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Assessment of groundwater quality for suitability of industrial purposes

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Abstract

In order to evaluate the suitability of groundwater for industrial use a comprehensive study was undertaken for the two adjoining towns namely Nalagarh and Baddi of the hill state, Himachal Pradesh in the north of India. A total of 25 and 40 groundwater samples were collected, from 65 different locations of Nalagarh and Baddi industrial areas during post-monsoon season of 2011 and pre and post-monsoon seasons of 2012. The overall corrosivity ratio (CR) of groundwater was ranged from 0.201-1.587 and 0.263-1.543 at Nalagarh and Baddi industrial areas respectively. The overall averaged corrosivity ratio value at Nalagarh and Baddi industrial areas were less than 1, hence suitable for industrial use. The findings also suggest that higher values of corrosivity ratio of groundwater are restricted to a few localized areas. Therefore, serious attention should be given to the industrialist, policy and decision makers to the locations having more than 1 corrosivity ratio value for better industrial production. However, conventional treatment of effluents from semi-urban and urban areas is highly desirable to minimize the corrosiveness of groundwater in such altered areas to arrest further deterioration. This study which is based on corrosivity ratio of groundwater can be considered as an eye opener for the localities.

Keywords: Groundwater, corrosivity ratio, Leptokurtic, Platykurtic, Nalagarh, Baddi.

Introduction

As we all are aware of the fact that industries/industrial activities are directly or indirectly responsible for causing severe environmental pollution and degradation of natural resources. And also more than thousands of agencies/organizations all over the globe either governmental or non-governmental raised fingers towards them. Although industries pollute the environment, till date no organization have any justified reason (except few cases) to shutting them up, except imposing certain stricter rules and regulations, guidelines and penalties (financial) on them. But these existing rules and regulations/guidelines have certain loopholes which again aggravate the situation. Although agriculture is considered as the backbone of any nation, but after agriculture industries play a significant role for strengthening the economic security of the nation by creating job opportunities, infrastructure development etc. There are a number of industries operating all over India e.g. pharmaceuticals, petrochemicals, power plants, metals and metalloids, textile, agro-based etc. and all of them consume huge amount of water either for production purposes or other. Many studies suggested that if the quality as well as quantity of water (groundwater in particular) will decrease up to a certain level then it could unfit for domestic use, reduces the agriculture and industrial productions also. Therefore water is considered as a key input for sustainable development.

The only source of water is precipitation in its various forms. Predominately water is obtained from two principal natural sources, surface water such as fresh water lakes, streams, rivers, ponds etc. and groundwater such as boreholes and wells. Water is required for domestic needs like drinking, cooking, bathing, washing, agricultural needs of irrigation, industrial needs, power generation, etc. The National water policy 2012 identifies the needs of water for various purposes and prioritized them as water for drinking and domestic needs, water for agriculture and water for industrial use[1]. Many studies on quality of ground and surface water sources on drinking water standards have been carried out by several researchers[2-20]. Although many studies have been conducted on suitability of groundwater for domestic and agriculture needs but a very little work have been done on suitability of water for industrial uses. Realizing the importance of water use in industrial sector a methodical study was scheduled and conducted. To assess the quality of groundwater of the two adjoining towns (Nalagarh and Baddi) for industrial use, corrosivity ratio was calculated and discussed.

Materials and methods

Description of study areas: 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. The adjacent towns, namely Nalagarh and Baddi of district Solan in the hill state of Himachal Pradesh, had been selected for the study. 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[1].

Industry: According to Geological Survey of India, following minerals are available in Himachal Pradesh include gypsum, mica, slate, lead, iron pyrites, clays, limestone, byrytes, salt and antimony. As per records up to the end of the year 2014, a total of 5677 micro, small, medium and large enterprises had been set up in the district (Table-1)[21]. A large number of units registered with the state industries department up to the year 2014 can be categorized under mechanical, chemicals, pharmaceuticals, electrical and electronics engineering groups.

Table-1: Industry of Solan district[21]

Head	Particulars in nos.
Registered (MSEs) industrial units	5,331
Registered medium scale units	240
Registered large scale units	106
Employment MSEs sector	69,492
Employment medium sector	21,095
Employment large sector	24,048
Number of industrial areas	15

The main exportable items are metal products, home appliances, MCBs, RCBO, automotive industrial filters, auto parts, tractors, mint cooling system, paper, cotton yarn, leather shoes, fabric, shawls, herbal extracts, cosmetic products, pharma, synthetic yarn, solar cells, glass, forging, inverters, computer software data, food products, essential oils, wooden products, decorative laminated sheets, aluminum rods, x-ray machines, PCB drills, tools for micro machines, chew gums, chemical, leather finishing chemicals, garments, condenser, multiget condenser, RCCV, sheet, adhesive, electrical items, electrical installations, paint and varnish, cement bricks and blocks, polyester staple fibers, steel furniture, watch dials, wires and cables etc.[21].

