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Multivariate Statistical Technique for the Assessment of Ground Water Quality in Coonoor Taluk, Nilgiri District, Tamilnadu, India

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Abstract

Ground water is one of the most important resources which play a key role in sustainable development. Over the last few decade, the industrial development and population growth has increased the water utilization which creates stress on both water and land resources. In such scenario, assessment of water quality is essential for proper management and utilization. This paper presents the usage of statistical method like Principal Component Analysis and Pearson Correlation coefficient analysis for analysing temporal variations of the ground water. From Coonoor Taluk of Nilgiri district, various samples were collected to analyse physico-chemical factors. The quality of the ground water and the compositions are to be determined by Water Quality Index (WQI) calculation method. A comparison of each parameter with that of standard permissible limit as recommended by WHO.

Keywords: Ground Water, Principal Component Analysis, Water Quality Index, WHO

1. Introduction

Ground Water is a vital natural resource of fresh water supply all over the world. The groundwater quality is as important as the quantity of groundwater due to the appropriateness of water for numerous purposes like drinking, livestock, irrigation, aquaculture, mining and industrial purposes. In recent years, developing countries like India facing the demand of pure water for drinking and other purposes are increased rapidly due to lack of ground water availability in most of the areas. The major factors that affects the quality of water due to rapid increase of industrialization and agricultural development activities and urbanization, which causes ground water gets contaminated[1]. According to WHO, the diseases spread through by water is about 80% to human beings.

Therefore continuous monitoring and evaluation is required to protect contamination of water quality. In this study, 10 samples are collected from various location of coonoor taluk, Nilgiri district and at certain places are exceed the world health organization limit of potable water. To analyse the quality of water, multivariate statistical techniques like principal component analysis and analysis of Pearson correlation are used for this work.

Principal Component Analysis (PCA) is an independent method has been widely used to analyse and reduce the number of variables in the dataset. The specified methods provide improved comprehension of the physico-chemical parameters of water based on their quality[2–5]. The main aim of this work is to discuss the suitability of weighted arithmetic water quality index is used to evaluate and classify the level of contamination in groundwater in coonoor taluk based on computed PCA and water quality index values.

2. Study Area

Coonoor Taluk is a municipality under the Nilgiri district of the state of Tamil Nadu, India. It is situated at 11.35°N 76.82°E and a usual altitude of 1850 metres (6070 feet)

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overhead sea level. According to 2011 census, the total population of the city is about 45,494. The entire Nilgiri District and Coonoor Taluk is showed below in Figure 1.

Being prominent for its making of Nilgiri tea, it is the largest hill station in the Nilgiri. These areas are situated in high altitude and it has a sub-tropical highland climate. The major source of revenue for this taluk is from tourism in Nilgiri. The district is popular for several beautiful hill stations and it attracts tourist in summer seasons.

3. Methodology

PCA is a process of data lessening with slightest loss of information which is original, where it is a transformation of larger set of variables that are dependent in to a lesser set of independent variables[6]. The first principal component has a greater variance than all the other component, then this component will dominate in the covariance matrix. The Eigen values are extracted from the principal components and it give a measure of the significance of the components: the most significant component has a higher Eigen value. The sample data are obtained from the paper[10].

The sum of the square loadings of the variables in the covariance matrix and by varimax rotation is performed to maximizing the most significant factors and also eliminating least value component based on the principles of Kaiser criterion over by 1[7].

$$z_{ij} = a_{i1}X_{1j} + a_{i2}X_{2j} + a_{i3}X_{3j} + \ldots\ldots + a_{in}X_{nj} \quad (1)$$

Where, z = component score, a = component loading, n = the total number of variables, x = variable's measured value, i = component number and j = sample number.

Three categories are characterized under principal component value[8]. The loadings with a value of over

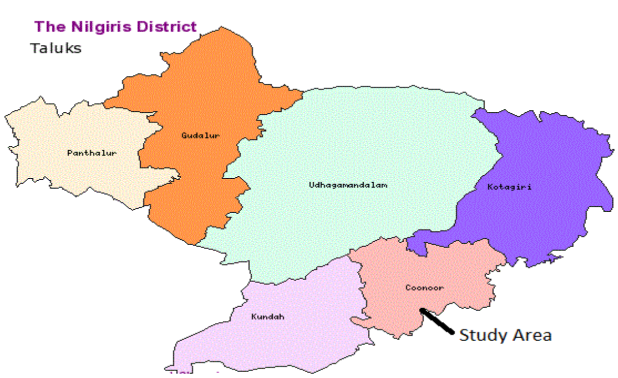

Figure 1. The Nilgiris district map and Coonoor taluk map.

