Statistical and Time series Analysis of Ground Water Parameters of Kalahandhi District, Odisha, India

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Abstract. The present research is based on both qualitative and quantitative analysis of ground water of a western state Kalahandi of Odisha, India. 15 physio chemical parameters in addition to ground water depth data has been collected from CGWB, Bhubaneswar, Odisha for all 13 blocks of the district. The main objective of this study is to derive significant relationships between the groundwater parameters and to understand the factors controlling these parameters. Plots of linear regression reveals strong co relationship between magnesium, bicarbonate ions with total alkalinity. Magnesium, chloride and bicarbonate ions are significantly controlling the electrical conductivity of the groundwater. An important implication derived from the time series plot that the pattern of most of the physiochemical and quantitative parameters cannot be assumed linear. Therefore, reliance on formal regression cannot be undertaken for trend analysis. Mann-Kendall test as a non-parametric method of trend testing is taken. Based on S statistics, parameters such as hardness and magnesium show increasing trend whereas pH, sodium and potassium show a significant decreasing trend. Groundwater depth shows surprising results of significantly increasing trend being the S value as high as 103, which leads to ample scope of utilization and reliance on groundwater of the district.

1. Introduction
Water is the most vital natural resource for livings to sustain life on earth. It has a crucial role in shaping and regulating climate. Water is necessity for all forms of life. The domestic utility of water involves drinking, cooking, bathing, cleaning, and for watering garden crops. However, when compared to the worldwide industrial application of water, domestic water utilizations merely form half of its quantity use. Furthermore, water is required to yield crops and to maintain the balance in environment ecology. Worldwide irrigation sector consumes a large share of surface and ground water. As about two – third of the cultivated area is rainfed in India, rest one -third is dependent on irrigation, from which the utilization of groundwater for irrigation consumes nearly 65 % of total water resources of our country. [1-19].
Due to the exponential increase in the population and expansion of industrialization, the globe has seen a tremendous increase in freshwater demand. As the demand is too high overexploitation, compromise with quality and quantity of water in daily life have become so common nowadays. The sharp reduction in surface water quality and groundwater draft in almost all major urban centres in the developing nation risks human health and creates a situation in these places where dwelling becomes almost impossible. Ground water depth in most of the places in the country has fallen to greater depths. Unregulated and unchecked access to groundwater, have resulted in overdraft of groundwater for domestic & irrigation
purposes; and to rapidly falling groundwater tables in prime aquifers. India with declining freshwater sources has an immense shortage of potable water of acceptable quality. The socio-economic growth in many parts of country is causally related to the availability of water resources of acceptable quality and is highly constrained by its non-availability. India’s demand for water is growing despite its expansion in supplies. In such a scenario, decision makers should come up with challenging policies to cater the water demand of the present population. In this context statistics and probabilistic studies can be viewed as effective decision-making tools to assess the quality and potential of surface and ground water source.

1.1. Groundwater scenario of the district

The area in the present study is no exception to the current scenario. With the growing population there is a marked growth in agriculture, industries, and domestic demands of water. The dependence on unsafe surface water sources to meet domestic needs paves way for unaccountable diseases and major health concern among persons of this region. In such a situation the groundwater is conceived as a major alternative source. But the serious concern associated with its over exploitation and probable contamination due to natural or artificial causes. Chemical contaminants such as fluoride, arsenic and nitrate pose major health issues in India. These Figures are alarmingly high and need to be addressed at least in the regions where dependency on groundwater is large. These chemicals with water from the irrigation fields or channels enter the sub surface to meet ground water table and may potentially hamper the quality of groundwater to a large extent at some downstream location [1-19].

1.2. Groundwater Resources of Kalahandi district

According to the reports of Central Groundwater Board the average depth of groundwater table in meter below the ground level of Kalahandi district during pre-monsoon ranges from 3.44 to 8.00 and during post monsoon it ranges from 1.74 to 5.48. These Figures indicate a fair amount of availability of groundwater resource and a reasonable reliability on groundwater sources. The theme of the present research is to examine underlying relationship between groundwater potential (in terms of metres of depth) and quality parameters. This research also focusses critically on the variation of groundwater quality parameters over a time scale of about 17 years, to be vigilant of probable contamination of groundwater resulting from anthropogenic or other activities. As discussed in the previous section the overdraft of groundwater being a serious concern, the real time monitoring of groundwater is also worked out to some extent in this research. The main objectives are,

- Performing linear regressions among various physiochemical parameters and groundwater depth to explain the nature and magnitude of relationships.
- Conducting spatially averaged time series test on different concentrations of physio chemical parameters as well as ground water depth parameter to identify trend using Mann-Kendall trend test.

