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Suitability Assessment of Groundwater for Irrigation Purpose with Reference to Residual Sodium Carbonate

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Abstract: To assess the seasonal variation of quality of groundwater of two adjoining towns of the hill state, Himachal Pradesh in the north of India, a study has been carried out. The specific study zone covering an area of about 120 sq. km. was selected near the industrial townships of Nalagarh and Baddi in district Solan. A total of 25 and 40 groundwater samples were collected, from 65 different locations during post-monsoon season of 2011 and pre and post-monsoon seasons of 2012. The overall residual sodium carbonate (RSC) of groundwater was ranged from -7.794 to 1.673 and -7.857 to 1.953 at Nalagarh and Baddi industrial areas respectively. The overall averaged residual sodium carbonate value at Nalagarh and Baddi industrial areas were less than 1.25, hence suitable for agriculture purposes. The findings also suggest that values of residual sodium carbonate of groundwater were far below the recommended standard value. Therefore it is suggested that regular attention should be given to the agricultural authorities, policy and decision makers to both the areas for better agriculture production. However, proper treatment of effluents from urban and industrial areas is highly desirable to maintain the residual sodium carbonate of groundwater in such areas to check further deterioration.
Keywords: Groundwater, Residual sodium carbonate, Platykurtic, Nalagarh, Baddi.

I. INTRODUCTION

In general water quality refers to the degree of suitability for a specific purpose and is largely depends on the physico-chemical characteristics/composition of its water [1]. Irrigation water contains certain quantities of dissolved salts originating from different sources i.e. either geogenic or anthropogenic. The suitability of water for irrigation purposes should therefore be assessed on the basis of its ability to create favourable conditions for crop growth or yield. However, the suitability of irrigation water has to be assessed on the basis of specific conditions like different agro-climatic conditions, types of crops (sensitive, semi-tolerant, tolerant), its varieties and cultural practices. There are some attempts have been made to classify/measure the quality of water for irrigation purpose [2,3,4,5,6,7,8,9,10,11]. Several measurements/guidelines are also developed and used to classify the suitability of water for irrigation, including sodium adsorption ratio (SAR), percent sodium (%Na), soluble sodium percentage (SSP), magnesium hazard (Mg haz.), Kelly's ratio (KR), residual sodium carbonate (RSC), base exchange (base exch.), meteoric genesis (met. gen.) etc. Due to differences in climatic as well as topographic conditions in different areas, one can consider the above computed parameters for evaluating irrigation water quality.

The concentration of bicarbonate and carbonate influences the suitability of water for irrigation purpose. One of the empirical approach was based on the assumption that calcium and magnesium precipitate as carbonate. Considering the above hypothesis the concept of residual sodium carbonate (RSC) was proposed for the measurement of high carbonate waters [2]. In this context assessment of suitability of irrigation water quality is important for successful crop production. The poor quality of the irrigation water may affect crop yields and physical conditions of soil [12]. Studies shows that, the average yield of wheat decreased by 24% [13], rice decreased by 39% [14], vegetables decreased by 30% [15], and corn decreased by 21% [16] over normal yield when poor quality water was used. The major irrigation water is judged by four important measures of salinity hazard, sodium hazard, toxicity hazard and residual sodium carbonate hazard [17]. As different crops require different irrigation water qualities, therefore, testing the irrigation water is quite important prior to contribute for effective management and utilization of the groundwater resources by clarifying relations among many hydrogeological considerations.

The groundwater quality studies reveals that water is suitable for drinking, agricultural and industrial purposes if certain water quality/computed parameters found within the desired limits. Many studies on quality of ground and surface water sources on drinking water standards have been carried out by several researchers [18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37]. Although many studies have been conducted on suitability of groundwater for domestic needs, however, no extensive study has been done on suitability of water for irrigation purposes with respect to residual sodium carbonate (RSC) in Solan district of the hilly state Himachal Pradesh. Realizing the importance of water for crop growth and existing research gap a systematic study was planned and conducted. In order to assess the suitability of groundwater of the two adjoining towns (Nalagarh and Baddi) for irrigation purpose, residual sodium carbonate (RSC) was computed and the results obtained have been discussed in the light of its suitability.

II. MATERIALS AND METHODS

A. *Description of Study Area*

To assess the seasonal variation of quality of groundwater of two adjoining towns of the hill state, Himachal Pradesh in the north of India, a study has been carried out. The specific study zone covering an area of about 120 sq. km was selected near the industrial townships of Nalagarh and Baddi in district Solan. Solan district is located between the latitudes 30° 03′ 00″ to 31° 09′ 00″ N and longitudes 76° 25′ 12″ to 77° 12′ 00″ E. Nalagarh and Baddi tehsils are located between the latitudes 30° 54′ 23″ to 31° 14′ 36″ N and longitudes 76° 35′ 21″ to 76° 51′ 30″ E. Natural storm drainage to the twin industrial towns of Nalagarh and Baddi is provided by a perennial river, named Sirsa. The river enters the Solan district near Baddi and soon enters the Punjab state. Near Ropar, it finally merges with river Sutlej. Secondary drainage of the region is provided by a number of tributaries, major among which are Chikni Khud near Nalagarh and Balad Nadi at Baddi [18].

