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Influence of Environmental Parameters on Groundwater Contamination in Rajasthan, India

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Abstract. Water is one of the most abundant resources on earth, covering three-fourths of the planet's surface. However, about 97% of the earth's water is salt water in the oceans, and only 3% is fresh water. The water from lakes, rivers and ground are majorly used for drinking purpose. Rajasthan being the largest state of India, which lies in the north western part of the country, is overly exploited state for groundwater. The current study identifies the major source of contamination, i.e. fluoride content, nitrate content and salinity which is also reflected by the electrical conductivity of the water. Various factors which influences the contamination like waste water generation, chemical pollution discharge into the environment, hazardous waste, groundwater depth below ground and rainfall are identified. All the district of the state is classified into four regions and statistical investigation is carried out on the same. The statistical correlation is made to check the fluctuation level among various variables. Further to validate the correlation, t-test and analysis of variance has been carried out to get a regression model and check the level of significance. The results show the direct correlation between fluoride content with hazardous pollution discharge into the environment specifically in the northern part of the state. The negative correlation of salinity with rainfall, which is also obtained as key result, implies that the salinity decreases with increase in rainfall in the region. The correlation of variables for the southern and eastern part of the state shows the high correlation of nitrate contamination with water sources as it is easily soluble in water. In the end, analysis of variance approach validates the significance of these parameters on groundwater contamination. The results may be used to reduce the toxic waste in the ground water by keeping a strong check on the identified polluting source.

Keywords: groundwater, environment pollution, pearson correlation, ANOVA, India

1. Introduction

Water is very essential for sustaining human life on earth. The availability of drinking water is major concern in most of the developing and low income nations. Earth, which is covered by 72% of water bodies has just 3% of fresh water sources. Among those resources, one of the majorly exploited resource is groundwater [1]. The water below the earth stored in aquafers and its depth varies from place to place. With increase or decrease in depth and with the external factors like pollution, rainfall, natural calamities, the contamination level of groundwater changes. Various studies have been carried out to identify the long term effect of contaminated water consumption [2]-[4]. In India, the Ministry of Water resources conducted various studies on groundwater availability and its contamination. One of its report states that in Rajasthan state, the groundwater level has reached the over exploited condition [5]. Further reports by the central and state government, on the water level and water content in the region show that the amount of Total Dissolved Solids is quite high as compared to the standards [6]. Research work on water level in Shekahwati Region [7], and in northern Rajasthan [8] shows that the water fluoride content has exceeded its permissible limits of 0.5–1.0 mg/l to 2.82 mg/l. Similar research on water quality for Pilani region reported that fluoride content and nitrate content makes groundwater unfit for drinking [9]. The current study investigates the various sources of contamination and tries to correlated statistically the effect of these parameters. Statistical tools are quite

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helpful in understanding the fluctuation and dependency on various factors [10], [11]. Pearson coefficient discusses the level of relation between two variables. Further, an attempt is made to perform an analysis of variance of correlated variables to model the relation between dependent variables and fixed factors.

Table I: Parameters and factors used for the correlation [5], [20]