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 recognized after preliminary survey 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[22].

Table-2: Status of industrial area of Solan district (As on December 2014)[21].

Name of Industrial Area	Land acquired (Hectare)	Land developed (Hectare)	No. of Units in Production
Ind. Estate, Chambaghat, Solan	1.5	1.5	5
Electronic Complex Chambaghat, Solan	5	5	16
New Electronic Complex, Chambaghat, Solan	1.2	1.2	4
Ind. Estate Wacknaghat	4	0	0
Ind. Area Mamlig	8	0	0
Ind. Area Banalgi	41	0	1
Ind. Area Dharmpur	0.4	0	4 (8: shed)
Ind. Area Baddi	36.09	-	119
Ind. Area Barotiwala	24.24	-	26
EPIP-Phase-I Jharmajri	79.28	-	189
EPIP-Phase-II, Thana	101.12	-	62
Apparel park Cum I.A. Katha Bhatolikalan	30	-	33
Ind. Area Lodhimajra	45.68	-	45
Ind. Area Sector-II, Parwanoo	10637.66 m^2	7220.66 m^2	5 (27: shed)
Ind. Area Sector-V, Parwanoo	695.71 m^2	695.71 m^2	8

*Though the state government has not notified any industrial area in the region, yet as per survey and land records more than 500 units are in position under section118 (un-classified land) of the land record.

Analytical methods: The water samples were analysed at Civil Engineering Department in Environmental Engineering Laboratory (M.M. University, Mullana) and all the precautions were taken as per standard methods[22]. Various analysed parameters/elements are chloride (Cl^-), sulphate (SO_4^{2-}), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). In order to calculate the corrosivity ratio (CR) of groundwater for industrial use, following equation/formula was used (for calculation all values were taken in meq/l):

$$CR^* = (Cl^- + SO_4^{2-}) / 2[(CO_3^{2-} + HCO_3^-)/100] \quad (1)$$[23]

Corrosivity ratio (CR) for industrial use was calculated and presented in Figures-1 to 12.

Results and discussion

Corrosivity ratio indicates susceptibility of groundwater to corrosion. Corrosive water can mobilize metals like lead, iron, copper etc. from pipes into drinking water and after a period of time may results in leaks in plumbing. The adverse effect of corrosion is loss in hydraulic capacity of metallic pipes. A few researchers have used the ratio to assess the corrosiveness of water on metallic pipes of different regions[23,24].

Corrosivity ratio (CR) of Nalagarh industrial area: The corrosivity ratio values of the groundwater samples of industrial area of Nalagarh varied from a minimum value of 0.482 at sampling location N23 to a maximum value of 1.587 at sampling location N10 during post-monsoon season 2011, minimum 0.201 at sampling location N21 to maximum 1.462 at sampling location N10 during pre-monsoon season 2012 and minimum 0.5 at sampling location N2 to maximum 1.469 at sampling location N10 during post-monsoon season 2012 (Figures 1, 3, 4, 5). The average values of corrosivity ratio (at individual sampling locations) varied from a minimum value of 0.458 at sampling location N24 to a maximum value of 1.506 at sampling location N10 (Figures 2 and 6). The average values of CR (average of all the 25 samples) were found to be 0.873±0.303, 0.544±0.328, and 0.757±0.26 during post-monsoon season 2011, pre-monsoon season 2012, and post-monsoon season 2012, respectively thus accounting for an overall average CR value of the groundwater samples of industrial area of Nalagarh as 0.725±0.279 (Figure 6). 36% (sampling locations N5, N6, N7, N8, N9, N10, N11, N13, N14 during post-monsoon season 2011), 12% (sampling locations N6, N7, N10 during pre-monsoon season 2012), and 16% (sampling locations N6, N7, N8, N10 during post-monsoon season 2012) of the groundwater samples had corrosivity ratio value of greater than 1 hence found to be unsuitable for industrial purposes at Nalagarh industrial area[23].

Statistical summary for frequency distribution of corrosivity ratio of groundwater samples is presented in Figures-3, 4 and 5. The curves for corrosivity ratio in the figures are positively skewed (0.749, 1.317 and 1.237) indicating spatial variation of corrosivity ratio for the groundwater samples within the study area. Figure 3 shows that the apex of the curve is flat-topped which indicate that the curve is platykurtic or the value of the coefficient of fourth standardized moment β_2 is less than 3. Figures-4 and 5 show that the apex of the curve is relatively high which indicate that the curve is leptokurtic or the values of the coefficient of fourth standardized moment β_2 is greater than 3. The graphical depiction of the statistical summary for average CR values of groundwater samples is also manifested in Figure-6 and shows the distribution to be leptokurtic.