2. Area for the Study

The study area Kalahandi, is a district of Odisha, which span across a geographical area of 7920 sq. KM and lies in 19°03’ & 20°45’ North latitude and from 82°18’ & 83°48’ East latitude. The position of Kalahandi district falls in the toposheet nos. 64 L, 64P, 65 I and 65 M of Survey of India. Administratively, Kalahandi comprises of two subdivisions, Bhawanipatna and Dharamgarh and Headquartered at Bhawanipatna. The district has 13 blocks i.e., Bhawanipatna, Jayapatna, Junagarh, Koksara, Madanpur Rampur, Karlamunda, Narla, Dharmagarh, Kesinga, Golamunda, Thuamul Rampur, Lanjigarh, Kalampur. The district is sharing its boundary with Bolangir and Nuapada districts in the North, on the east by Kandhamal, by Koraput on the south and Nabarangpur on the west.
3. Data Collection

Ground water quality and depth data were collected from Central Ground Water Board, Bhubaneswar (Odisha) for Kalahandi district consisting of 13 blocks (Bhawanipatna, Dharmagarh, Golamunda, Jaipatna, Junagarh, Karlamunda, Kesinga, Lanjigarh, Rampur, Narla, Koksara, Madanpur, T.Rampur) and 45 stations. 15 numbers of physiochemical parameters pertaining to 45 stations for pre monsoon seasons were collected from the year 2000 to the year 2017. For groundwater potential study ground water depth (in meters below the ground level) for the same 45 numbers of station of Kalahandi district were collected from the same source.

The ground water data of each station and year are sorted for pre-monsoon period for 15 hydro chemical parameters and one groundwater depth parameter. For the present research, the data has been sorted and arranged basically in two ways:

a) Spatial averaged time values: The data collected for 45 different stations is averaged and arranged over a period of 18 years and 21 years for ground water quality and quantity studies, respectively. This type of data setting is necessary for multivariate analysis like regression studies component analysis studies etc.

b) Temporal averaged space values: Here the data collected for 18 years and 21 years for ground water quality and quantity studies respectively is averaged and placed over 45 data stations. For timeseries analysis or trend studies, such arrangement of data is required.

4. Materials and Method

4.1 Regression Analysis

Linear regression is a method to access the extent of relationships among various parameters where all dependent variables are plotted against independent variables. The process of performing a regression allows to identify the dependent variables that affects the independent variable the most. Regression analysis serves as an indicative study as to ignore or drop the factors that impacts an independent variable the least. The dependence and corelation among the dependent variables can also be reflected from these analyses. Time averaged spatial values of parameters are utilized for these analyses. For the current research, four independent variables such as total alkalinity, electrical conductivity, hardness, and
groundwater depth are selected, and other variables are plotted against these variables. The regression line fitting the data plot is given by a linear or straight-line equation.

\[ Y = \alpha X + \beta \]  

(1)

The regression line is dependent upon the relationship between independent variable and dependent variable. The aforesaid relationship is represented below by Pearson’s correlation co-efficient:

\[ r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2 - (\Sigma x)^2)[n(\Sigma y^2 - (\Sigma y)^2)]}} \]  

(2)

4.2 Trend Analysis

A chronological time series analysis of gathering information and attempting to recognize a pattern called Trend Analysis is considering in the study. In statistics, this refers to techniques for understanding an hidden pattern of behaviour in a time series, which would otherwise be partly or completely concealed by noise commonly referred as error. A formal regression analysis is undertaken if the trend can be assumed linear, as described in trend estimation. If the trends assumes a non-linear curve, trend testing can be performed by non-parametric methods, e.g. Mann-Kendall test, which is a type of Kendall rank correlation coefficient. Smoothing techniques aids testing and recognizing of nonlinear trends.