0.75 are strong, variables with less than 0.5 values are considered weak and those varying between 0.5 and 0.75 are moderate.

3.1 Water Quality Index Calculation

In Water Quality Index formulation provides a number between 0 to 100 and it gives overall quality of water at various sample areas based on different water quality parameter are studied from the standpoint of rightness for human use. WQI can be calculated as[9].

$$WQI = \frac{\sum_{i=1}^{n}(Q_i W)}{\sum_{i=1}^{n}(W_i)} \quad (2)$$

The factors used are i - number of factors taken, W_i - unit weightage for the ith factor, P_i - Highest permitted ith factor value, Q_i - sub index of the ith factor and O_i – value observed from the ith factor.

The correlation between the parameters x and y is given by the Karl Pearson Coefficient, given by the formula[12]:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - (\sum x)^2}\sqrt{n\sum y^2 - (\sum y)^2}} \quad (3)$$

where,

x- value of array 1.

y- value at array 2.

n- Number of observation.

4. Results and Discussion

The Principal Component Analysis is the process of reduction in number of components and explanation of variance with reduced number of components. Eigen values greater than one are considered most significant component: The components with higher variance and it gives more information about data. Rotations are performed to maximize the variables and it creates new sets of factors from the original variables. These variables are orthogonal and symmetric and it showed in the Table 1. A Scree plot is showed below in Figure 2.

XLSTAT 2015 software is used dimensionality reduction in this paper. We use PCA to further divide into five components. PC1, PC2 and PC3 have Eigen values over 1 and a variance of 79.605%. Factor plot is showed in Figure 3 and Figure 4 and Figure 5.

Table 1. Summary of principal components, Eigen values and variance

	Minimum	Maximum	Mean	Std. deviation	F1	F2	F3	F4	F5
pH	6.320	7.290	6.921	0.293	0.298	–0.389	–0.509	0.697	0.092
Hardness	69	127	101.923	20.658	0.914	–0.241	0.245	0.092	0.163
turbidity	0	4	2.923	1.320	0.800	0.218	–0.325	–0.322	–0.242
Total dissolved solid	410	575	487.769	64.229	0.019	0.413	0.724	0.470	–0.278
Sulphate	163	250	225.231	23.707	0.003	0.884	0.011	0.038	0.456
chloride	169	247	210.462	25.445	0.444	0.733	–0.403	0.150	–0.187
calcium	48	116	83.769	21.745	0.864	–0.201	0.409	–0.127	0.120
Eigen Value					2.508	1.786	1.279	0.859	0.428
Variance					35.826	25.512	18.267	12.268	6.118
C.V (%)					35.826	61.337	79.605	91.873	97.991

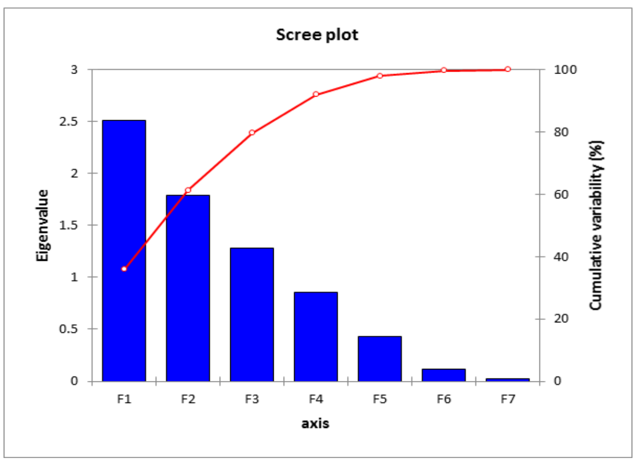

Figure 2. A Scree plot of the components.