B. *Sampling of Groundwater*

A total of 25 and 40 groundwater samples were collected, from 65 different locations of Nalagarh and Baddi industrial areas of Solan district, Himachal Pradesh. Sampling of groundwater samples was carried out from post-monsoon season 2011 to post-monsoon season 2012. The sampling sites were identified after reconnaissance of Nalagarh and Baddi industrial areas of Solan district, so as to represent the whole area. All the precautions were taken as given in standard methods for sampling and analysis [38].

C. *Analytical Methods*

The water samples were analyzed in the Environmental Engineering Laboratory (M.M. Engineering College, Maharishi Markandeshwar University, Mullana) and all the precautions were taken as per standard methods [38]. Various analysed parameters/elements are bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), calcium (Ca^{2+}) and magnesium (Mg^{2+}). Calcium (Ca^{2+}) and magnesium (Mg2+) were estimated by EDTA titration method. In order to calculate the residual sodium carbonate (RSC) for irrigation purposes, following equation/formula was used (for calculation all values were taken in meq/l):

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad \text{……………………(i)} \qquad [2]$$

Residual sodium carbonate (RSC) for irrigation purpose was calculated and presented in Figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12.

III. RESULTS AND DISCUSSIONS

Residual sodium carbonate (RSC) is defined as the difference in milliequivalents per litre between the carbonate (CO_3^{2-}) plus bicarbonate (HCO_3^-) ions and those of calcium (Ca^{2+}) plus magnesium (Mg^{2+}) ions present in water. Water having high RSC, extended use of that water for irrigation will lead to an accumulation of sodium (Na^+) in the soil. The relative sodium concentration in the exchangeable complex increases resulting in the dispersion of soil. The results of this include 1) Direct toxicity to crops, 2) Excess soil salinity and associated poor plant performance, and 3) Where appreciable clay or silt is present in the soil, loss of soil structure and decrease in soil permeability. Calcium and magnesium may react with bicarbonate and precipitate as carbonates. When the residual sodium carbonate (RSC) value is less than 1.25, in between 1.25-2.5, more than 2.5 meq/l, water is considered as good, marginal, harmful quality respectively for irrigation purposes [2].

A. *Residual Sodium Carbonate (RSC) of Nalagarh Industrial Area*

The residual sodium carbonate values of the groundwater samples of industrial area of Nalagarh varied from a minimum value of -7.593 at sampling location N3 to a maximum value of -1.261 at sampling location N21 during post-monsoon season 2011, minimum -4.814 at sampling location N3 to maximum 1.673 at sampling location N21 during pre-monsoon season 2012 and minimum -7.794 at sampling location N3 to maximum -0.85 at sampling location N21 during post-monsoon season 2012. The observations have been presented in Figures 1, 3, 4 and 5. The average values of residual sodium carbonate (at individual sampling locations) varied from a minimum value of -6.734 at sampling location N3 to a maximum value of -0.361 at sampling location N21 (Figures 2 and 6). The average values of RSC (average of all the 25 samples) were found to be -3.479±1.409, -2.133±1.644, and -3.615±1.623 during post-monsoon season 2011, pre-monsoon season 2012, and post-monsoon season 2012 respectively thus accounting for an overall average RSC value of the groundwater samples of industrial area of Nalagarh as -3.076±1.449 (Figure 6). The results indicate that only one groundwater sample (sampling location N21) having residual sodium carbonate (RSC) value more than 1.25 and below 2.5 during pre-monsoon season of 2012, hence found marginally suitable for irrigation [2]. Considering the average values no groundwater samples having residual sodium carbonate (RSC) value exceeding 1.25 and found very good in quality for irrigation purposes [2].