4.2.1 Mann-Kendall trend test (M-K test)

The M-K test is used to analyze data collected over chronological time for consistently increasing or decreasing trends. Moreover Mann-Kendall test is used to determine whether there is a linear monotonic trend in a given time series data. Mann-Kendall trend test is a non-parametric test for trend closely related to the concept of Kendall’s correlation coefficient and the data should have no serial correlation. The procedure follows Gilbert (1987). Data \( x_1, \ldots, x_n \) are assumed to be in a sequential order of collection time, or in spatial sequence. The indicator function is defined as

\[ Sgn x = \begin{cases} 
1, & \text{if } x > 0 \\
0, & \text{if } x = 0 \\
-1, & \text{if } x < 0 
\end{cases} \]  

(3)

The \( S \) statistic is calculated as below:

\[ S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \]  

(4)

\( S \) is taken as negative for a negative trend, zero for no trend, and positive for an increasing trend. For \( n \leq 10 \), the \( p \) value is taken from a table of exact values (Gilbert 1987). For \( n > 10 \), a normal approximation is used, as follows. The total number of groups of ties \( g \) and the number of tied values \( t_j \) within each group, in the sorted sequence is determined. Then the standard deviation of \( S \) is estimated by

\[ SD = \frac{1}{\sqrt{18n(n-1)(2n+5) - \sum_{j=1}^{g} t_j (t_j - 1)(2t_j + 5)}} \]  

(5)

The \( Z \) statistic, is then

\[ Z = \frac{|S| - 1}{SD} \]  

(6)

That used to find out \( p \) from the cumulative normal distribution. The subtraction of 1 indicates the continuity correction.
5. Results and Discussions

Table 1. Normal statistics parameters of water quality for ground water samples

| Parameters | Maximum | Minimum | A_m | Median | Q_1 | Q_3 | S_d | C_v |
|------------|---------|---------|-----|--------|-----|-----|-----|-----|
| pH         | 8.273   | 7.43    | 7.96 | 7.985  | 7.86| 8.09| 0.19| 2.43|
| EC         | 1336    | 320     | 659.14| 601.57| 517.25| 726.13| 233.39| 35.41|
| TDS        | 976     | 256     | 479.77| 447.83| 406  | 534.07| 143.29| 29.87|
| Total      | 320     | 68      | 209.68| 208    | 183  | 229.65| 43.59| 20.79|

5.1 Statistical Results

The central tendency and the measures of variability parameters are determined for the temporal averaged values of spatial ground water quality and depth data. The statistical parameters such as arithmetic mean, median, quartiles, standard deviation and coefficient of variance are calculated and listed in the Table 1. The inferences or the preliminary observations are made from the data of normal statistics discussed in the following section.

All units except pH and Electrical Conductivity are in mg/l, AM- Arithmetic mean, SD – Standard deviation, CV- Coefficient variation, Q1 – Median of the lower half, Q3 – Median of the upper half. Table 1 reveals a wide range of values in most of the chemical parameters except pH and fluoride. Higher values of standard deviations have been detected for electrical conductivity, total dissolved solids and hardness, which indicate that the values are widespread around the mean. In the district, the nitrate value varies from 1.3 to 72 ppm for the pre-monsoon period. The nitrate value for the study area is found to be more than 45 ppm as per WHO (1994) in 6 stations. The highest nitrate concentration is observed in Junagarh block, which is irrigation prone area. The higher concentration in this region owes to over application of fertilizer, which paves its way with water towards ground water reservoir. Chloride is also found to be widely distributed in the present study area, ranging from 11 to 306 ppm. The highest chloride concentration pertains to a location in Golamunda block. Even alkalinity in this location is found to be on higher side, which indicates that there may be interrelation between these two variables.