District(s)	Fl (mg/l) (X)	EC (µS/cm) (Y)	NO_3^- (mg/l) (Z)	IWW (MLD) (A)	DWW (MLD) (B)	Hazardous Wastes (t/d) (C)	Fertilizers usage (t/d) (D)	Pesticides usage (t/y) (E)	BOD (t/d) (F)	GW depth (mbgl) (G)	Annual Rainfall (mm) (H)
North											
Ganganagar	1.75	4238	119.25	4.12	27.25	0.011	104.3	181	5.45	43.2	201.4
Hanumangarh	1.69	4293	143.47	4.12	23.91	0.005	83.4	279	4.78	30	252.5
Bikaner	1.44	3880	158.38	0.38	69.17	0.099	35.6	110	13.83	110.2	228.7
Churu	1.89	4595	298.13	0.08	31.08	-	7.5	17	6.22	-	313.7
Nagaur	2.43	4964	245.33	-	20.86	0.186	41.1	53	4.17	80	348.5
Jhunjhunu	1.58	1995	108.69	8.1	12.86	0.001	17.2	43	2.57	73.29	410
Sikar	1.3	1681	101.86	1.4	31.29	0.021	28.4	35	6.26	30.8	402.5
West											
Jaisalmer	1.99	4107	122.36	-	4.87	0.548	14.9	23	0.97	108.86	158.4
Jodhpur	2.1	4115	149.06	20.45	167.3	24.168	47.6	89	33.46	77.94	274.5
Barmer	1.85	4760	158.38	69.63	15.15	22.521	11.2	88	3.03	111.9	243.4
Jalore	2.52	3917	98.13	0.25	3.02	-	30	311	0.6	78	394.2
Sirohi	2.07	1891	73.29	1.82	2.87	4.455	18	12	0.57	50	868.6
Pali	2.25	4379	71.43	40.85	20.04	0.704	21.4	24	4.01	-	446.7
South											
Udaipur	0.89	1294	57.76	21.16	62.35	299.085	32.7	12	12.47	31.23	591.3
Chittaurgarh	0.76	1230	57.14	4.19	14.25	1064.337	66.9	46	2.85	25	709.7
Rajsamand	1.23	1732	63.35	28.96	4.45	503.96	9.8	6	0.89	20.99	506
Banswara	0.84	673	33.54	10.26	7.03	2.09	38.5	5	1.41	13.35	831.8
Dungarpur	1.5	997	39.13	3.23	-	1.178	12.5	3	0	55.32	637.8
Bhilwara	1.86	1981	78.88	91.41	21.65	67.648	47.4	39	4.33	24	580.9
Bundi	0.95	1223	42.23	-	7.44	0.693	55.9	19	1.49	25	655.9
Kota	0.72	1453	57.14	36.75	189.92	32.254	66	237	37.98	20.72	746.3
Baran	0.59	1022	59.00	36.46	6.14	-	63.8	1439	1.23	11.55	792.2
Jhalawar	0.63	1191	51.55	1.15	6.96	0.219	11.9	184	1.39	16	855.1
East											
Bharatpur	1.22	3872	213.04	-	16.18	0.931	65.3	28	3.24	22.07	557.6
Dhaulpur	1.21	1339	53.41	1.75	14.17	0.644	27.7	36	2.83	20	612.1
Karauli	0.86	1652	86.95	-	9.73	-	29.1	16	1.95	-	637.4
Sawai Madhopur	1.18	1750	100.00	-	11.33	-	33.8	18	2.27	21.35	664
Ajmer	2.51	3422	72.05	2.99	93.47	1.357	19.5	27	18.69	30.8	429.6
Tonk	2.02	2062	75.15	2.56	11.6	0.299	44.6	53	2.32	21	566
Jaipur	1.82	1794	213.66	52.02	397.31	23.11	57.8	119	79.46	70.2	524.6
Alwar	1.07	1891	206.83	28.76	22.88	39.895	74.5	30	4.58	77	555.3
Dausa	1.25	1720	67.08	-	3.78	0.102	38.9	12	0.76	-	650

2. Background and Research Methodology

2.1. About Rajasthan

In India, the water depth below the ground level varies drastically from coastal to hilly regions and from humid to arid regions. Rajasthan, which is India's largest state, has the vast climatic diversity [12]-[14]. The Rajasthan state lies in the north western part and consists of semi-arid, and arid regions to humid and moderate climatic regions [15]. The state has 33 districts, which as per this study, has divided into four different regions, i.e. north (Ganganagar, Hanumangarh, Bikaner, Churu, Nagaur, Jhunjhunu, Sikar), west (Jaisalmer, Jodhpur, Barmer, Jalore, Sirohi, Pali), South (Udaipur, Chittorgarh, Rajsamand, Banswara, Dungarpur, Pratapgarh, Bhilwara, Bundi, Kota, Baran, Jhalawar), and East (Ajmer, Tonk, Jaipur, Alwar, Dausa, Bharatpur, Karauli, Dhaulpur, Sawaimadhopur). The western region is desert area which receives less rainfall and is blessed with high solar insolation for solar projects [16]-[18]. The current study discusses the contamination level for each district with different influential variables. The analysis for all the districts of the state has been carried out except Pratapgarh as it is a newly formed district and its data is not available accurately. The major source of water availability in the state is Chambal and Luni river. The number of lakes in the southern and eastern part of the state also provides fresh water to the masses. Iirrigation uses the largest amount of water in the State and the demand is continuously rising. With existing high population growth rate, the per capita water availability is declining to alarmingly low levels, indicating that the challenges for the water sector in the State are great.