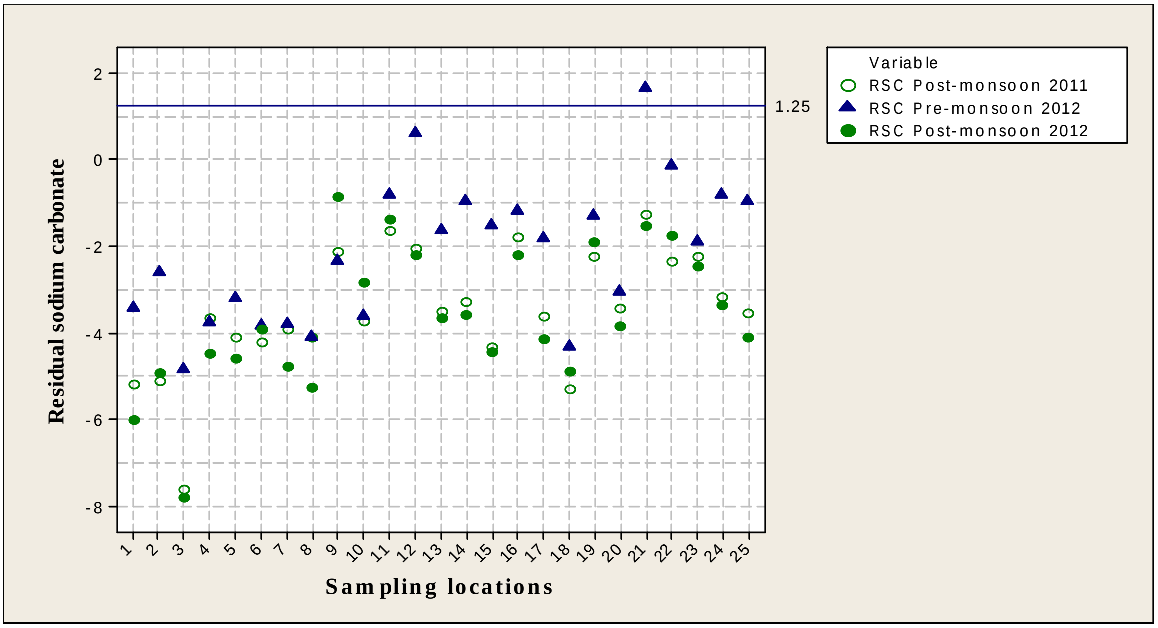

Fig. 1 Variation of RSC values of groundwater at sampling locations of Nalagarh industrial area

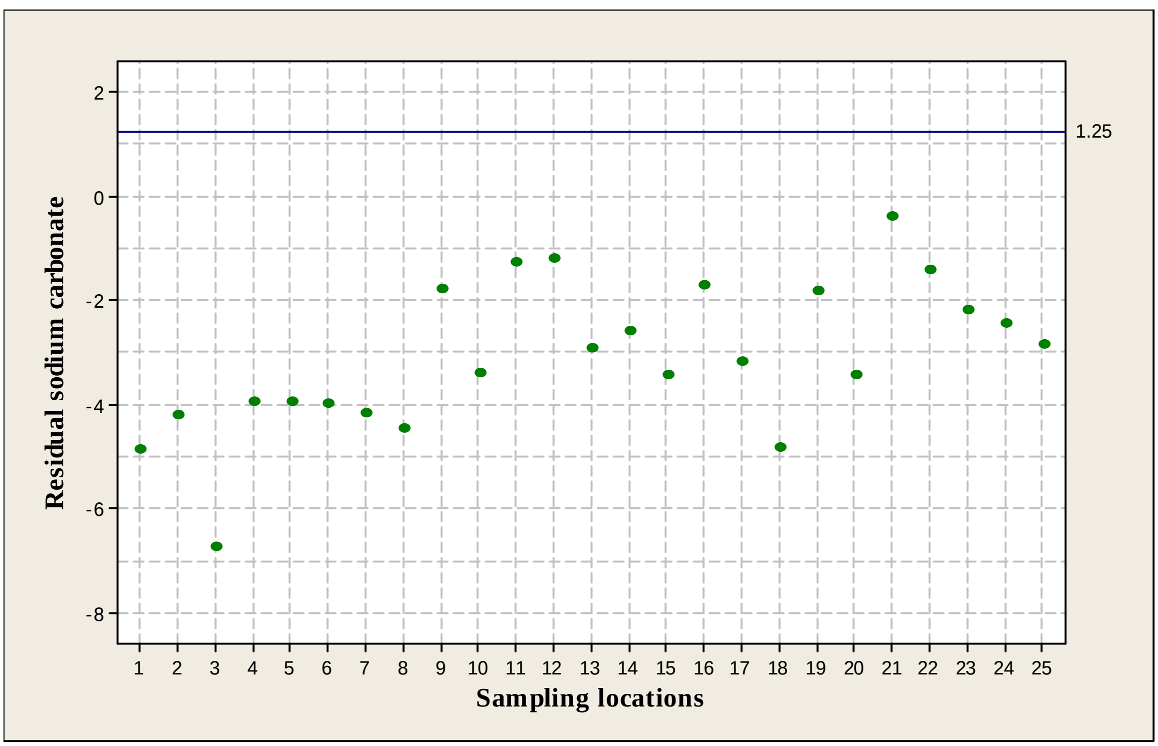

Fig. 2 Variation of average RSC values of groundwater at sampling locations of Nalagarh industrial area

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One blue-coloured horizontal line has been drawn on the Figures 1 and 2 which show the suitability of quality of groundwater for irrigation purposes.

The graphical manifestation of the statistical summary for residual sodium carbonate of groundwater samples is presented in Figures 3, 4 and 5. While the curves for residual sodium carbonate in Figures 3 and 5 are negatively skewed (-0.846 and -0.388), Figure 4 is positively skewed (0.372) indicating spatial variation of residual sodium carbonate for the groundwater samples within the study area. The figures show that the curves are platykurtic or the values of the coefficient of fourth standardized moment $\beta_2 < 3$. The graphical depiction of the statistical summary for average RSC values of groundwater samples is also made in Figure 6 and the distribution is found to be platykurtic.