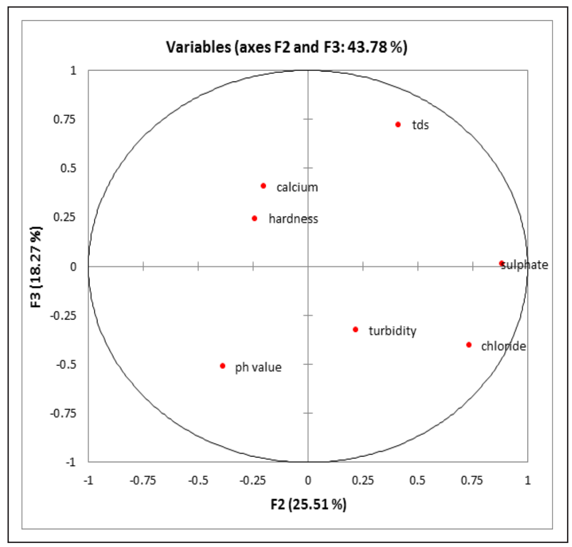

Figure 4. Factor loading plot of F2 and F3.

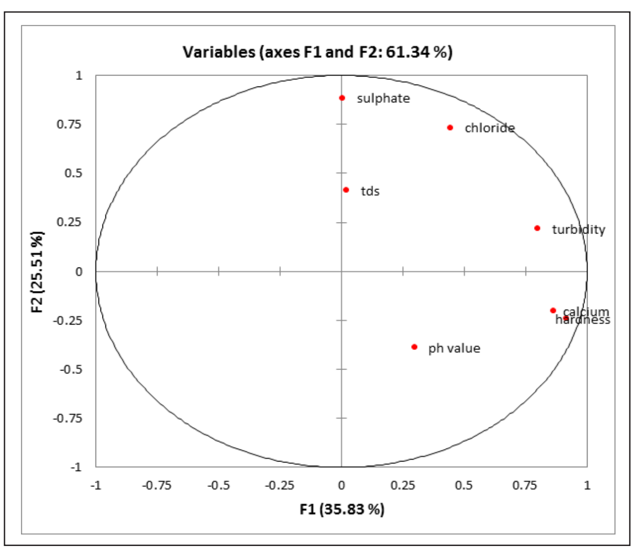

Figure 3. Factor loading plot of F1 and F2.

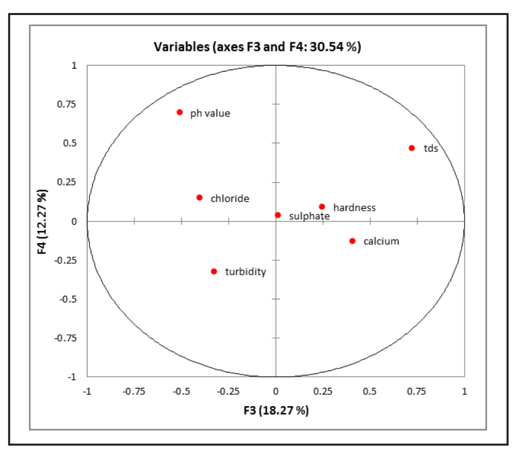

Figure 5. Factor loading plot of F3 and F4.

PC1 has an Eigen score of 2.508 and the equivalent variance of 35.826 % (Table 1.) with positive loadings on pH, total hardness, calcium, sulphate, TDS, turbidity, chloride and no negative loadings values in the component. PC2 has an Eigen score and variance of 1.786 and 25.512 % (Table 1.) respectively with positive loadings on turbidity, TDS, sulphate and chloride and negative loadings on pH, calcium and hardness. PC3 has an Eigen score of 1.279 and variance of 18.267 % (Table 1.) with positive loadings on TDS, total hardness, and sulphate, calcium while pH, turbidity and chloride have negative loadings. The variance and Eigen score of PC4 are 12.268% and 0.859 (Table 1.) respectively.

The positive loadings noted in PC4 are pH, chloride, sulphate, hardness and TDS where the negative loadings are turbidity and calcium. PC5 has an Eigen value 0.428 and equivalent variance of 6.118% (Table 1.) with positive loadings on pH, total hardness, calcium and sulphate while turbidity, TDS and chloride have negative loadings.

