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Evaluation of groundwater quality for drinking and irrigation purposes: a case study of Peddavanka watershed, Anantapur District, Andhra Pradesh, India

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Abstract

Quality of groundwater in a 398 km² Peddavanka watershed of a semi-arid region of south India is taken up for study and evaluation of its suitability for drinking and irrigation purposes. The main lithologic units in the watershed are quartzite, limestone, shale, and alluvium. Seventy-six water samples were collected from the open-wells and bore-wells covering the entire watershed. The water samples collected in the post-monsoon (winter) and pre-monsoon (summer) were analyzed and interpreted. The water quality assessment is made through the estimation of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, *total hardness as* $CaCO_3$*, TDS, EC, pH and calculation of Sodium adsorption ratio (SAR), % sodium, Residual sodium carbonate (RSC), Kelley's ratio, magnesium ratio, Gibbs' ratio, permeability index etc. According to the overall assessment of the quality of groundwater, it was found to be suitable for drinking and irrigation purposes.*

Keywords *Groundwater quality assessment – Drinking – Irrigation - Peddavanka watershed - Andhra Pradesh - India.*

1. Introduction

The chemical quality of groundwater is directly related to lithology of the area and the residence time the water is in contact with minerals of the rock material. Weathered mantle, soils, and, atmosphere are the important factors responsible for contribution of dissolved solids to water. Areal differences in geology lead to areal differences in the relative proportions of the principle ions in the groundwater. In addition to biological and climate factors, sources of pollution and other related aspects bear a direct influence on the chemical quality of groundwater. It is impossible to control the dissolution of undesirable constituents in the waters after they enter the ground (Johnson 1979; Fetter 1984; Sastri 1994; Aswathanarayana 1995). Keeping in view that

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agriculture is the main occupation in the study area, emphasis is laid on its utility for agricultural purposes in assessing the quality of groundwater in addition to rating waters for drinking in the present study.

The Peddavanka river rises from Mutchukota hills of Erramalai hill ranges and flows in southern direction to join the Pennar river near Tadipatri of Anantapur district, Andhra Pradesh, India, covering an area of 398 Km^2, in between Latitudes 14º55’24”-15º12’50” N and Longitudes 77º51’20” - 78º03’26” E (Figure 1). The climate of the watershed is hot and semi-arid in nature. The watershed receives an average annual rainfall of 550 mm, out of which 90 % is received during the southwest (June-Sept) and the northeast (Oct-Dec) monsoon periods.

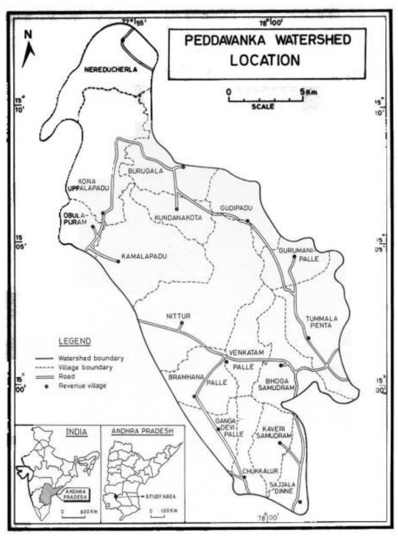

Fig. 1. Location map of Peddavanka watershed

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2. Geology

Most of the watershed area is occupied by the middle Proterozoic Cuddapah Group of rocks mainly represented by shale with interbedded layers of flaggy limestone, quartzite and mafic volcanic flows (Ramam and Murty 1997). Alluvium of recent age comprises sand, silt, and clay, which occur all along the course of the stream and at the confluence of the stream with Pennar River in the southern portion of the watershed (Figure 2).

3. Materials and Methods

Water samples were collected from groundwater and surface water bodies representing pre and post-monsoon seasons by following the standards methods of collection to study the seasonal variations in chemical composition. Techniques and methods followed for collection, preservation, analyses and interpretation of water samples are those given by Fetter 1984; Karanth 1987; Apello 1988; Hem 1989; Apello and Postma 1993; APHA 1995; Buurman and others 1996; Elango and others 2003.