5.2. Time Series Analysis

The space averaged temporal values of concentrations (in mg/l) are plotted over a time of 18 years. Figure 2 shows the bar chart representation and time series plots of various hydro chemical parameters of groundwater. These graphs present an overall notion of variation of these parameters over a period. In the Figure 2, it can be generally inferred that the values of physiochemical parameters are well below the permissible limits. But for most of the parameters the values are less than the acceptable limits for most of the time as these parameters are plotted over a time scale of 18 years. These plots revealed some parameters for most of the time less than acceptable limit. Major ions like Ca^{++} and Mg^{++} values are found to be 94 % and 67 % of the time respectively, down the acceptable limit. Similarly, values of
hardness, TDS and total alkalinity falls below the acceptable limits for 11%, 56% and 33% respectively of the time. Most of the parameters such as Cl\textsuperscript{-}, SO\textsubscript{4}\textsuperscript{2-}, F\textsuperscript{-} and NO\textsubscript{3}\textsuperscript{-} the values remain less than acceptable limits for all the time. IS 10500:2012 standard for drinking water suggests values in excess of those mentioned under ‘acceptable’ render the water not suitable, but still may be considered in the absence of an alternative source but up to the limits indicated under ‘permissible limit in the absence of ‘alternate source’, above which the sources will have to be rejected.

From the Figure 2 it is also noticeably clear that the underlying pattern of most of the physiochemical and quantitative parameters cannot be assumed to be linear. Therefore, trend analysis cannot be undertaken within formal regression analysis. A non-parametric method of trend testing i.e., Mann-Kendall test is hence adopted for present set of data.

**Figure 2.** Time series of different groundwater parameters plotted with acceptable and permissible limits

5.3. **Mann Kendall Test Result**

Mann-Kendall test is performed with the space averaged temporal values of concentration and depth of ground water. Since the present study is focussed on only pre monsoon ground water data, the data set is devoid of any periodicities (or seasonal effects).
| Ground Water Parameters |  $S$ |  $Z$ |  $p$ | Remarks |
|-------------------------|-----|-----|-----|---------|
| pH                      | -51 | 1.8966 | 0.05788 | Statistically significant decreasing trend |
| Electrical Conductivity  | 2   | 0.041193 | 0.96714 | Not statistically significant trend |
| TDS                     | -9  | 0.30302 | 0.76187 | Not statistically significant trend |
| Total alkalinity         | 23  | 0.83331 | 0.40467 | Not statistically significant trend |
| Hardness                 | 63  | 2.3484 | 0.018853 | Statistically significant increasing trend |
| Ca$^{++}$                | 13  | 0.45453 | 0.64945 | Not statistically significant trend |
| Mg$^{++}$                | 65  | 2.4242 | 0.015343 | Statistically significant increasing trend |
| Na$^+$                   | -72 | 2.9247 | 0.0034481 | Statistically significant decreasing trend |
| K$^+$                    | -52 | 2.1008 | 0.035656 | Statistically significant decreasing trend |
| Cl$^-$                   | 9   | 0.30302 | 0.76187 | Not statistically significant trend |
| SO$_4^{2-}$              | -12 | 0.45312 | 0.65046 | Not statistically significant trend |
| CO$_3^{2-}$              | -25 | 0.90906 | 0.36332 | Not statistically significant trend |
| HCO$_3^-$                | 23  | 0.83331 | 0.40467 | Not statistically significant trend |
| Groundwater Depth        | 103 | 3.0843 | 0.0020403 | Statistically significant increasing trend |

**Figure 3.** Linear regression plots of independent variables [TA, Hardness, EC and GWD] with table dependent variables
The Mann-Kendall test results for different qualitative and quantitative ground water parameters has been tabulated in Table 2. Remarkable $S$ values has been observed for statistically significant trend either increasing or decreasing. The direction of $S$ shows the trend is either increasing or decreasing. The $S$ values for hardness and magnesium ions is positive and on higher side resulting in increasing trend. Whereas parameters like pH, sodium and potassium ions for which $S$ value is negative shows a significant decreasing trend. Statistically no trend has been found for some parameters like EC, TDS, total alkalinity, calcium ions, chloride ions, carbonate, and bicarbonate ions. However, groundwater depth shows surprising results of significantly increasing trend being the $S$ value as high as 103. To determine the nature and extent of relationships among various qualitative and quantity parameter, the concentrations of all dependent variables are plotted against independent variables. Time averaged spatial values of parameters are utilized for these analyses. In the present study four independent variables has been chosen and plotted against a set of dependent variables. Independent variable as total alkalinity, electrical conductivity, hardness and ground water depth and the choice of it is arbitrary.