A red coloured horizontal line has been drawn on the Figures-1 and 2 show the suitability of quality of groundwater for industrial use.

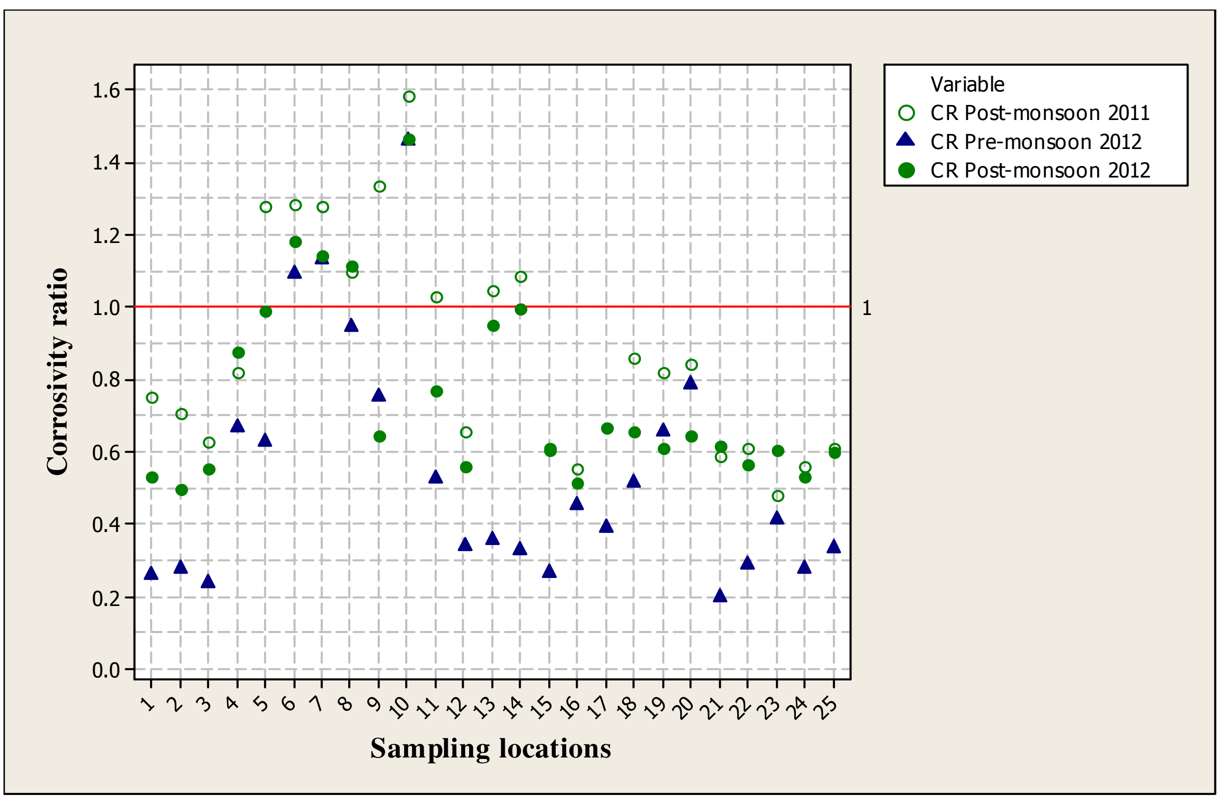

Figure-1: Variation of corrosivity ratio values of groundwater at sampling locations of Nalagarh industrial area.