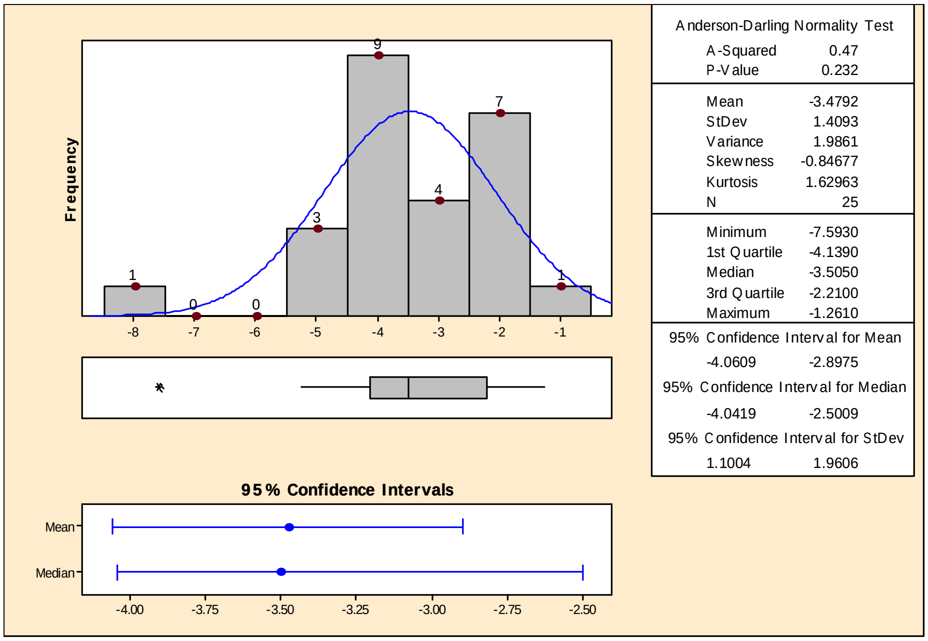

Fig. Graphical presentation of statistical summary for RSC of groundwater at Nalagarh industrial area (Post-monsoon season 2011)

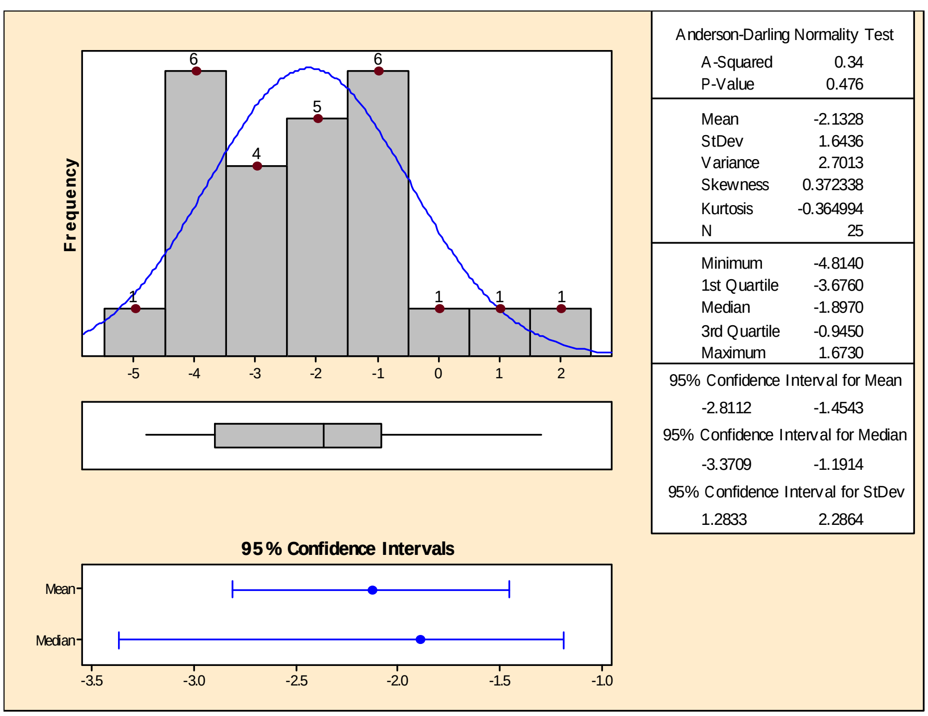

Fig. Graphical presentation of statistical summary for RSC of groundwater at Nalagarh industrial area (Pre-monsoon season 2012)

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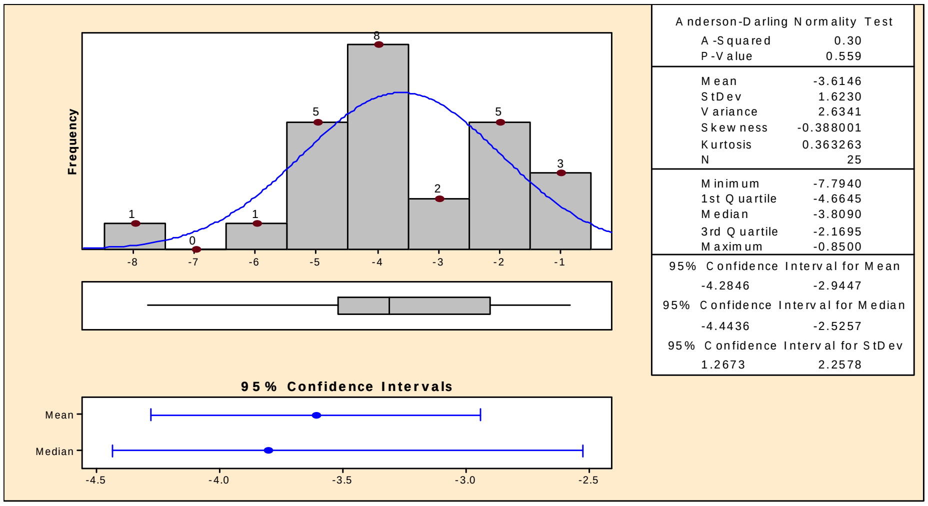

