and surface water samples collected from the various places in and around Jhansi city were analyzed for various physicochemical parameters such as pH, EC, TSS, TS,TDS, total hardness, Ca, Mg , alkalinity, acidity, Cl, DO, BOD, free CO_2,temperature and MPN. According to this study, the total hardness, TDS and acidity value are higher than the tolerance value for most of the places. The highly polluted site was Laxmi Tal lake in which the waste of the city and sewage is directly open into the lake. CA classified the water received at sampling stations into three significant groups depending on similarities among them. The present results were also proved correct by using chemometric tools. In addition, the different pollution types in the above results along with present work indicated that water samples of each site had unique physical and chemical characteristics and results suggested that pollution factors in water that play important roles in influencing the quality in one environment may not be important in another.

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