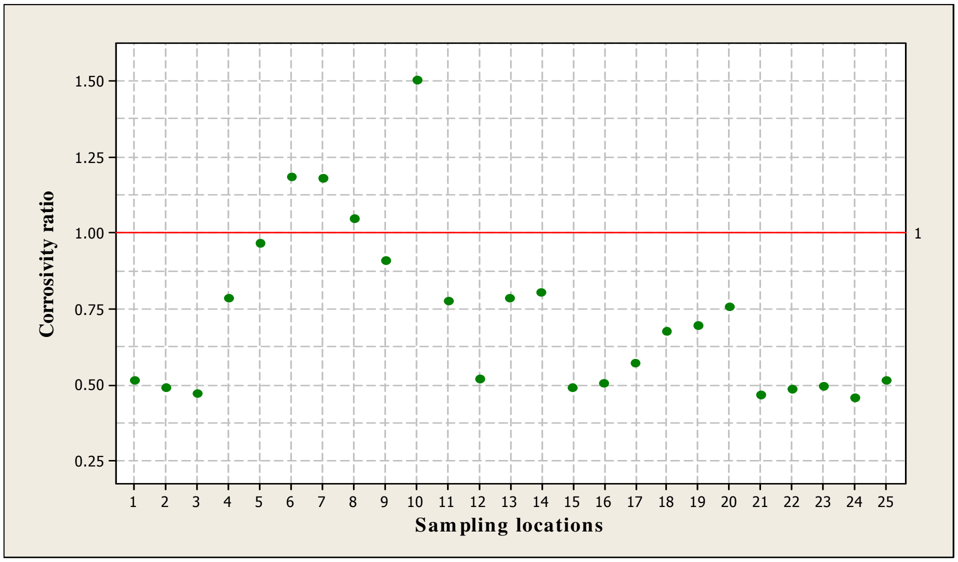

Figure-2: Variation of average corrosivity ratio values of groundwater at sampling locations of Nalagarh industrial area.

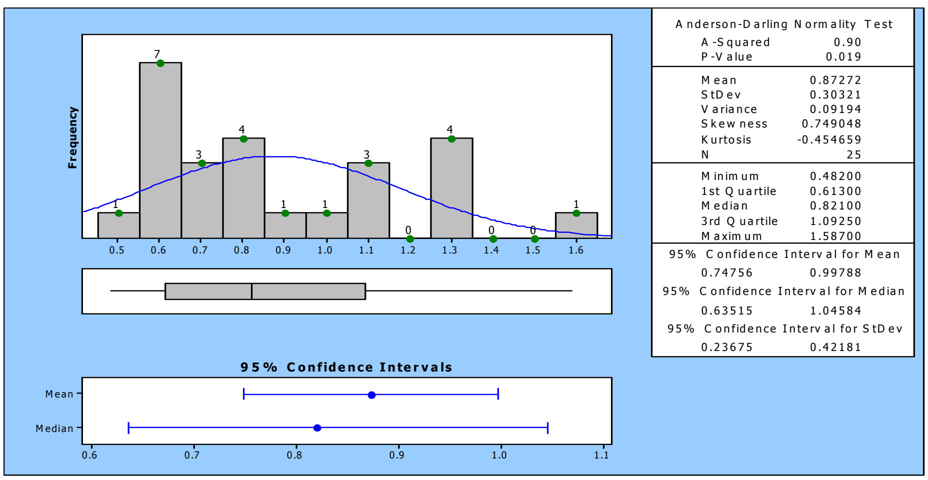

Figure-3: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Nalagarh industrial area (Post-monsoon season 2011).

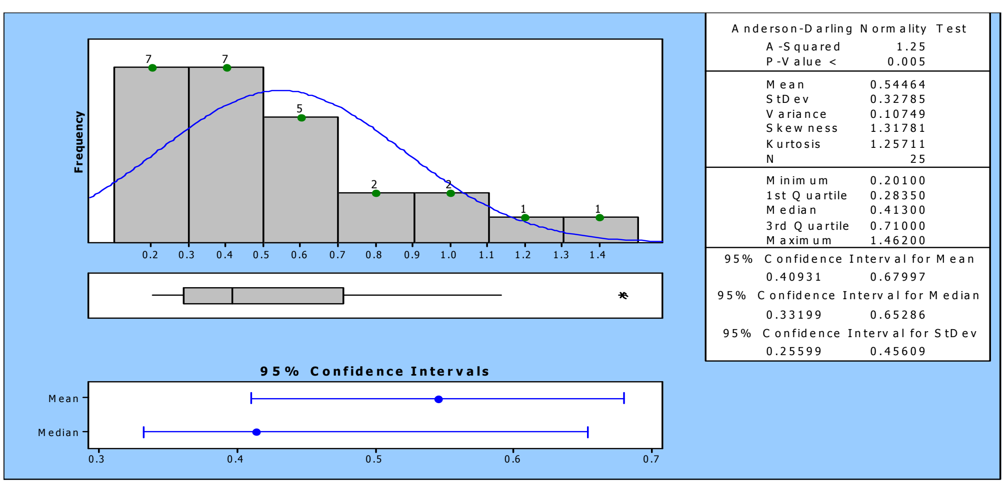

Figure-4: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Nalagarh industrial area (Pre-monsoon season 2012).