2.2. Data Analysis

The various factors which influence the increase or decrease in fluoride (Fl) (mg/l), salinity and nitrate (NO_3^-)(mg/l) are estimated for all the districts of the state using literature review [19]. The salinity, which represents the water quality is also reflected by Electrical Conductivity (EC) of the water in uS/cm. The factors which might influence the contamination are Industrial Waste water (IWW), Domestic Waste Water (DWW), Hazardous waste, use of NPK fertilizers, pesticide consumption, Biological Oxygen Dissolve (BOD), maximum depth of groundwater in pre monsoon and average annual rainfall of the location. The data for each parameter has been identified from the literature and is shown in Table I. [5] BOD is the amount of dissolved oxygen required by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. It determines the water quality and is quite essential to estimate the contamination level of groundwater. In case of waste water generation, most of the industrial effluents and domestic sewage are not treated properly and flow directly into the river, thus can be a potential source for contamination of land as well as groundwater. Similarly, use of fertilizers (NPK or Nitrogenous) and pesticides when dissolves with water can easily contaminate, and are also taken for this study. The data for all the districts are taken and are compared. The districts are further classified as per their region, i.e. north, south, east and west. The level of correlation is carried out for each of the region. The *t*-test includes the paired combination of strongly correlated variable to identify the significance of them on the dependent variable. Finally the ANOVA is carried out to estimate the regression model for the entire state. The corresponding probability plots for each of the contamination are also made.

2.3. Methodology Adopted

The hypothesis for the statistical analysis includes the correlation between the output factors (X,Y,Z) with the dependent variable (A-H). The Pearson correlation coefficient (r) indicates the extent of fluctuation of different variables. It is identified using statistical tool to estimate the relation between each parameter. The bivariate approach has been taken to identify the correlation. Mathematical equations for correlation which measure statistical and indicates the extent to which two or more variables (X and Y) fluctuate together is shown in Eqn (1)

$$r_{x,y} = \frac{\sum (x - x_m)(y - y_m)}{\sqrt{\left[\sum (x - x_m)\right]^2 \left[\sum (y - y_m)\right]^2}} \tag{1}$$

The regression model which correlate the linear variation with each of the fixed variable is given by

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \tag{2}$$

3. Results and Discussion

3.1. Correlation between Various Factors

The Pearson correlation coefficient (r) is estimated which ranges between -1 to 1 and depicts the level of correlation between various factors. The zero value shows no correlation between the factors. The positive value of *r* with respect to factor shows that it has direct influence on the outcome. Thus, if one factor increases the dependent variable also increases to some proportion. In this way the correlation tries to establish the nature of relationship between the variables. In the present study, the correlation is estimated by making clusters of different regions and districts in these regions. The variable Fluoride content (X), Electrical

Conductivity (Y) and Nitrate content (Z) are correlated with fixed factors (A to H) which are shown in Table I. The correlation results for northern part, southern part, eastern part and western part of the state are shown in Table II.

Table II: Correlation between variables on groundwater contamination in Rajasthan State.

		X	Y	Z	A	B	C	D	E	F	G	H
Correlation results for Northern part of the Rajasthan State												
Fluoride	Correlation (r)	1	.732	.695	.067	-.386	.700	.064	-.085	-.386	.176	-.019
(X)	N	7	7	7	6	7	6	7	7	7	6	7
EC	Correlation (r)	.732	1	.697	-.373	.130	.560	.347	.331	.130	.210	-.638
(Y)	N	7	7	7	6	7	6	7	7	7	6	7
Nitrate	Correlation (r)	.695	.697	1	-.565	.033	.932**	-.386	-.351	.034	.462	-.029
(Z)	N	7	7	7	6	7	6	7	7	7	6	7
Correlation results for Southern part of the Rajasthan State												
Fluoride	Correlation (r)	1	.554	.345	.565	-.165	-.174	-.318	-.424	-.229	.535	-.690*
(X)	N	10	10	10	9	9	9	10	10	10	10	10
EC	Correlation (r)	.554	1	.869**	.733*	.180	.157	-.016	-.217	.222	-.010	-.675*
(Y)	N	10	10	10	9	9	9	10	10	10	10	10
Nitrate	Correlation (r)	.345	.869**	1	.795*	.116	.301	.177	.160	.181	-.212	-.452
(Z)	N	10	10	10	9	9	9	10	10	10	10	10
Correlation results for Eastern part of the Rajasthan State												
Fluoride	Correlation (r)	1	.416	-.151	-.222	.404	-.281	-.256	.399	.404	-.089	-.797*
(X)	N	9	9	9	5	9	7	9	9	9	7	9
EC	Correlation (r)	.416	1	.310	-.278	-.038	-.285	.151	-.120	-.038	-.244	-.628
(Y)	N	9	9	9	5	9	7	9	9	9	7	9
Nitrate	Correlation (r)	-.151	.310	1	.937*	.475	.682	.886**	.467	.476	.685	-.271
(Z)	N	9	9	9	5	9	7	9	9	9	7	9
Correlation results for Western part of the Rajasthan State.												
Fluoride	Correlation (r)	1	-.078	-.543	-.656	-.087	-.459	.424	.709	-.087	-.438	.193
(X)	N	6	6	6	5	6	5	6	6	6	5	6
EC	Correlation (r)	-.078	1	.574	.703	.190	.349	.046	.199	.190	.869	-.886*
(Y)	N	6	6	6	5	6	5	6	6	6	5	6
Nitrate	Correlation (r)	-.543	.574	1	.521	.492	.818	.178	.086	.492	.740	-.727
(Z)	N	6	6	6	5	6	5	6	6	6	5	6