Table 3. Regression analysis test results for independent and dependent variables

| Independent Variables | Dependent Variables | $\alpha$ | $\beta$ | $R^2$ | $p$ value | Relationship |
|-----------------------|---------------------|----------|---------|-------|-----------|--------------|
| Total                 | Ca$^{++}$           | 0.137    | 26.99   | 0.25  | 0.037     | Reasonable   |
| Alkalinity            | Mg$^{++}$           | 0.135    | -2.091  | 0.68  | 0         | Significant  |
|                       | Na$^+$              | 0.132    | 0.535   | 0.56  | 0.0006    | Reasonable   |
|                       | K$^+$               | -0.016   | 7.033   | 0.02  | 0.321     | Nil          |
|                       | Cl$^-$              | 0.460    | -24.03  | 0.366 | 0.0132    | Reasonable   |
|                       | CO$_3^{2-}$         | 0.001    | 3.491   | -     | 0.909     | Nil          |
|                       | SO$_4^{2-}$         | 0.057    | 3.286   | 0.29  | 0.049     | Reasonable   |
|                       | HCO$_3^-$           | 1.203    | -6.168  | 0.89  | 0         | Significant  |
|                       | F$^-$               | 0.046    | 4.278   | 0.02  | 0.783     | Nil          |
|                       | NO$_3^-$            | 0.116    | 1.700   | 0.17  | 0.054     | Nil          |
| Electrical Conductivity| Ca$^{++}$           | 0.072    | 9.216   | 0.78  | 0         | Significant  |
|                       | Mg$^{++}$           | 0.026    | 9.216   | 0.65  | 0         | Significant  |
|                       | Na$^+$              | 0.023    | 13.02   | 0.58  | 0.0088    | Reasonable   |
|                       | Cl$^-$              | 0.212    | -64.43  | 0.79  | 0         | Significant  |
|                       | CO$_2^{2-}$         | -0.001   | 4.666   | 0.008 | 0.567     | Nil          |
|                       | HCO$_3^-$           | 0.179    | 126.0   | 0.61  | 0         | Significant  |
|                       | TDS                 | 0.566    | 102.38  | 0.94  | 0         | Significant  |
|                       | GWP                 | 0.000    | 6.446   | 0.009 | 0.52      | Nil          |
| Hardness              | Ca$^{++}$           | 0.202    | 5.085   | 0.72  | 0         | Significant  |
|                       | Mg$^{++}$           | 0.063    | 9.781   | 0.55  | 0.00026   | Reasonable   |
|                       | Cl$^-$              | 0.512    | 56.34   | 0.62  | 0         | Significant  |
|                       | SO$_4^{2-}$         | 0.046    | 3.736   | 0.64  | 0         | Significant  |
|                       | CO$_2^{2-}$         | -0.006   | 5.237   | 0.02  | 0.354     | Nil          |
|                       | HCO$_3^-$           | 0.463    | 125.3   | 0.57  | 0.0045    | Reasonable   |
| Ground water Depth    | Mg$^{++}$           | -0.915   | 30.93   | 0.02  | 0.312     | Nil          |
|                       | Na$^+$              | -0.856   | 32.72   | 0.01  | 0.489     | Nil          |
|                       | Cl$^-$              | -0.392   | 72.25   | -     | 0.946     | Nil          |
|                       | SO$_4^{2-}$         | -0.493   | 18.03   | 0.007 | 0.372     | Nil          |
|                       | CO$_2^{2-}$         | -0.303   | 5.572   | 0.019 | 0.583     | Nil          |
|                       | NO$_3^-$            | -1.551   | 32.91   | 0.01  | 0.641     | Nil          |