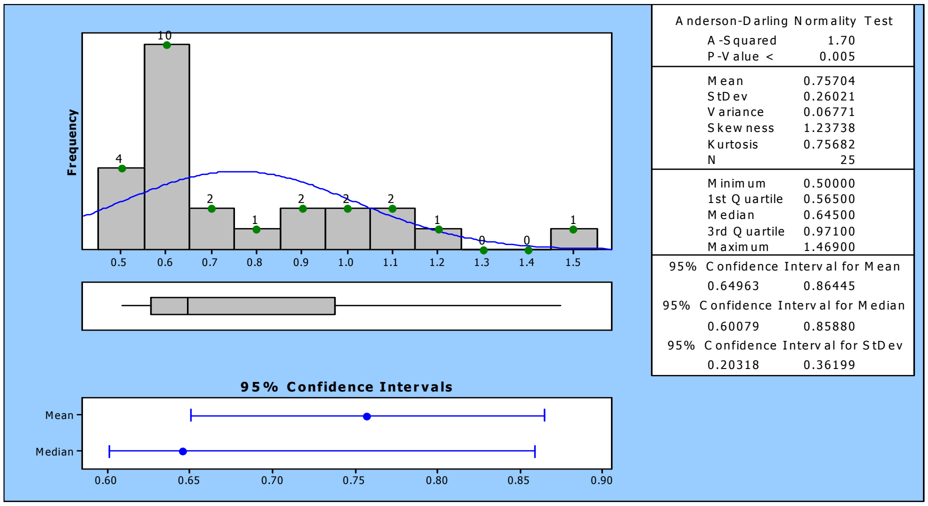

Figure-5: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Nalagarh industrial area (Post-monsoon season 2012).

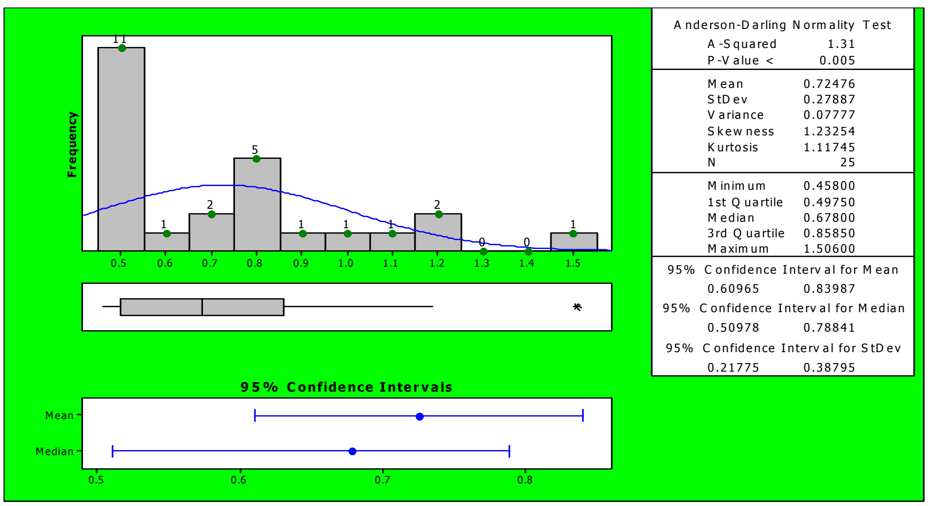

Figure-6: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Nalagarh industrial area (Average).

Student's t-test conducted on the mean CR values of groundwater samples of Nalagarh industrial area for different seasons is shown in Table-3. The test was conducted with two seasons dealt with at one time.

Table-3: Results of the student's t-test of the mean values of CR of groundwater samples of Nalagarh industrial area.

Pairs	t-value	Significant	Not significant
Post-monsoon 2011 *vs* Pre-monsoon 2012	3.67	√	X
Pre-monsoon 2012 *vs* Post-monsoon 2012	2.53	√	X
Post-monsoon 2011 *vs* Post-monsoon 2012	1.45	X	√
Pre-monsoon 2012 *vs* Avg. of Post-monsoon 2011 and 2012	3.17	√	X

Corrosivity ratio (CR) of Baddi industrial area: The corrosivity ratio values of the groundwater samples of industrial area of Baddi varied from a minimum value of 0.453 at sampling location B21 to a maximum value of 1.28 at sampling location B5 during post-monsoon season 2011, minimum 0.263 at sampling location B16 to maximum 1.543 at sampling location B29 during pre-monsoon season 2012 and minimum 0.443 at sampling location B37 to maximum 1.109 at sampling location B25 during post-monsoon season 2012 (Figures-7, 9, 10, 11). The average values of corrosivity ratio (at individual sampling locations) varied from a minimum value of 0.418 at sampling location B21 to a maximum value of 1.223 at sampling location B29 (Figures 8 and 12). The average values of CR (average of all the 40 samples) were found to be 0.735±0.227, 0.556±0.304, and 0.686±0.159 during post-monsoon season 2011, pre-monsoon season 2012, and post-monsoon season 2012 respectively thus accounting for an overall average CR value of the groundwater samples of industrial area of Baddi as 0.659±0.189 (Figure-12). 12.5% (sampling locations B3, B5, B7, B29, B30 during post-monsoon season 2011), 12.5% (sampling locations B3, B9, B10, B25, B29, during pre-monsoon season 2012), and 5% (sampling locations B25, B27 during post-monsoon season 2012), of the groundwater samples had corrosivity ratio value of greater than 1 hence found to be unsuitable for industrial purposes at Baddi industrial area[23].