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed).

From the Table II, it is observed that in north part of the state, fluoride content is moderately correlated to the EC by 73.2%. In this region it is also related to the discharge of hazardous waste into the environment by the factor of 0.70. On the contrary, it doesn't depend upon the fertilizer or pesticide usage in the region. The EC which indicated salinity, is directly correlated to fluoride content (+0.732), nitrate content (+0.697) and is in negative correlation with rainfall in the region (-0.638). This may be due to the fact that, the region is semi arid and lacks adequate water supply and with increase in rainfall the saline concentration decreases. In southern part of the state the scenario changes because that southern part is blessed with adequate water supply, thus fluoride content moderately depends upon BOD in the water (0.535). Also, it is in negative correlation (-0.69) with rainfall in the region. EC in this region is highly correlated (+0.869) to the nitrate content as it soluble and availability of water in this region increases its solubility and thus contaminates the groundwater. Both EC and nitrate are in positive correlation with IWW generated in the region.

The eastern part is also blessed with river and lakes and has ample water supply. That may be the reason for not having any significant correlation of fluoride content as well as EC with respect to any other variables. However, the nitrate content in this region is in strong correlation with IWW (+0.937) and NPK fertilizers usage (+0.886) in the region. The western part of the Rajasthan is arid region which lacks adequate rainfall and is blessed with plenty of sunshine. In this region also, fluoride content doesn't show any significant correlation with any other variable except pesticide usage. In case of EC of the region, it has strong correlation with maximum groundwater depth (+0.869) and IWW (+0.703). Nitrate content in this region also exhibits moderate positive correlation with groundwater depth (+0.74) and hazardous waste discharge (+0.818) into the environment.

3.2. t-Test for Correlated Factors

The influence of strongly correlated variables is paired to perform the t-test and validate the significance of these variables. The t-test for four different regions of the state are estimated and is shown in Table III.

Table III: 't-Test' estimation for the paired differences of correlated variables