From the regression analysis the dependency of the observed variables and independent variable are established and it is found to be different and not significant for all parameters. Concentrations of most...
variables increased with increasing independent variables (Table 3). The results of the multivariate analysis with the general linear regression model (Figure 3) shows strong positive relationships ($p \text{ value}<0.05$) of total alkalinity with calcium, magnesium, sodium, chloride, sulphate and bicarbonate ions; electrical conductivity with magnesium, sodium, chloride and bicarbonate ions; hardness with calcium, magnesium, chloride, sulphate and bicarbonate whereas ground water depth is found to have no or meagre co-relation with any other parameters. Some of the dependent variables shows strong relationship with the independent ones. For example, a strong co relationship is revealed between magnesium, bicarbonate ions with total alkalinity, which means these, are the major two underlying factors controlling the alkalinity of the groundwater. All other parameters listed in the table except potassium, carbonate, fluoride and nitrate ions are reasonably related. Similarly, magnesium, chloride and bicarbonate ions are significantly controlling the electrical conductivity of the groundwater, which is obvious. The strong factors affecting hardness are calcium, sulphate, and chloride ions whereas magnesium and bicarbonate are moderately related to hardness.

From these observations, it can be concluded that the hardness is permanent in nature in ground water. Among all independent and dependent variables, the strongest relationship is revealed between EC and TDS with coefficient of correlation $R^2 = 0.94$. Ground water depth fails to establish correlation with the any of the parameters in consideration.

6. Conclusions

The current research is restricted to the preliminary results of multivariate analysis in which linear regression component is only stressed on. Time series and trend analysis forms another part of this research. Nevertheless, prior to this an attempt is to reduce the large data set and search for the inter relations that co-exist between various ground water parameters. The salient features have been concluded in the following points.

- Strong co relationship is established between magnesium, bicarbonate ions with total alkalinity, which means these, are the major two underlying factors controlling the alkalinity of the groundwater. Water alkalinity is primarily a function of geology of the area and dissolution of carbon dioxide from atmosphere. The ions responsible for alkalinity originate from dissolution of geological minerals into rain and ground water. High alkalinity in the groundwater is usually traced in the areas with limestone formations, this is attributed to the dissolution of bicarbonates and carbonates.

- Similarly, magnesium, chloride and bicarbonate ions are significantly controlling the electrical conductivity of the groundwater, which is obvious. Electrical conductivity of water can be immediately related to the concentration of dissolved ions in water. Dissolved solids in water is able to conduct electrical current. Hence, an incredibly significant relationship is observed between EC and TDS.

- The strong factors affecting hardness are calcium, sulphate, and chloride ions whereas magnesium and bicarbonates are moderately related to hardness. From these observations, it can be concluded that the hardness of ground water is permanent in nature.

- The relationship of groundwater depth with other parameters merely can be correlated. For the present study area, any variations in the physiochemical parameter have null effect on the depth parameter.

- Time series plots depicts that the physiochemical parameters of groundwater are well below the permissible limit which gives clear view of contamination free groundwater and is acceptable. Major ions like Ca$^{2+}$ and Mg$^{2+}$ for most of the time remain below the acceptable limit and are the major ions towards unsafe side. Nevertheless, from past few years, Mg$^{2+}$ values are exceeding the acceptable limit, which should be diagnosed rigorously. Since strong co-relationship is depicted between magnesium ions and total alkalinity from linear regression analysis. If such groundwater is withdrawn and utilized for irrigation purpose, it may render salinity problems in culturable area. TDS and total alkalinity moderately exceed acceptable limits. Hardness in the groundwater is an instinct problem of this region. Around 89 % of the time (i.e., over 18 years) hardness exceeds
acceptable limit which is quite high. Most of the parameters such as Cl\textsuperscript{−}, SO\textsubscript{4}\textsuperscript{2−}, F\textsuperscript{−} and NO\textsubscript{3}\textsuperscript{−} the values remain less than acceptable limits for all the time. These are parameters under safe category. Measures of all major ions do not exceed acceptable limits prescribed in Indian Standards for groundwater quality except for Ca\textsuperscript{2+} and Mg\textsuperscript{2+} in scattered areas, indicating the confined water is potable.

- Mann-Kendall test reveals significantly increasing trend for hardness and magnesium ions which is a key factor contributing to the total alkalinity. Parameters like sodium and potassium ions shows a significant decreasing trend. Statistically no trend has been found for some parameters like EC, TDS, total alkalinity, calcium ions, chloride ions, sulphate ions, carbonate, and bicarbonate ions. However, groundwater depth shows surprising results of significantly increasing trend being the $S$ value as high as 103.

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