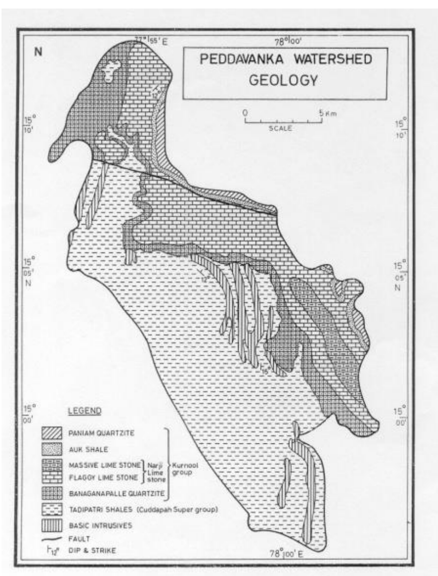

Fig. 2.Geological map of Peddavanka watershed

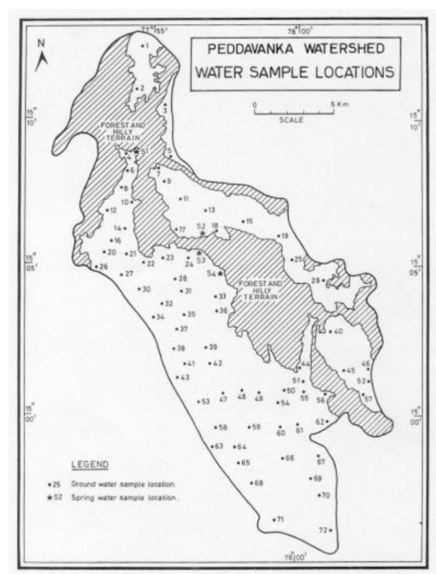

Fig. 3.Map depicting the water sample locations

A total of seventy-six water samples covering the entire watershed area were collected out of which four are surface water samples namely S1, S2, S3, and S4 (Fig. 3). The water samples

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were collected from the open-wells and bore-wells, twice from the same location during post-monsoon (winter) and pre-monsoon (summer).

The chemical constituents of the water samples were analyzed and the parameters computed include Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, dissolved solids, hardness as $CaCO_3$, non-carbonate hardness, hydrogen-ion-concentration (pH), specific conductance in micromhos/cm at 25°C, sodium adsorption ratio (SAR), % sodium, potential salinity (PS), residual sodium carbonate (RSC), Kelley's ratio, magnesium ratio, Gibbs ratio, permeability index, chloroalkaline indices etc.,

Silica content was determined by Molybdate Blue method using indigenous Elico spectrophotometer. Na^{+} and K^{+} were estimated by using a flame photometer. Total hardness as $CaCO_3$, calcium (Ca^{2+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}) and, chloride (Cl^{-}) were analysed by volumetric methods. Mg^{2+} was calculated from total hardness and calcium. Sulphates (SO_4) were estimated using the colorimetric technique. Total dissolved solids (TDS) were estimated by evaporation and calculation methods (Hem 1989). EC and pH of water samples were measured in the field immediately after the collection of samples using a portable field kit. Except pH, which is expressed as dimensionless number, all other constituents are expressed in mg/l. Non-Carbonate hardness was calculated using the values of hardness and alkalinity. Iron, manganese and fluoride were found only in traces and hence not included.

4. Results and discussion

The analytical results of water samples collected during post-monsoon and pre-monsoon are given in Table 1. The maximum, minimum and mean values of different constituents and the computed values are given in Tables 2 and 3.

4.1 Water for domestic purpose

The water used for drinking should be colorless, odorless, free from turbidity and without harmful microorganisms varying from insipid to brackish in some places. According to Stumm and Morgan 1979; Ward and others 1985; van Duijvenbooden and others 1986; Karanth 1987;

BIS 1991; USPHA 1993; Todd 1995, WHO 1996, the pH limits are between 7.0 and 8.5, for TDS 500 ppm maximum upper limit. Like wise permissible limits of hardness, calcium, and magnesium are 100, 75 and 500 ppm respectively, while it is 200 ppm each for chloride and sulphates (Edmunds and Smedley 1996). BIS (1991) recommended an upper limit of 500 ppm for bicarbonates and 200ppm for sodium. The pH of groundwater has no direct effect on health but all biochemical reactions are sensitive to the variation in pH (De 1994). The pH of the basin waters ranges from 6.8 to 8.8 with an average of 8.36 in post-monsoon samples and from 6.7 to 8.6 with an average of 8.45 in pre-monsoon samples indicating an alkaline type.

The dissolved solids (TDS) indicate the general quality of groundwater. Based on the concentration of TDS, the waters are classified as desirable for drinking, if TDS is less than 500 mg/l and permissible up to 1000 mg/l, while they are classified as useful for irrigation, if the TDS is below 3000mg/l and unfit beyond 3000 mg/l (WHO 1996).

According to the above classification, 90% of the waters of the basin are useful in post-monsoon and 94% in the pre-monsoon seasons for drinking. According to WHO (1996), the hardness of water may be rated according to the combined compounds of Ca^{2+} and Mg^{2+} as $CaCO_3$ in mg/l, Hardness of water in the study area ranges from 80 to 912mg/l in post-monsoon and 72 to 524 mg/l in post-monsoon season. According to BIS (1991) classification, ground waters in the study area are moderately hard and very hard. It is interesting that very often the low and high hardness patches are located adjacent to each other. Hard water is generally believed to have no harmful effects on man. Its relation to urinary concretions is controversial. Cardiovascular diseases are reported to be confined more to the areas of soft water than those having hard water (Crawford 1972).