t test pairing (Northern region)		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
1	X-C	1.644500	.346400	.141417	1.280976	2.008024	11.629	5	.000
2	Y-C	3508.446167	1344.171300	548.755635	2097.824899	4919.067435	6.393	5	.001
3	Y-G	3447.25167	1337.85120	546.17546	2043.26294	4851.24039	6.312	5	.001
4	Y-H	3355.5286	1348.6984	509.7601	2108.1906	4602.8666	6.583	6	.001
5	Y-Z	3495.841429	1242.818844	469.741369	2346.425705	4645.257152	7.442	6	.000
6	Y-X	3661.988571	1293.716410	488.978841	2465.500450	4858.476693	7.489	6	.000
7	Z-C	146.109500	53.000313	21.637287	90.489083	201.729917	6.753	5	.001
8	Z-X	166.147143	74.885784	28.304166	96.889344	235.404942	5.870	6	.001
t test pairing (Southern region)									
1	Y-H	588.9000	459.5565	145.3245	260.1531	917.6469	4.052	9	.003
2	Y-A	1259.936667	375.210456	125.070152	971.524379	1548.348955	10.074	8	.000
3	Y-Z	1225.628000	362.013743	114.478797	966.658969	1484.597031	10.706	9	.000
4	Y-X	1278.603000	373.135350	117.995758	1011.678050	1545.527950	10.836	9	.000
5	Z-A	29.324444	19.488331	6.496110	14.344387	44.304501	4.514	8	.002
6	Z-X	52.975000	12.985060	4.106237	43.686048	62.263952	12.901	9	.000
t test pairing (Eastern region)									
1	Y-C	2290.523143	959.426730	362.629218	1403.201411	3177.844875	6.316	6	.001
2	Y-G	2266.79714	958.24220	362.18151	1380.57092	3153.02337	6.259	6	.001
3	Y-H	1589.4889	916.3112	305.4371	885.1497	2293.8281	5.204	8	.001
4	Y-Z	2045.981111	849.562286	283.187429	1392.949729	2699.012493	7.225	8	.000
5	Y-X	2165.428889	868.172629	289.390876	1498.092331	2832.765446	7.483	8	.000
6	Z-C	119.268857	67.653379	25.570574	56.699917	181.837797	4.664	6	.003
7	Z-X	119.447778	69.002037	23.000679	66.408117	172.487439	5.193	8	.001
t test pairing (Western region)									
1	X-D	-21.720000	13.186569	5.383394	-35.558455	-7.881545	-4.035	5	.010
2	Y-H	3463.8667	1238.4449	505.5930	2164.1984	4763.5349	6.851	5	.001
3	Y-A	3785.800000	1099.201903	491.578035	2420.960570	5150.639430	7.701	4	.002
4	Y-X	3859.370000	1008.541018	411.735147	2800.971111	4917.768889	9.373	5	.000
5	Z-C	104.424800	32.060774	14.338014	64.616091	144.233509	7.283	4	.002
6	Z-D	88.258333	37.331534	15.240535	49.081291	127.435375	5.791	5	.002
7	Z-X	109.978333	37.458909	15.292536	70.667619	149.289048	7.192	5	.001

The t test validates the correlation of dependent variable with fixed factors. It is observed statistically from the Table III that in the northern region of Rajasthan, the fluoride content is in significant relation with discharge of hazardous waste into the environment and salinity (EC) of the area. The southern part is highly influenced by nitrate contamination due to water availability. The significance of IWW remains prominent in eastern part to estimate the salinity of the region. The western part shows 2 tailed test significant level in ground water with salinity of the region.

3.3. ANOVA Test to Validate the Model Fit

In the end, to validate the correlation and estimate the model fit, the analysis of variance is also carried out for the entire state. The regression model takes each of the contamination as dependent factor and influencing factors as fixed variables. The independent factors are takes with high Pearson correlation factor for the simplicity of the model. The model summary obtained after regression analysis is shown in Table IV.

The analysis of variable validates the fitness of the model. The histogram indicating the frequency of dependent variable with respect to regression standardized residual for all the three cases is shown in Fig. 1.

Table IV: Model Summary for regression analysis

Dependent variable	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Fluoride	1	.701[a]	.491	.427	.436899
EC	2	.864[b]	.746	.706	693.664
Nitrate	3	.753[c]	.567	.490	38.399746

[a]Predictors: (X), Y,G,H
[b]Predictors: (Y), A,G,H
[c]Predictors: (Z), A,C,G

The model summary to estimate R and R2 indicates that the model fit of EC is close to 75% which means the variables can significantly predict change in EC value. The regression and residue vales obtained after ANOVA for all the three dependent variable are shown in Table V.

Table V: Analysis of Variance estimation from the linear regression model

Dependent variable	Model		Sum of Squares	df	Mean Square	F	Sig.
Fluoride	1	Regression	4.414	3	1.471	7.708	.001[i]
		Residual	4.581	24	.191		
		Total	8.995	27			
EC	2	Regression	26855135.061	3	8951711.687	18.604	.000[j]
		Residual	9142233.548	19	481170.187		
		Total	35997368.609	22			
Nitrate	3	Regression	32788.876	3	10929.625	7.412	.002[k]
		Residual	25067.188	17	1474.540		
		Total	57856.065	20			

