Groundwater Quality Investigations in Salem Corporation by using Multivariate Statistical Techniques

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***Abstract*— Groundwater quality of the Salem Corporation was assessed to understand the contamination processes due to the presence of various contaminant sources and the suitability of groundwater for drinking purpose. Groundwater samples were collected during the period of pre- monsoon and post-monsoon of 2014-15 at 10 different locations of Salem Corporation of Tamilnadu state of India. Their physicochemical parameters like colour, odour, turbidity, TDS, EC, pH, TA, TH, Ca2+, Mg2+, Fe2+, Na+, K+, NH3+, NO3-, Cl-, F-, SO42-& PO42- were assessed. The results were compared with the drinking water guidelines of Indian Standard (IS) and World Health Organization (WHO). The multivariate statistical studies of Correlation co-efficient (r) analysis, Factor analysis and Cluster analysis were analyzed using SPSS (version 19.0) to determine the various types of pollution formation in the Salem Corporation**

Key Words: Cluster analysis, Correlation co-efficient analysis, Factor analysis, Groundwater, IS, Physicochemical parameters, SPSS, and WHO.

I. INTRODUCTION

Ground water is a part of precipitation that infiltrates through the soil to the water table. Groundwater occurs as a part of the hydrological metamorphosis of permeable structured zones of the rocks, gravel and sand. Groundwater can be obtained from aquifers and hypopheric zones. Ground water is always moving by the force of gravity from recharge areas to discharge areas. In India, as groundwater is ultimate and key water resource, people use groundwater for drinking purpose. In addition to this, groundwater is also used in agricultural and industrial fields. If the groundwater used for drinking and other domestic activities is contaminated due to increase in population, industrialization and urbanization and it creates intimidation to the health of the people. To protect and manage quality and quantity of groundwater is essential for the healthy development of any country.

A. Objectives of the study

- To evaluate the groundwater quality by physico-chemical parameters analysis at various locations of Salem Corporation.
- To assess the ground water suitability for drinking purpose by comparing the physico-chemical parameters with the IS & WHO standards.
- To identify the types of pollution causes the groundwater contamination.
- Finally to suggest the suitable remedial measures to control the GW pollution.

II. STUDY AREA

The present study is related to the groundwater quality of some places of the Salem Corporation which is situated in Salem district of Tamilnadu state of India. Salem is the Fifth largest City in Tamil Nadu. It lies to the Latitudes between 11°14' N to 12°53' N and Longitudes between 77°44' E to 78°50' E. Salem Corporation covers an area of 91.34 sq km and it consists of 60 wards categorized under 4 Zonal Offices of Suramangalam, Hasthampatty, Ammapet & Kondalampatty. Population of Salem in 2011 is 831,038; of which male and female are 418,337 and 412,701 respectively. The density of population is about 9098 per sq km for the area. The sex ratio is 987 per 1000. It indicates an increase of population by 20 % in 2011 compare to 2001. Rainfall contributes into four different seasons such as Winter, Summer, SW and NE Monsoons. In 2014, average rainfall of these four seasons is 36.9, 133, 303.1 & 450 mm respectively. The total annual rainfall of 2014 is 923 mm. Salem district enjoys a tropical climate. Weather of this Salem Corporation is dry and hot. In winter, temperature goes down to 19.7° C and while in summer, temperature raises up to 38.6°C. The ground-water level within aquifer (open well) fluctuates constantly with respect to rainfall, evapotranspiration, ground-water movement (including recharge and discharge). Land use map of study area as shown in *fig.1*

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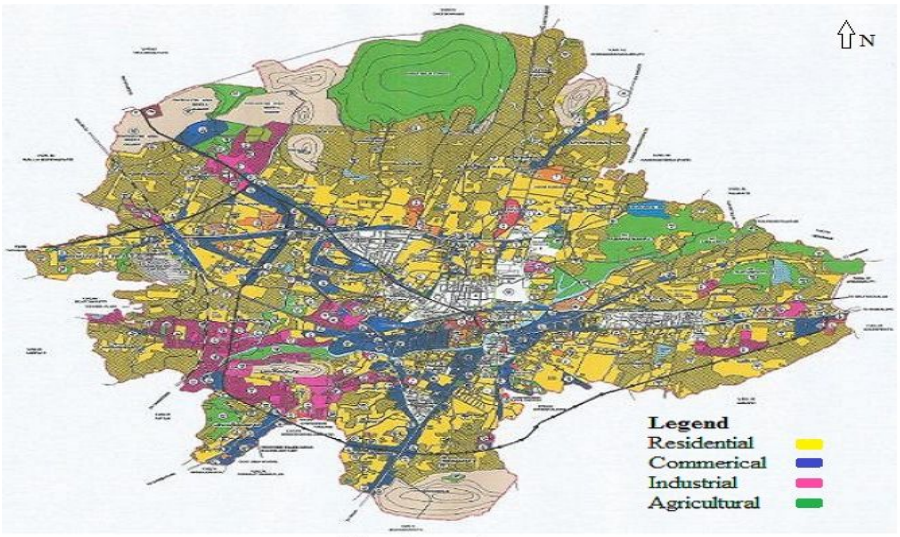

Fig. 1 - Land use map of Salem Corporation

III. MATERIALS COLLECTION

Groundwater samples of open wells were collected in the period of pre-monsoon (Sep-2014) and post-monsoon (Feb-2015) seasons at ten different places such as Solampallam, Kasakanoor, Reddiyur, Gorimedu, Maravaneri, Kattuvalavu, Kitchipalayam, Dadagapatti, Pallapatti and Sivadapuram which are come under domestic, commercial, agricultural & industrial areas of Salem Corporation. Groundwater samples are handled with one litre capacity of polyethylene bottles and analyzed in the laboratory. Physical-chemical parameters such as Turbidity, Total Dissolved Solids, Electrical Conductivity, pH, Total Alkalinity, Total Hardness, Calcium, Magnesium, Sodium, Potassium, Iron, Ammonia, Nitrate, Chloride, Fluoride, Sulphate, Phosphate and Dissolved Oxygen are evaluated.