A high concentration of chloride content imparts a salty taste to the water (Feth 1981). People who are not accustomed to high chlorides in waters are subjected to laxative effect as suggested by Raviprakash and Krishna Rao (1994). Though 200mg/l is the limit allowed, the upper limit is given as 1000 mg/l for Indian conditions (Prasad and Subramania Iyer 1983; Subba Rao 2001). But according to WHO (1996), 600mg/l is the highest permissible limit. In the study area chlorides ranges from 11 to 514 mg/l in post-monsoon and 10 to 418 mg/l in pre-monsoon season. Persons suffering from hypertension or congestive heart failure are required to consume sodium-restricted diet in which case the intake of sodium in drinking waters will become significant.

4.2 Water for irrigation purpose

Utilization of groundwater for irrigation depends on many factors, such as texture and composition of soil, type of crop, climate and irrigation practices, in addition to the chemical quality of groundwater (Chadwick and others 1987; Sami Ahmed and Rashid Umer 1991; Chourasia and Tellam 1992; Minhas and Gupta 1992; Sami 1992; Elango and others 2003). The permissible ranges of different ion concentrations vary according to these factors. A few important chemical parameters, such as sodium adsorption ratio (SAR), % sodium, residual sodium carbonate (RSC), Kelley's ratio, magnesium ratio, Gibbs' ratio, and permeability index (PI), chloroalkaline indices are determined to assess the general suitability for irrigation.

4.2.1 Sodium Adsorption Ratio

Excess sodium in irrigation waters reacts with the soil to reduce its permeability as a result of clogging of particles (Chadwick and others 1987). According to the U.S. Salinity Laboratory (1954), the sodium adsorption ratio (SAR) predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil. High values for sodium adsorption ratio imply a hazard of sodium replacing adsorbed calcium and magnesium, a situation ultimately damaging to soil structure. Therefore the sodium adsorption ratio (SAR) is used in adjudicating the irrigation waters. It is obtained by the equation.

$$\text{Sodium adsorption ratio} = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+}) + (Mg^{2+})}{2}}}$$

where ionic concentrations are expressed in milliequivalents per liter.

Irrigation waters are classified by Richards (1954) based on sodium adsorption ratio as given below:

Sodium adsorption ratio	Water category
0-10	Excellent
10-18	Good
18-26	Fail
>26	Poor

Based on the above classification, ninety-seven % of the water samples of the watershed area fall in excellent category and three % samples falls in good category in post-monsoon season and ninety-nine % of the samples falls in excellent category and one % falls in good category in pre-monsoon season. Therefore, none of the samples is of poor category for irrigation in either season. A more detailed analysis, however with respect to the irrigation suitability of the water was made by plotting the data on US Salinity Laboratory diagram (Figs 4a and 4b).

4.2.2 Percent Sodium

The concentration of sodium is important in classifying irrigation waters because it reacts with the soil affecting its permeability. Sodium saturated soils namely alkaline soils formed on account of excess sodium in soil with carbonate as predominant anion or saline soils formed due to excess presence of sodium with either chloride or sulphate as predominant anion stunt the growth of plants. Therefore Wilcox (1955) used % sodium and specific conductance in evaluating irrigation waters using Wilcox diagram as given in Figure 5a and 5b. The % sodium is obtained from the equation.

$$\text{Percent sodium} = \frac{Na^{+}\ K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

where ionic concentrations are expressed in milliequivalents per litre.

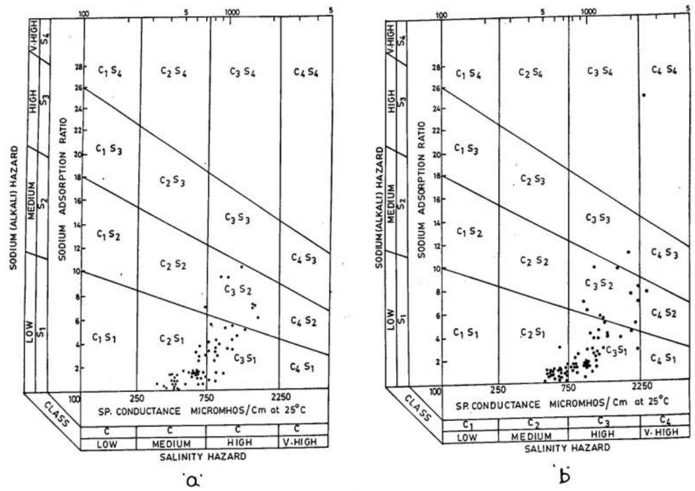

Fig. 4. Rating of water samples in relation to salinity and sodium hazard (USSL 1954)
a) Pre-monsoon b) Post-monsoon