4.1 Physical and Chemical Parameter Analysis

The 2006 guidelines of WHO is utilised in this study to analyse groundwater quality in various location of study area[11]. Table 2 depicts the physico-chemical constituents of the samples of groundwater. Biplot of variables and observation is showed in Figure 6 and Figure 7 and Figure 8.

Table 2. Summary of different water quality parameters and quality of water

Location	Altitude	pH	Hardness	Turbidity	Tds	Sulphate	Chloride	Calcium	WQI	Water Quality
Shantur1	1852	6.51	73	3	540	250	234	62	66.7482	Moderate
Shantur2	1862	6.73	88	4	542	241	245	73	80.01836	Very poor
Palada	1835	6.89	117	4	418	244	241	92	81.64519	Very poor
Kattery dam	1847	7.26	126	4	475	163	197	104	83.4477	Very poor
Thaimalai1	1596	6.78	109	3	410	213	194	98	69.47369	Moderate
Thaimalai2	1565	6.32	103	1	575	221	169	96	43.94173	Good
Selas	1697	7.07	86	2	415	203	194	74	57.60742	Moderate
Karrumpalam	1625	7.29	84	0	540	229	187	52	33.90602	Good
Hulical	1743	7.06	97	4	418	236	209	71	81.05121	Very poor
Brooklands	1810	7.06	127	4	572	227	228	106	83.03193	Very poor
Sims park	1846	7.27	119	3	518	246	247	97	71.76648	Moderate
Yedapalli	2026	6.83	69	2	423	213	194	48	55.27498	Moderate
Kodamalai	1941	6.9	127	4	495	242	197	116	82.7629	Very poor

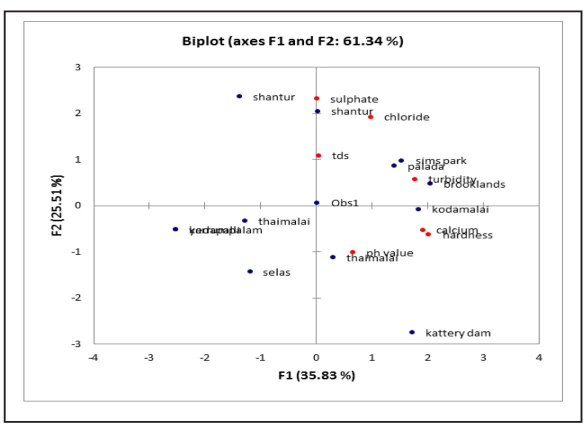

Figure 6. Biplot of variables and observation (axes F1 and F2).

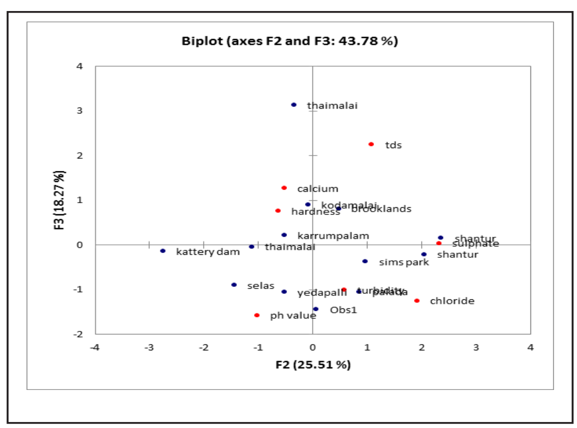

Figure 7. Biplot of variables and observation (axes F2 and F3).

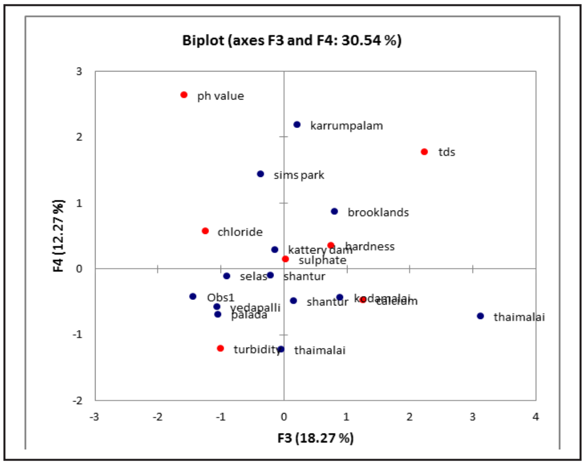

Figure 8. Biplot of variables and observation (axes F3 and F4).

pH is the test of water's acidity value. The pH value varied from 6.320 to 7.290 which are under the WHO allowable limit. On study, an area called Karrumpalam has uppermost pH with 7.290, however the least pH value of 6.320 is at Thaimalai2. When it exceeds the limit it causes irritation in eyes and skin to human beings.