Fig. 5 Graphical presentation of statistical summary for RSC of groundwater at Nalagarh industrial area (Post-monsoon season 2012)

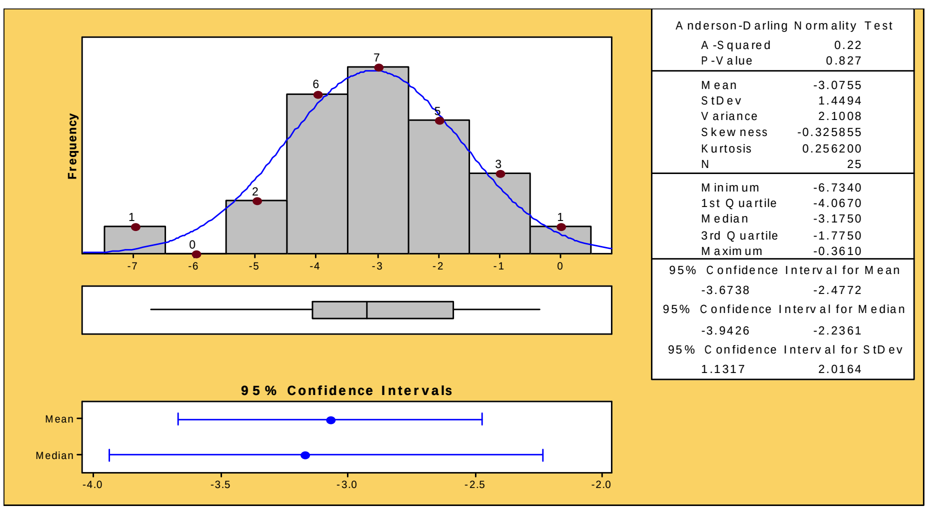

Fig. 6 Graphical presentation of statistical summary for RSC of groundwater at Nalagarh industrial area (Average)

Student's t-test conducted on the mean RSC values of groundwater samples of Nalagarh industrial area for different seasons is shown in Table 1. The test was conducted with two seasons dealt with at one time.

TABLE I
RESULTS OF THE STUDENT'S T-TEST OF THE MEAN VALUES OF RSC OF GROUNDWATER SAMPLES OF NALAGARH INDUSTRIAL AREA

Seasons	t-value	Significant	Not significant
Post-monsoon 2011 *vs* Pre-monsoon 2012	3.11*	√	X
Pre-monsoon 2012 *vs* Post-monsoon 2012	3.2*	√	X
Post-monsoon 2011 *vs* Post-monsoon 2012	0.315	X	√
Pre-monsoon 2012 *vs* Avg. of Post-monsoon 2011 and 2012	3.184*	√	X

* $p < 0.05$

B. Residual Sodium Carbonate (RSC) of Baddi Industrial Area

The residual sodium carbonate values of the groundwater samples of industrial area of Baddi varied from a minimum value of -6.701 at sampling location B22 to a maximum value of -1.129 at sampling location B23 during post-monsoon season 2011, minimum -5.707 at sampling location B11 to maximum 1.953 at sampling location B7 during pre-monsoon season 2012 and minimum -7.857 at sampling location B22 to maximum -1.634 at sampling location B23 during post-monsoon season 2012. The observations have been presented in Figures 7, 9, 10 and 11. The average values of residual sodium carbonate (at individual sampling locations) varied from a minimum value of -6.567 at sampling location B22 to a maximum value of -0.609 at sampling location B7 (Figures 8 and 12). The average values of RSC (average of all the 40 samples) were found to be -3.622±1.101, -3.059±1.889, and -3.801±1.262 during post-monsoon season 2011, pre-monsoon season 2012, and post-monsoon season 2012 respectively thus accounting for an overall average RSC value of the groundwater samples of industrial area of Baddi as -3.494±1.286 (Figure 12). The results indicate that 100, 97.5, and 100 % of groundwater samples having residual sodium carbonate (RSC) value remained negative during post, pre and post-monsoon seasons of 2011, 2012 and 2012 respectively, hence found suitable for irrigation [2]. The results also indicate that only one groundwater sample (sampling location B7) having residual sodium carbonate (RSC) value more than 1.25 and below 2.5 during pre-monsoon season of 2012, hence found marginally suitable for irrigation [2].