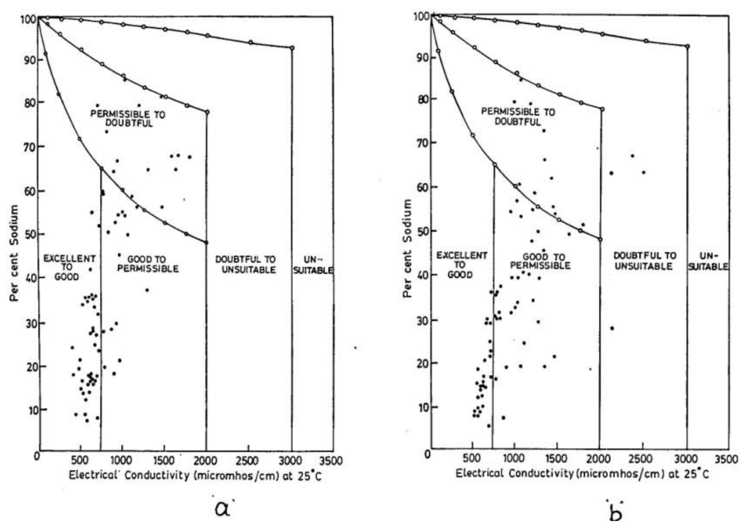

Fig. 5. Specific conductance and % sodium relationship for rating irrigation water (Wilcox 1955)
a) Pre-monsoon b) Post-monsoon

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The Wilcox diagram is divided into five areas and the waters are rated as given below.

Season	Area	No. of water samples	Percentage
Post-monsoon	Excellent to Good	26	34
	Good to Permissible	33	43
	Permissible to Doubtful	6	8
	Doubtful to Unsuitable	11	15
Pre-monsoon	Excellent to Good	40	58
	Good to Permissible	15	22
	Permissible to Doubtful	14	20

Most of the water samples in two seasons fall in excellent to good and good to permissible areas indicating their usefulness for irrigation. No water sample is strictly unsuitable for irrigation.

4.2.3 Residual Sodium Carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes (Richards 1954). This excess is known as residual sodium carbonate (RSC) and is obtained by using the equation:

Residual Sodium Carbonate = $(CO_3^{2-} + HCO_3^{-}) - (Ca^{2} + Mg^{2+})$,
where the concentrations are expressed in milli equivalents per litre.

According to U.S Salinity Laboratory (1954), residual sodium carbonate of less than 1.25 meq/1 in waters is probably safe for irrigation while the waters are unsuitable for irrigation with residual sodium carbonate value more than 2.5 meq / l. Waters containing values in between the above two can be rated as of marginal quality. The following table gives the results and rating of waters based on residual sodium carbonate.

The residual sodium carbonate varies from 0 to 17.56 with an average of 3.36 in post-monsoon waters while it varies from 0 to 7.86 with an average of 2.70 in pre-monsoon waters. It is observed that the water quality declines in post-monsoon season. But as far as the unsuitable category is concerned it is about 25 %. The poor agricultural returns owe partly to this season.

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The residual sodium carbonate distribution and the iso-concentration diagrams are depicted in Figures 6a and 6b.

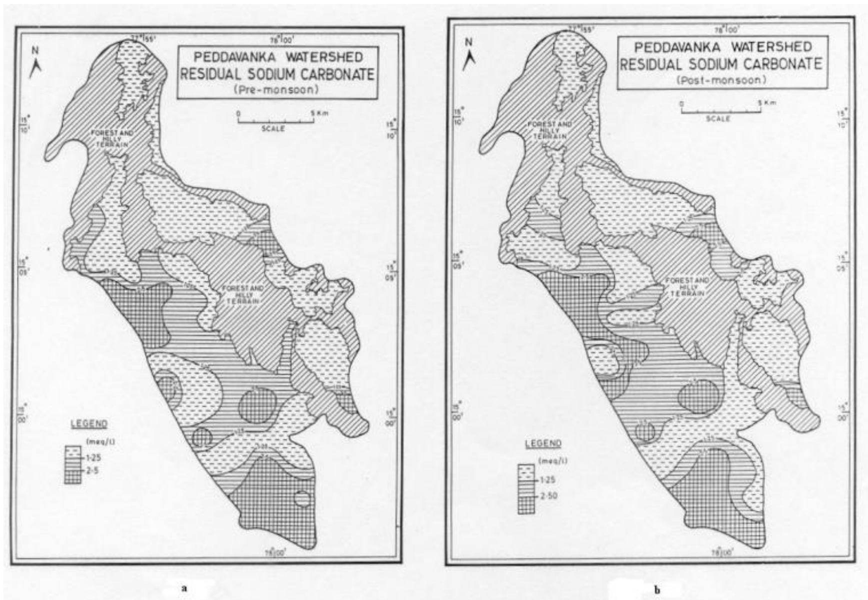

Fig. 6. Residual sodium carbonate (RSC) distribution map
a) Pre-monsoon b) Post-monsoon