The total hardness of water origin from the natural sources like metallic ion concentration from sedimentary rocks and run off from the soils. The value of sample lies between 69 mg/L and 127 mg/L, the values comes under the allowable range of WHO (500 mg/L). It is perceived that a peak value of 127 mg/L is noted at Brooklands and Kodamalai and lowermost value of 69 mg/L at Yedapalli and above the allowable limit it generates scaling in water heaters and boilers.

The source of calcium content in water is present naturally. The extreme and least value of calcium in water is 116 mg/L in Kodaimalai and 48 mg/L in Yedapalli correspondingly and the values that surpass the extreme limit quantified as per WHO (75mg/L) affects the growth of teeth and bones.

The contamination of chloride is due to excess usage of manures, industrialized wastes, mineral deposits and marine water. The value of chloride varies from least (169 mg/L) at Thaimalai2 to extreme (247 mg/L) at Sims Park and the values are in allowable range of WHO bounds (250 mg/L). These values are obtained from the paper[10].

The animal manure, septic scheme and industrialized wastes are the key motives for the contamination of sulphate in water. The value of sulphate in varies from 163 mg/L to 250 mg/L. According to WHO, the allowable bound of sulphate in ground water is understood to be 400 mg/L. On study, it is found that the extreme value of sulphate is noted as 250 mg/L at Shantur1 and least value of 163 mg/L at Kattery dam.

The bases which lead to contamination of turbidity are due to construction, mining and agriculture. The value of ground water sample ranges from 0 to 4 NTU. On analysis, an area named shantur2, palada, kattery dam, helical, rooks land and kodaimalai has highest value of turdidity with 4 NTU, whereas the minimum turbidity value of zero NTU is at karrumpalam.

Total dissolved solids in water supplies instigate from natural causes, manure, metropolitan and cultivated runoff and industrialized wastewater. The TDS assessment of ground water model in this method varies from 410 mg/L to 575 mg/L, which is under WHO allowable bound of 1000. On study, an area named Thaimalai2 has uppermost value of TDS with 575 mg/L, while the least TDS value of 410 mg/L is noted at Thaimalai1.

4.2 Water Quality Index

The water quality is categorized into five broad types. When the index rating values vary between 0 and 25, the quality of water is excellent. When the range is between 26 and 50, the water quality is good; the range of 51 to 75 is noted as moderate and the values in the range of 76 to 100 is not worthwhile due to its poor quality. When the value surpasses 100, it is clearly perceived that drinking is not desirable.

The water quality in Thaimalai2 and Karrumpalam are in the category of good water quality. The areas are classified based on moderate water quality are Shantur1, Thaimalai1, Salas, Yedapalli and Sims Park. The poor water quality is observed in various areas like Shantur2, Palada, Katterydam, Hulical, Brooksland and Kodamalai. The most contaminated and high risks areas in sample areas are Kattery dam and Brooksland.

5. Conclusion

Principal component analysis is helpful to identify the area which is more contaminated is observed based on different Eigen values and most of the variation is found in Principal Component 1 by the combination of various water quality parameters. It plays a vital role for assessing a total of 10 water quality factors obtained from various location of coonoor taluk in Nilgiri District, Tamilnadu.

The multivariate tool shows that out of 10 factors, five PCs are mined from the data. The total variance of PC1 is observed as 35.826% and PC2 is 25.512% . The water quality index calculation is efficient for classification of the water sample dataset and also polluted areas are identified. It is extremely obvious from the analysis of WQI values that areas altogether have suitable evaluations of the quality of water excluding for Kattery dam, Brooksland and Kodaimalai which requires instant attention to be watched upon. The case study conceded out in this paper for the area of Coonoor Taluk indicates the scope of PCA to examine and these outcomes are significant to yield decisions to manage groundwater quality well.

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