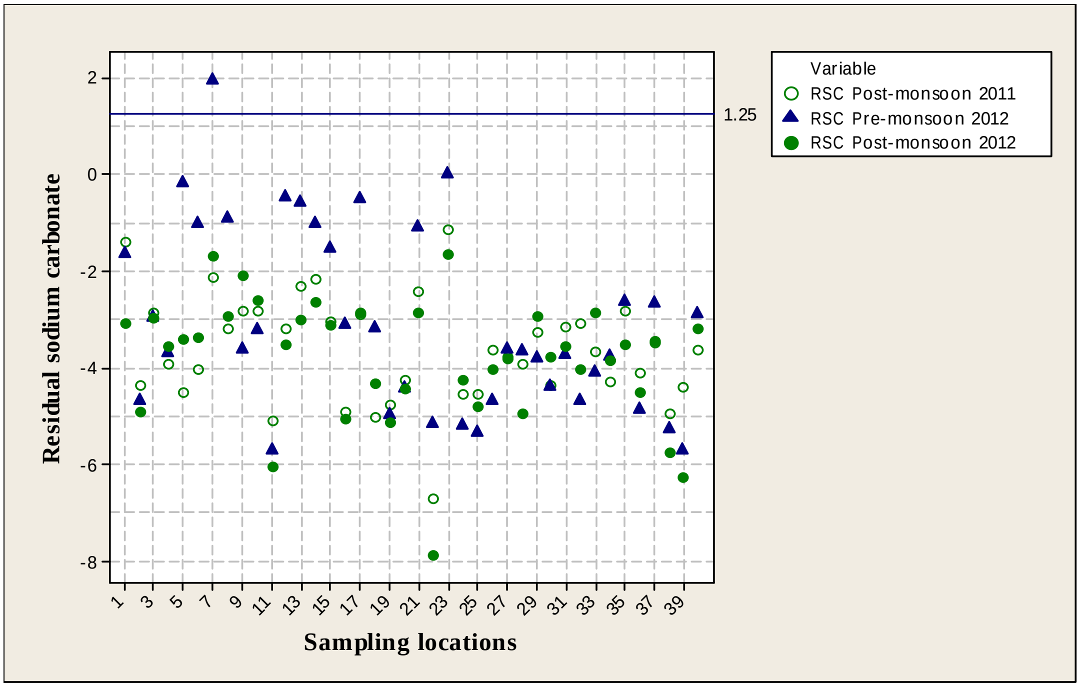

Fig. 7 Variation of RSC values of groundwater at sampling locations of Baddi industrial area

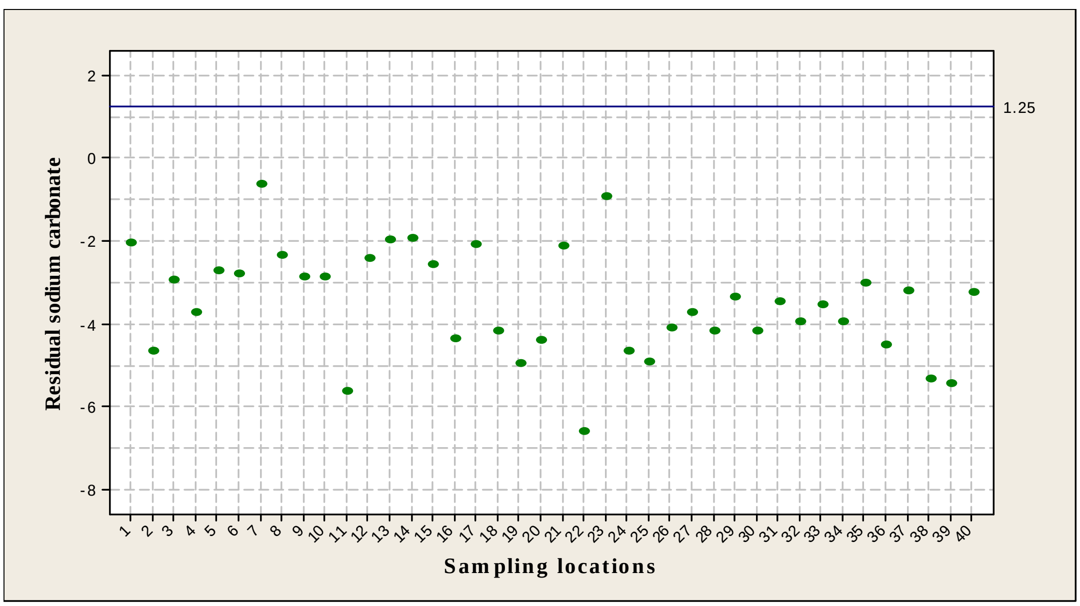

Fig. 8 Variation of average RSC of groundwater at sampling locations of Baddi industrial area

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One blue-coloured horizontal line has been drawn on the Figures 7 and 8 which show the suitability of quality of groundwater for irrigation purposes.

Figures 9, 10 and 11 show the statistical summary for residual sodium carbonate of groundwater samples. The curves for residual sodium carbonate in Figures 9 and 11 are negatively skewed (-0.071 and -0.986), Figure 10 is positively skewed (0.637) indicating spatial variation of residual sodium carbonate for the groundwater samples within the study area. The figures show that the curves are flat-topped which indicate that the curves are platykurtic or the values of the coefficient of fourth standardized moment $\beta_2 < 3$. The statistical summary for frequency distribution of average RSC values of groundwater samples is also presented in Figure 12 and shows the distribution be platykurtic.

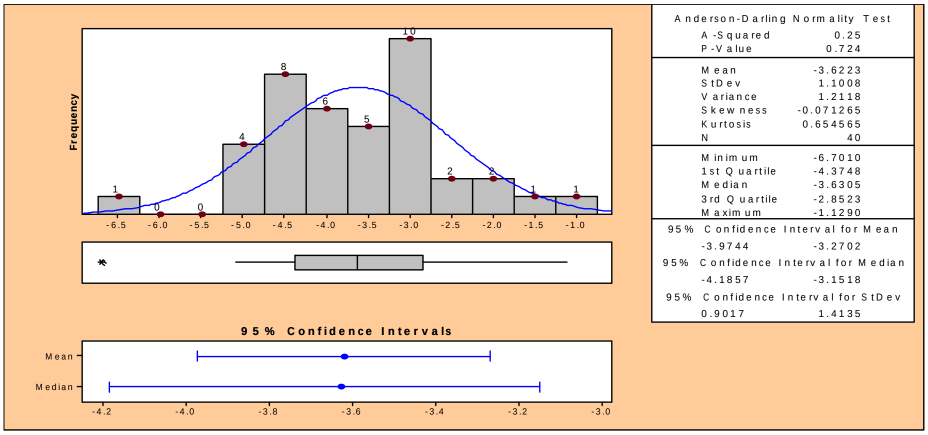

Fig. 9 Graphical presentation of statistical summary for RSC of groundwater at Baddi industrial area (Post-monsoon season 2011)