RSC meq / 1	Irrigation Class	Number of samples			
		Post-monsoon		Pre-monsoon	
		No.	%	No.	%
< 1.25	Safe	45	59	38	55
1.25-2.50	Marginal	12	16	13	19
>2.50	Unsuitable	19	25	18	26

4.2.4 Kelley's Ratio

Based on Kelley's ratio, the waters are classified for irrigation. Sodium measured against Ca^{2+} and Mg^{2+} was considered by Kelley (1951) to calculate the Kelley's ratio. Thus,

$$\text{Kelley's ratio} = (Na / (Ca + Ng)),$$

where ions are expressed in milliequivalents per litre.

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Having the values of Kelley's ratio more than 1 indicates excess level of sodium in waters. Therefore waters with Kelley's ratio less than 1 are suitable for irrigation while those with more than 1 are unsuitable for irrigation.

Kelley's ratio varies from 0.05 to 15.99 in the post-monsoon samples while it ranges from 0.01 to 5.70 in those of the pre-monsoon waters. Therefore according to Kelley's ratio, 68 % of the samples in the post-monsoon period are suitable for irrigation while it is 64 % for the pre-monsoon waters. Hence, there is not much seasonal variation. The results are depicted in Figure 7a and 7b and the Kelley's ratios are given in Table 3 and 4.

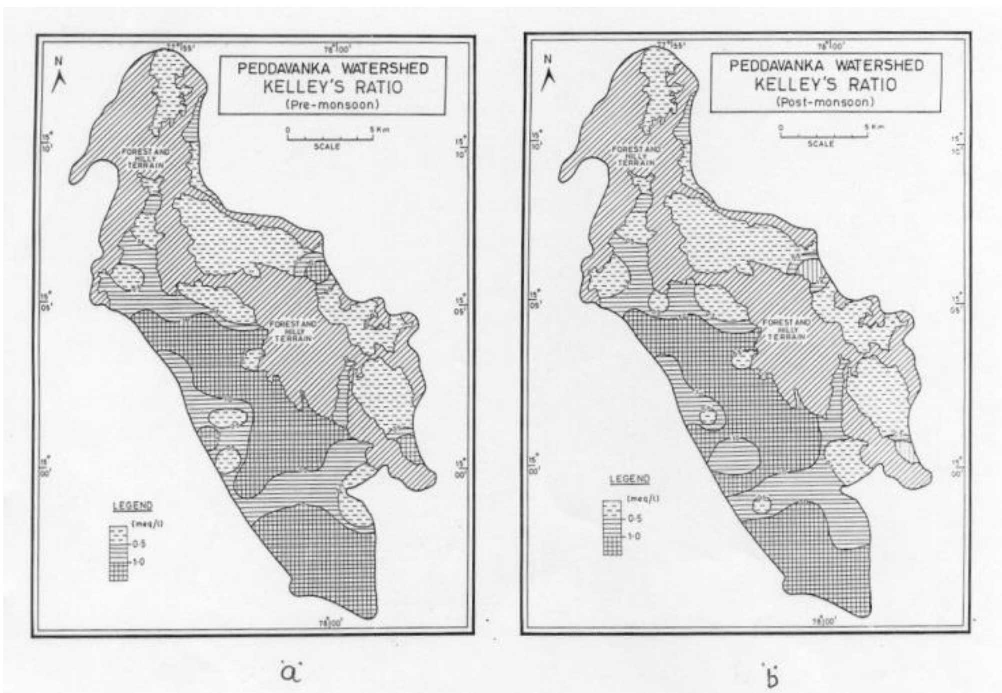

Fig. 7. Distribution of Kelley's ratio
a) Pre-monsoon b) Post-monsoon

4.2.5 Magnesium Ratio

Calcium and magnesium maintain a state of equilibrium generally in most waters. In equilibrium with more Mg^{2+} being present in waters will adversely affect the soil quality converting it to alkaline and this in turn affects the crop yields. As the rocks in the watershed area contain more

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magnesium bearing rocks such as dolomite and basalt, it is observed that most waters contain Mg^{2+} more than Ca^{2+}. The magnesium ratio is calculated using the formula.

$$\text{Magnesium ratio} = \frac{Mg^{2+}}{Ca^{+} + Mg^{2+}} \times 100$$

where ions are expressed in milliequivalents per liter.

76 % of the post-monsoon waters contain magnesium ratio more than 50 % while 78 % of pre-monsoon waters contain magnesium ratio more than 50 %. The magnesium ratios are given in Table 3 and 4.