[i]Predictors: (X), Y,G,H
[j]Predictors: (Y), A,G,H
[k]Predictors: (Z), A,C,G

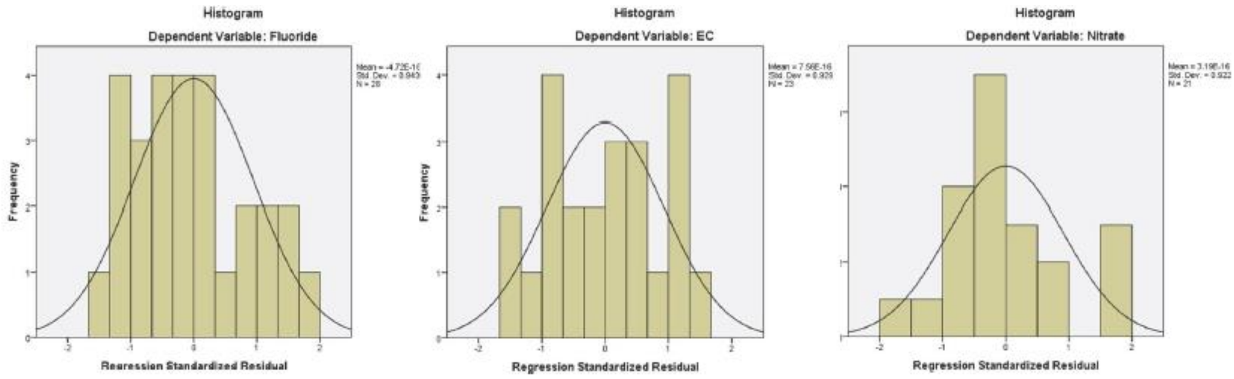

Fig. 1: Histogram for regression standardized residual for Fluoride, EC and Nitrate

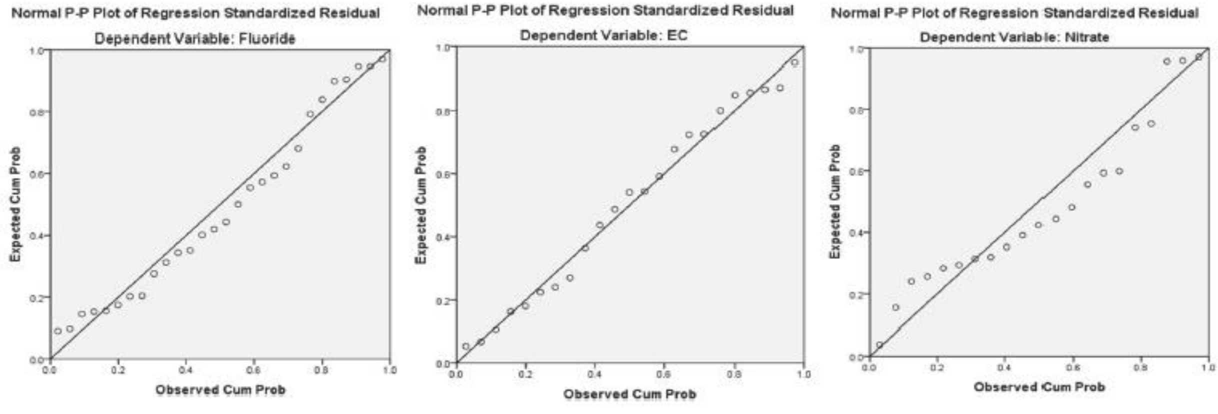

Fig. 2: Probability plot for cumulative values for Fluoride, EC and Nitrate

Similarly the probability plot obtained for cumulative observed versus expected to regression standardized residual is shown in Fig. 2.

4. Conclusion

The current paper discusses the groundwater scenario for Rajasthan, India by identifying various contamination factors (Fluoride, Electrical conductivity and Nitrate content). The potential sources for these contamination is also identified and bivariate correlation model is established to check the significant relation between the various factors. The results shows the direct correlation of fluoride content in the northern part of the state with the salinity and hazardous pollution discharge into the environment. On the other hand, the results shows that the salinity decreases with increase in rainfall in the region. The correlation for the southern and eastern part of the state shows the high correlation of nitrate contamination with water sources as it is easily soluble in water. The western part of the state lack adequate rainfall and the groundwater level has gone beyond the critical level. The results indicates that the discharge of chemical and hazardous polluting factors into the environment are worsening the situation. Further a t-test to check the significance of paired factors has been carried out which shows the significant level by 0.05. In the end, ANOVA is carried out for the entire state to establish a model which correlates the dependent factors with influencing variable. The results shows the significant level of relation between paired and other contaminating factors. The current study would help out to curb the potential source of pollution in Rajasthan state of India.

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