A red-coloured horizontal line has been drawn on the Figures-7 and 8 show the suitability of quality of groundwater for industrial use.

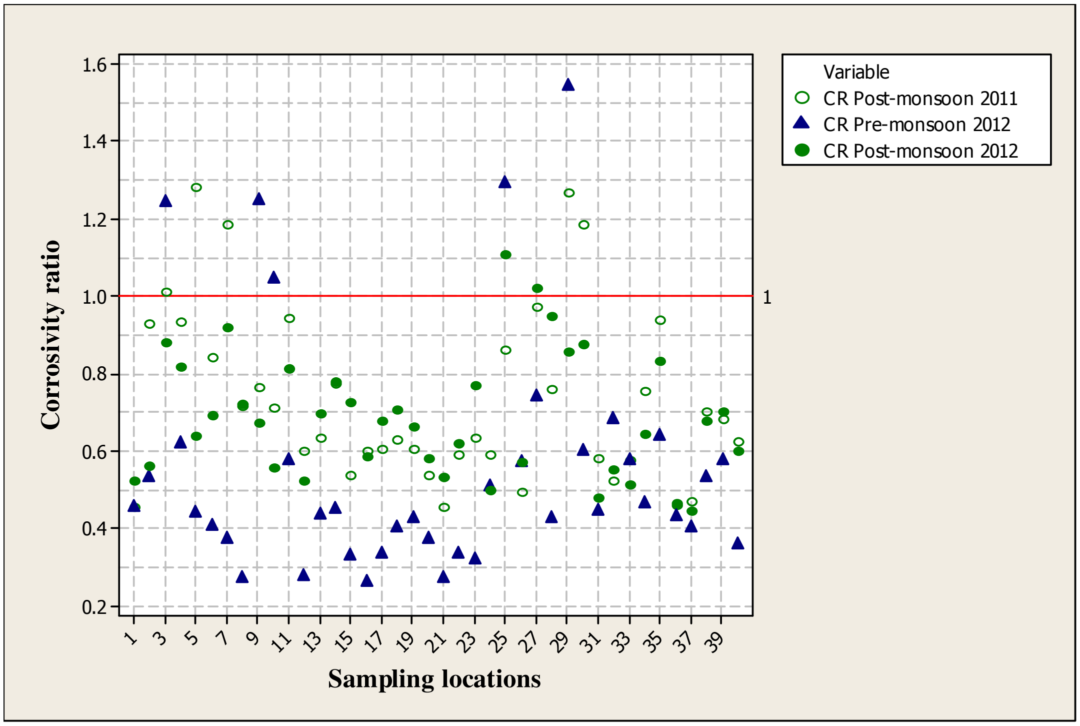

Figure-7: Variation of corrosivity ratio values of groundwater at sampling locations of Baddi industrial area.