4.2.6 Gibbs' ratio

Gibbs' diagram is widely used to establish the relationships of water composition and aquifer lithology. Gibbs' ratios are calculated as per the formulae given below (Gibbs 1970):

Gibbs' Ratio I = $Cl / Cl + HCO_3$

(for Anion)

Gibbs' Ratio II = $Na + K / (Na+K+Ca)$

(for Cation)

where ions are expressed in milliequivalents per litre.

Ramesam (1982) has carried out some work in this direction. The diagram used for evaluating water chemistry is shown in Figures 8a and 8b. The diagram consists of three areas namely precipitation dominance area at the bottom and evaporation dominance area on the top and rock dominance area in the middle. Gibbs' ratios are given in Table 3 and 4. The Gibbs' ratios of the water samples are plotted against the total dissolved solids. It is observed that almost all the samples from post-monsoon and pre-monsoon seasons fall in the rock dominance area indicating the interaction between rock chemistry and the chemistry of the percolating waters in the subsurface.

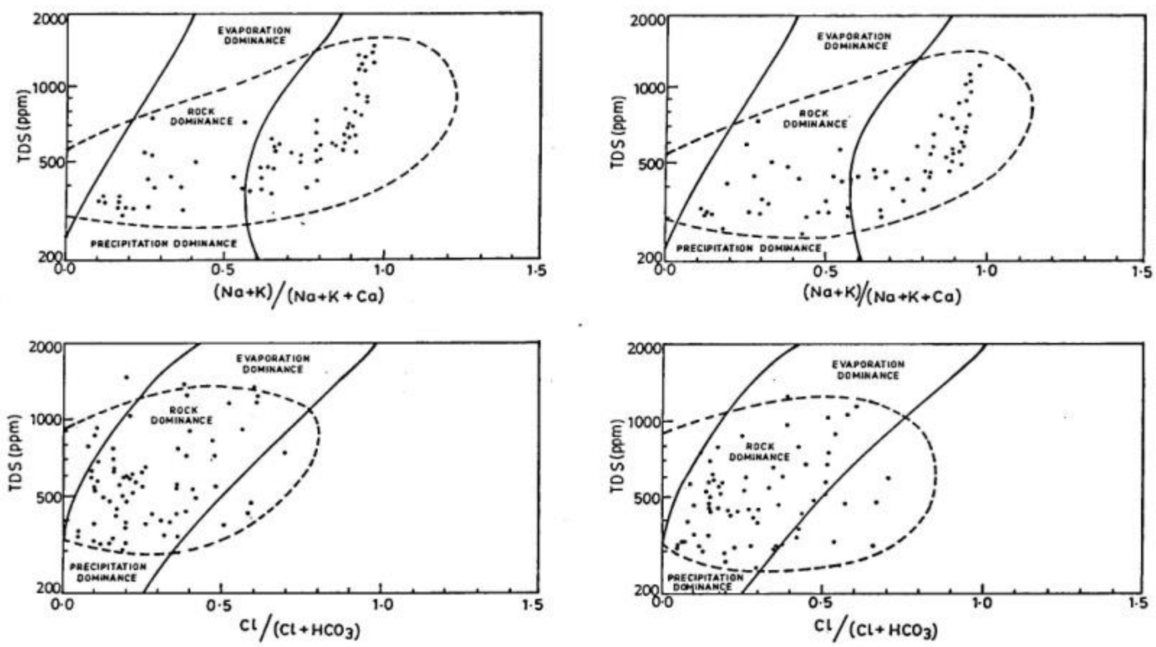

Fig. 8. Map depicting the mechanism controlling the chemistry of ground water (Gibbs 1970)
a) Pre-monsoon b) Post-monsoon

4.2.7 Index of Base Exchange

It is essential to know the changes in chemical composition of groundwater during its travel in the sub-surface (Sastri 1994). The Chloro-alkaline indices CAI 1 and CAI 2 are suggested by Schoeller (1977), which throw light on ion exchange between the groundwater and its host environment. The Chloro-alkaline indices used in the evaluation of Base Exchange are calculated using the formulae.

1. Chloro Alkaline Indices I = (Cl–(Na+K)) / Cl
2. Chloro Alkaline Indices II = (Cl–(Na+K) / (SO_4+HCO_3+CO_3+NO_3)

If there is ion exchange of Na^+ and K^+ from water with magnesium and calcium in the rock, the exchange is known as direct when the indices are positive. If the exchange is reverse then exchange is indirect and the indices are found to be negative.

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Direct

$Na^{+} + K^{+} \longrightarrow Ca^{2+} + Mg^{2+}$

Water $<$———— Rock

The Chloroalkaline Indices are calculated for the post-monsoon and pre-monsoon waters of the watershed as given in Tables 3 and 4 and the ratios are plotted in Figures 9a and 9b. From the above diagrams it is noted that 72 % of the post-monsoon and 71 % of the pre-monsoon waters show negative ratios and 28 % of the post-monsoon and 29 % of the pre-monsoon waters show positive ratios. Seasonally there is not much deviation in the Chloroalkaline Indices.