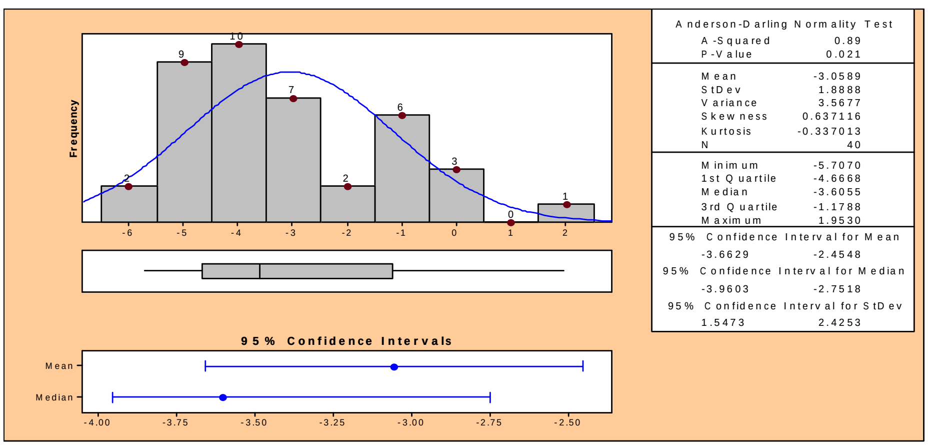

Fig. 10 Graphical presentation of statistical summary for RSC of groundwater at Baddi industrial area (Pre-monsoon season 2012)

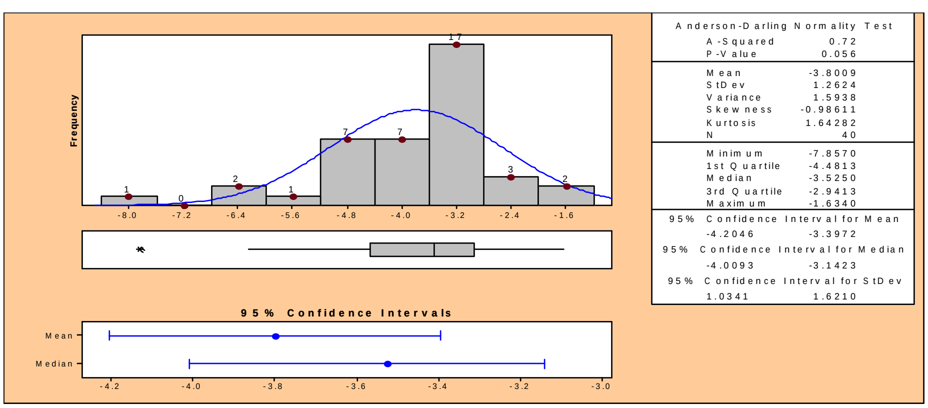

Fig. 11 Graphical presentation of statistical summary for RSC of groundwater at Baddi industrial area (Post-monsoon season 2012)

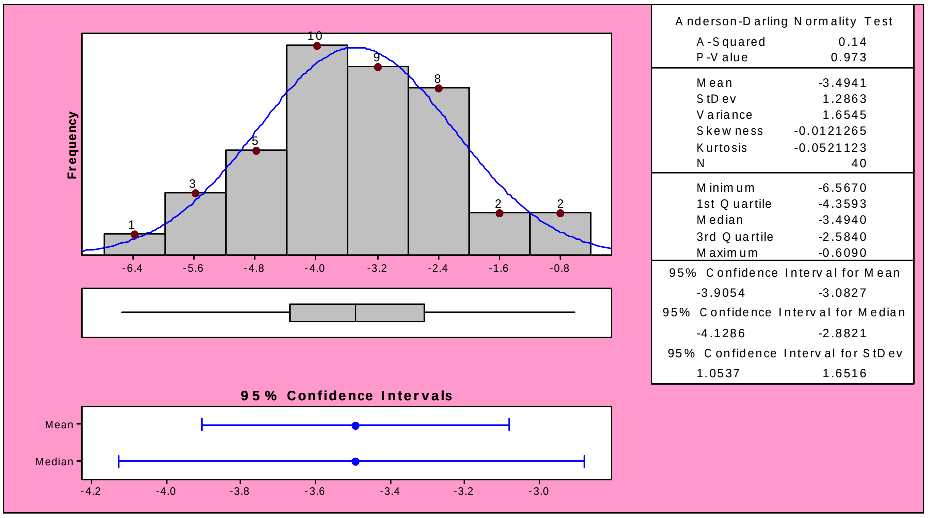

Fig. 12 Graphical presentation of statistical summary for RSC of groundwater at Baddi industrial area (Average)

Student's t-test conducted on the mean RSC values of groundwater samples of Baddi industrial area for different seasons is shown in Table 2. The test was conducted with two seasons dealt with at one time.