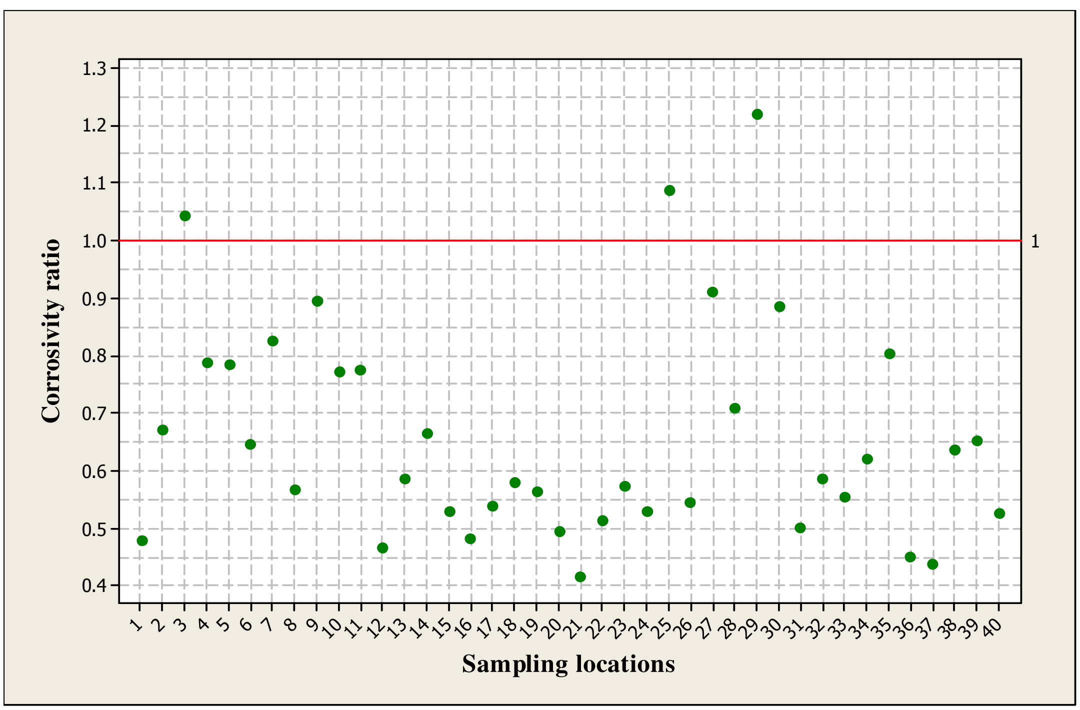

Figure-8: Variation of average corrosivity ratio values of groundwater at sampling locations of Baddi industrial area.

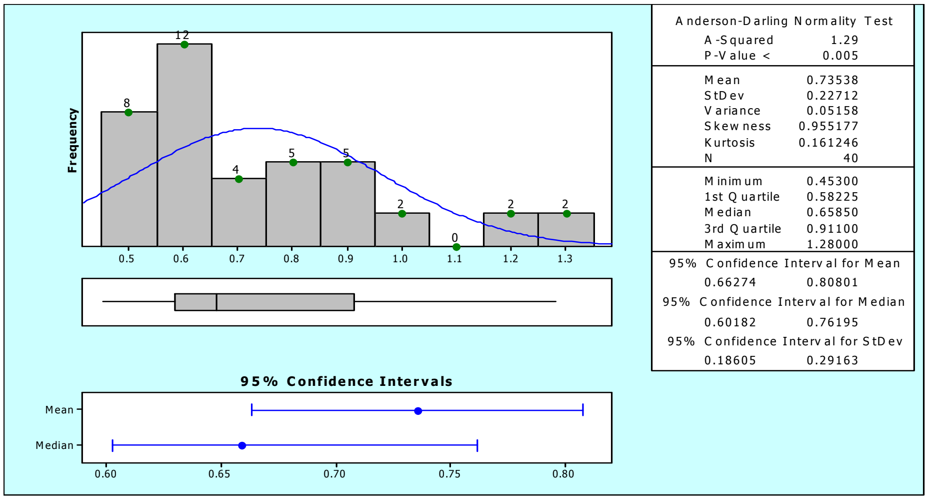

Figure-9: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Baddi industrial area (Post-monsoon season 2011).

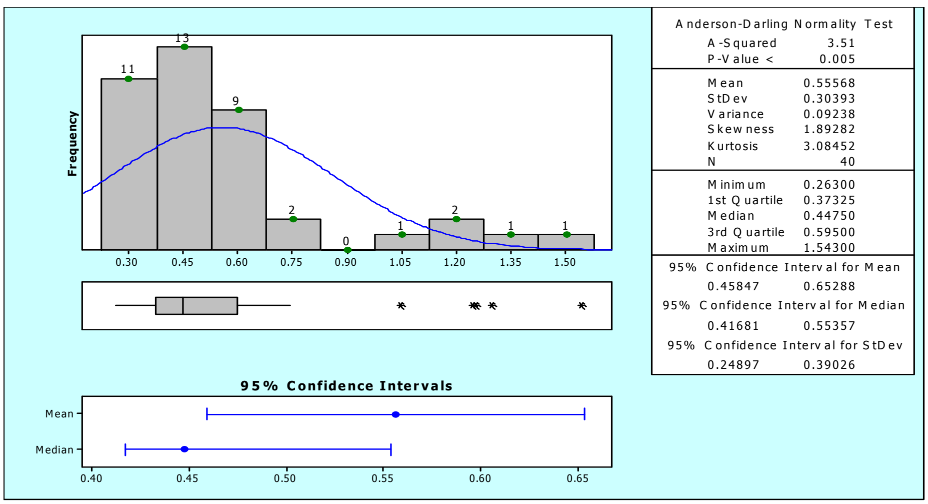

Figure-10: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Baddi industrial area (Pre-monsoon season 2012).