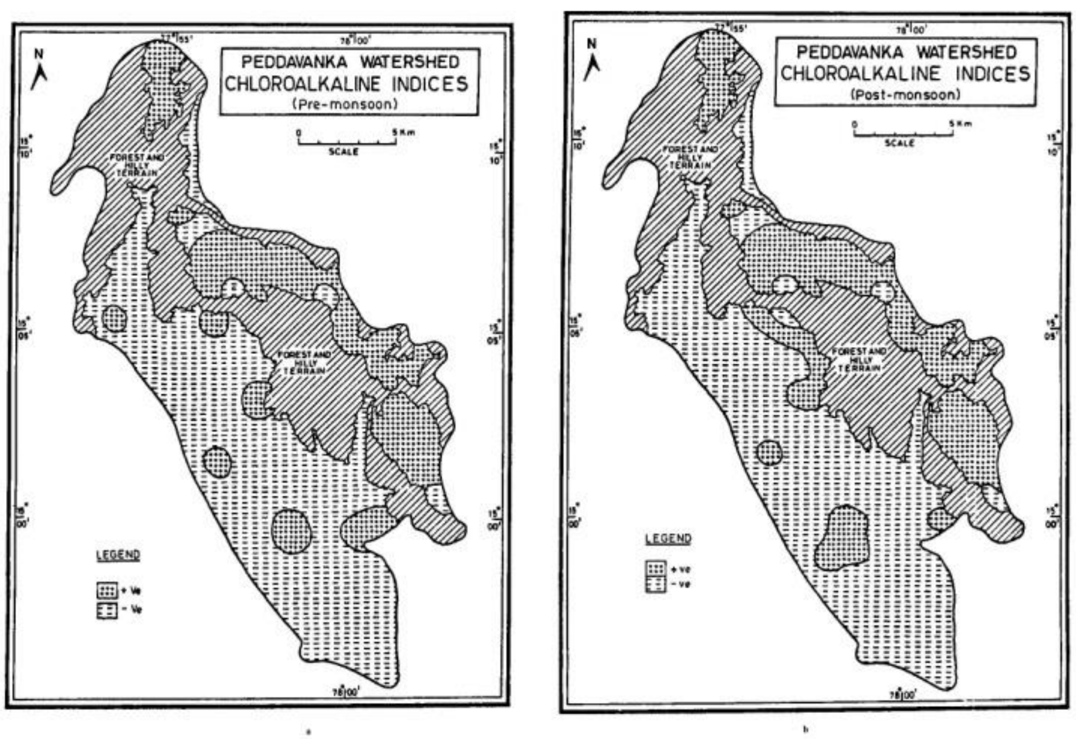

Fig.9. Map depicting the Chloroalkaline indices (Schoeller 1977)
a) Pre-monsoon b) Post-monsoon

4.2.8 Permeability Index

The soil permeability is affected by long-term use of irrigation water. It is influenced by Na^{+}, Ca^{2+}, Mg^{2+} , HCO_3^{-} contents of the soil. Todd (1995) has evolved a criterion for assessing the suitability of water for irrigation based on permeability index.

$$\text{Permeability Index} = \frac{(Na + HCO3)}{(Ca + Mg + Na)} \times 100$$

According to the permeability index values, 28% of the groundwater comes under class I (P.I.>7.5%) category and 72% comes under class II (P.I. ranges from 25 to 75%) category in post-monsoon, while 32% comes under class I (P.I. > 7.5%) category and 68% comes under class II (P.I ranges from 25 to 75%) category in pre-monsoon season.

4.2.9 Graphical representation of water analyses and interpretation

The evolution of water and relationship between rock types and water composition can be deciphered from the trilinear Piper (1953) diagram. The three cations, calcium, magnesium, and sodium + potassium, as percentage reacting values are plotted as a single point on the left triangular field while those of the anion group, bicarbonate + carbonate, chloride, and sulphate are similarly plotted on the right triangular field. The relative concentration of the several dissolved constituents of a water sample is shown by each of the points on the two triangular fields. The overall characteristics of the water was presented in the diamond shaped field by projecting the position of the plots in the two triangular fields as shown in Figures 10 a and 10 b. Different types of groundwater can be distinguished by the position of their plottings in the following nine sub areas of the diamond shaped filed.