TABLE II
RESULTS OF THE STUDENT'S T-TEST OF THE MEAN VALUES OF RSC OF GROUNDWATER SAMPLES OF BADDI INDUSTRIAL AREA

Seasons	t-value	Significant	Not significant
Post-monsoon 2011 *vs* Pre-monsoon 2012	1.63*	X	√
Pre-monsoon 2012 *vs* Post-monsoon 2012	2.06*	√	X
Post-monsoon 2011 *vs* Post-monsoon 2012	0.674	X	√
Pre-monsoon 2012 *vs* Avg. of Post-monsoon 2011 and 2012	1.87*	X	√

* $p < 0.05$

IV. CONCLUSIONS

A. Significant conclusions derived from the study are

1) Only one groundwater sample (sampling location N21 & B7) at both the industrial areas having residual sodium carbonate value more than 1.25 and below 2.5 during pre-monsoon season of 2012, hence found marginally suitable for irrigation.

2) The overall average value (-3.076±1.449) of residual sodium carbonate (RSC) of Nalagarh industrial area remained negative, hence suitable for irrigation.

3) The overall average value (-3.494±1.286) of residual sodium carbonate (RSC) of Baddi industrial area remained negative, hence suitable for irrigation.

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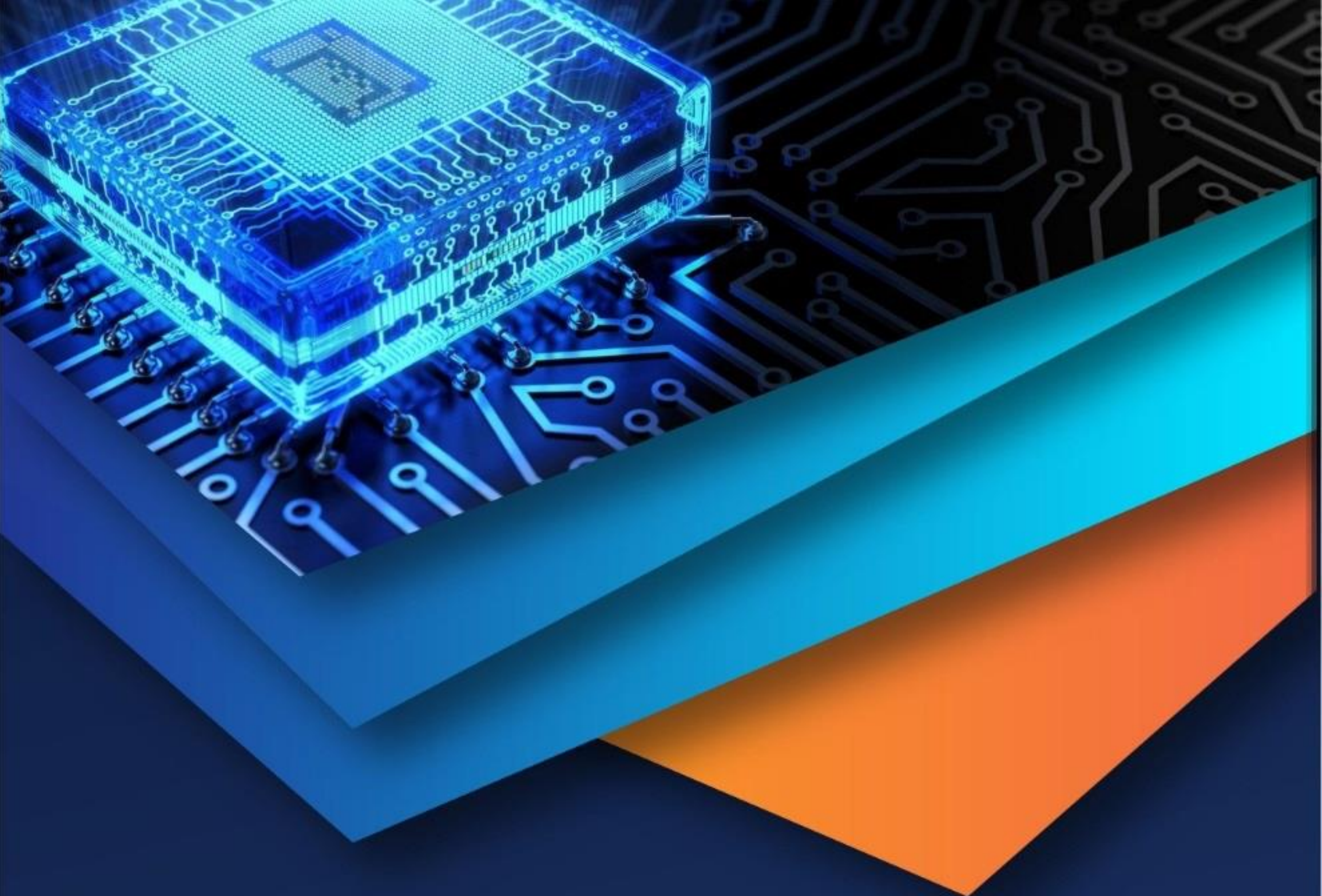

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