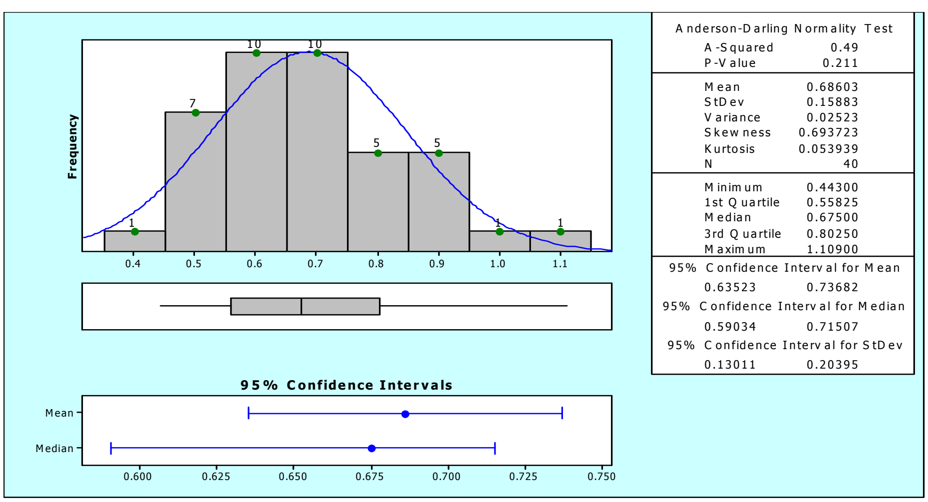

Figure-11: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Baddi industrial area (Post-monsoon season 2012).

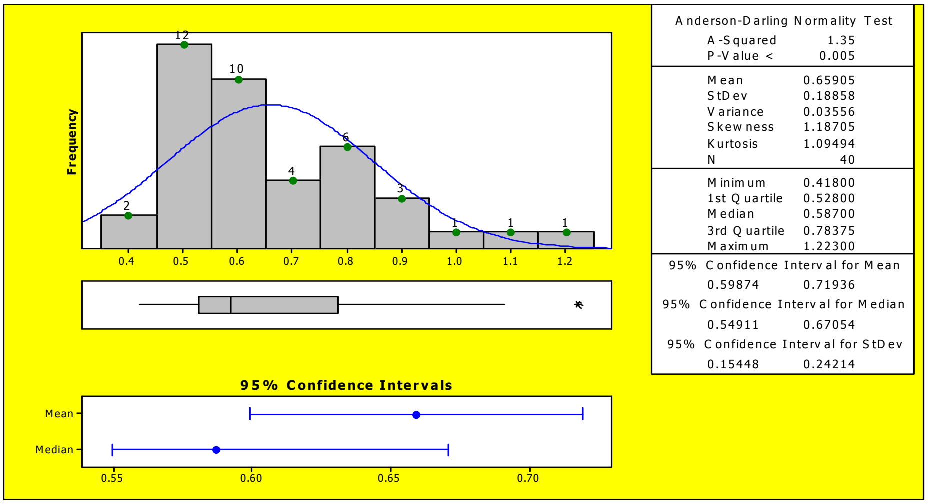

Figure-12: Graphical presentation of statistical summary for corrosivity ratio of groundwater at Baddi industrial area (Average).

Figures-9, 10 and 11 present the statistical summary for frequency distribution of corrosivity ratio of groundwater samples. The curves for corrosivity ratio in these figures are positively skewed (0.955, 1.892 and 0.693) indicating spatial variation of corrosivity ratio for the groundwater samples within the study area. The relatively higher peaks of the curves in these figures indicate that the curves are leptokurtic or the values of the coefficient of fourth standardized moment β2 is greater than 3. The graphical presentation of the statistical summary for average CR values of groundwater samples is also presented in Figure 12 and the distribution is found to be leptokurtic.

Student's t-test conducted on the mean CR values of groundwater samples of Baddi industrial area for different seasons is shown in Table-4. The test was conducted with two seasons dealt with at one time.

Table-4: Results of the student's t-test of the mean values of CR of groundwater samples of Baddi industrial area.

Pairs	t-value	Significant	Not significant
Post-monsoon 2011 *vs* Pre-monsoon 2012	2.99	√	X
Pre-monsoon 2012 *vs* Post-monsoon 2012	2.4	√	X
Post-monsoon 2011 *vs* Post-monsoon 2012	1.12	X	√
Pre-monsoon 2012 *vs* Avg. of Post-monsoon 2011 and 2012	2.79	√	X

Conclusion

Significant conclusions derived from the study are: i. 16% (sampling locations N6, N7, N8, N10 considering the average values of all the seasons), of the groundwater samples had corrosivity ratio value greater than 1 hence found to be unsuitable for industrial purposes at Nalagarh industrial area. ii. 7.5% (Sampling locations B3, B25, B29 considering the average values of all the seasons), of the groundwater samples had corrosivity ratio values greater than 1 and were found unsuitable for industrial purposes at Baddi industrial area. iii. Since the overall average value (0.725±0.279 at Nalagarh industrial area and 0.659±0.189 at Baddi industrial area) of corrosivity ratio less than 1, hence suitable for industrial uses at both the industrial areas.

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