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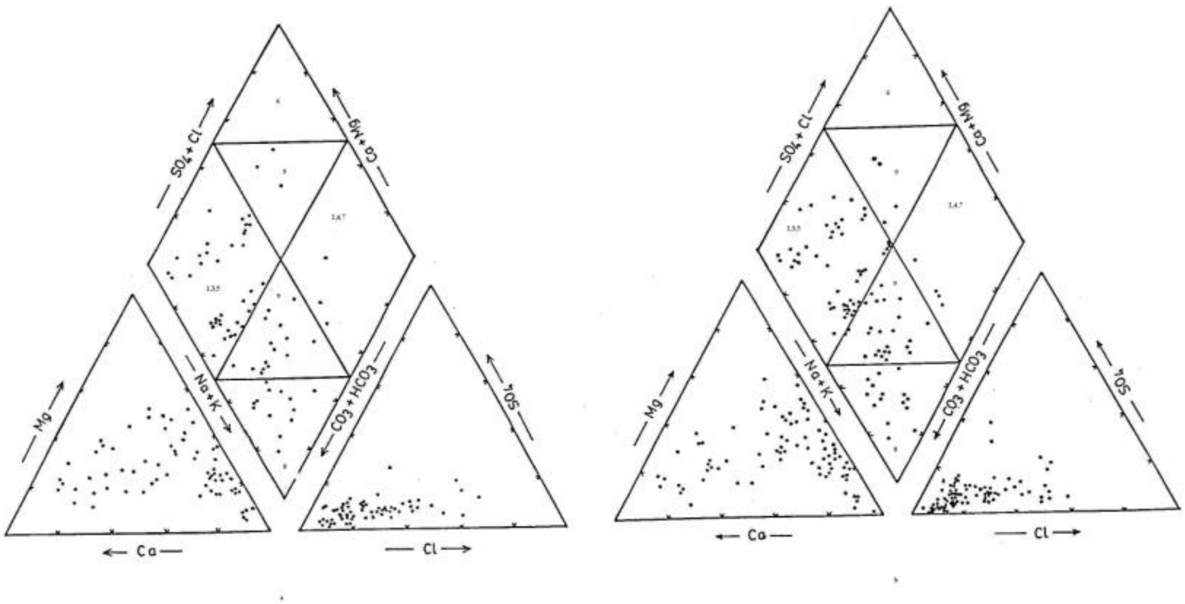

Fig.10. Trilinear diagram for representing analyses of ground water quality (Piper 1953).
a) Pre-monsoon b) Post-monsoon

Groundwater types	Classification
Area 1	Alkaline earths exceed alkalies
Area 2	Alkalies exceed alkaline earths
Area 3	Weak acids > strong acids
Area 4	Strong acids < weak acids
Area 5	Carbonate hardness exceeds 50%
Area 6	Non-carbonate hardness exceeds 50%
Area 7	Non-carbonate alkali exceeds 50%
Area 8	Carbonate alkali exceeds 50%
Area 9	None of the cation or anion pairs exceeds 50%

The analytical values obtained from the groundwater samples, and plotted on a Piper diagram reveal that the major cations are Ca^{2+}, Na^{-} and Mg^{2+} and the anions are HCO_3, Cl^{-} and SO_4^{2-}, In the study area, alkaline earths (Ca^{2+}, Mg^{2+}) are significantly dominating over the alkalies (Na^{-}, K^{+}) and weak acids (CO_3^{2-}, HCO_3^{-}) dominate over strong acids ($Cl^{-}SO_4{}^{2-}$). The ground water has secondary salinity, as indicated by carbonate hardness for pre and post-monsoon seasons.

5. Conclusions

Water samples collected from the pre and post-monsoon seasons were analysed, interpreted and assessed for their suitability for drinking and irrigation purposes. Graphical representation of the chemical data on the irrigation suitability diagram (USSL, 1954) shows that medium salinity – low sodium (C2 S1) and high salinity-low sodium (C3 S 1) waters are present which need adequate drainage to overcome the salinity problem. According to Richards (1954) classification of water based on sodium adsorption ration (SAR), ninety-seven % samples are good category for irrigation. According to Wilcox (1948) diagram, most of the samples are excellent to good and good to permissible category, increased after post-monsoon recharge of groundwater and leads to decline of water quality. According to Kelley's ratio 64 % of the samples in the pre-monsoon period and 68 % of the samples in the post-monsoon period are suitable for irrigation. As the rocks in the watershed area contain more Mg^{2+} bearing minerals it is observed that most waters contain Mg^{2+} more than Ca^{2+} Based on Gibbs' ratios of water samples plotted against total dissolved solids, it is observed that almost all the water samples from pre and post-monsoon seasons fall in the rock dominance area indicating the interaction between rock chemistry and the chemistry of the percolating precipitation waters in the sub-surface. The Schoeller indices values are negative except in some locations showing a cation-anion exchange in two seasons. According to the permeability index values, pre and post-monsoon waters comes under class II category, where permeability index ranges from 25-75%. The Piper trilinear diagram shows that in general the watershed has basic water and it is chemically characterized by the intermediate class at many locations. The entire watershed is devoid of primary alkaline and secondary saline waters. According to the overall assessment of the watershed, water quality was found to be useful for drinking and irrigation purposes, barring a few patches in the west and southwest.

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