IV. METHODOLOGY

Groundwater samples of Salem Corporation area are analyzed and quality of groundwater is compared with the drinking water guidelines of IS &WHO. Groundwater quality investigations are done by using multivariate statistical analysis methods such as Correlation co-efficient (r) analysis, Factor analysis and Cluster analysis by SPSS (version 19.0).

V. RESULTS AND DISCUSSION

Values of different physicochemical characteristics of groundwater samples for pre & post monsoon seasons are shown in *Table 1*. Quality of these water samples is compared with IS & WHO Standards. pH and Sulphate values of all ground water samples were found within the desirable limit. It indicates groundwater suitability to drinking purpose. Values of Total Dissolved Solids, Total Alkalinity, Total Hardness and Concentrations of Calcium, Magnesium, Nitrate & Chloride ion values of the groundwater samples exceeded the desirable limit but within permissible limit in the absence of alternate source. It indicates groundwater slightly not suitable for drinking purpose.

Turbidity values and Concentrations of Iron, Ammonia & Fluoride ion values of the GW samples exceeded the permissible limit. It indicates groundwater not suitable to drinking purpose and requires pretreatments. There is no desirable limit for values of Electrical conductivity& Dissolved Oxygen and Concentrations of Sodium, Potassium & Phosphate ion values of the groundwater samples. Usage of groundwater without pretreatment causes gastro intentional irritation, tasteless, blue baby syndrome, respiratory failure, variation in blood pressure, paralysis, dental & skeletal fluorosis, etc., to human beings.

To improve groundwater quality by adopting pretreatments such as filtration, aeration, chlorination processes, etc., and also artificial recharge techniques. Artificial recharge is used to store and retrieve water of good quality by adopting several artificial recharge methods such as injection wells, recharge shafts such as vertical and lateral shafts, recharge by dug wells and hand pumps, ponding over large area such as check dams, percolation tanks, etc.,

A. Statistical Analysis

Multivariate statistical methods including correlation co-efficient, factor and cluster analysis can be used to understand complex nature of water quality issues and determine the various types of pollution & priorities to improve water quality by using Statistical calculations were performed using the Statistical Package for the Social Sciences Software - SPSS (ver. 19.0). CCA is used for the measurement of the strength and statistical significance of the relation between two or more water quality parameters. The correlation coefficients (r) were calculated and correlation matrix was obtained by pearson correlation coefficient method as shown in *Table 2*. Here, r is a dimensionless index which is in the range of -1.0 to +1.0 inclusive 0. Factors extracted by the Principal Component Analysis method, rotated by Varimax with Kaiser Normalization as shown in *Table3*.

Table 1 – Values of Physicochemical parameters of groundwater samples for Pre & Post Monsoon seasons

Physical Chemical Parameters	Water Limit			Ground Water Sample No																	
	IS		WHO	Pre-Monsoon										Post-Monsoon							
	(A)	(B)		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Appearance	-	-	-	CL	G	CL	CL	SG	CL	CL	CL	SG	SY	CL	G	CL	CL	G	CL	CL	CL	G	SY
Odour	Agreeable	Agreeable	-	O	A	O	O	A	O	O	A	A	A	O	A	O	O	A	O	O	O	A	A
Tur. (NTU)	1	5	< 5	9	14	18	4	12	3	9	11	16	22	8	15	19	4	11	2	11	12	14	20
TDS (mg/l)	500	2000	-	1850	1044	1278	786	975	1025	1546	813	2215	3185	1663	1122	1345	836	928	989	1625	874	2076	2995
EC (µS/cm)	-	-	250	2644	1492	1826	1123	1393	1464	2208	1162	3165	4550	2378	1631	1954	1235	1084	1232	2313	1308	2856	4031
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	7.26	7.36	7.27	7.28	6.98	7.23	7.18	7.32	6.87	6.89	7.05	7.81	7.63	7.45	6.65	6.91	7.46	7.73	6.62	6.58
TA (mg/l)	200	600	-	624	464	536	184	396	424	484	324	604	780	603	481	557	202	369	398	503	349	579	753
TH (mg/l)	200	600	150 - 500	720	524	424	310	448	484	560	396	670	840	695	553	448	339	427	452	576	415	644	813
Ca^{2+} (mg/l)	75	200	-	196	116	102	76	96	108	118	96	152	256	168	98	81	58	67	79	87	72	129	209
Mg^{2+} (mg/l)	30	100	-	84	42	44	28	34	42	56	32	76	132	67	29	32	21	25	31	43	26	58	104
Na^{+} (mg/l)	-	-	-	268	152	224	128	128	148	264	116	396	456	305	171	243	152	163	174	279	142	423	479
K^{+} (mg/l)	-	-	-	46	16	26	12	14	16	38	12	52	96	35	18	21	11	17	13	33	15	45	81
Fe^{2+} (mg/l)	0.3	0.3	0.3	0.6	1	1.5	0.2	0.8	0.3	1.2	0.6	1	1.8	0.5	0.8	1.4	0.3	0.8	0.2	1.1	0.5	0.8	1.6
NH_3^{+} (mg/l)	0.5	0.5	-	3.5	1.5	2.2	1.5	1	1.5	2.2	0.8	3	2.5	3.7	1.6	2.3	2.6	1.2	1.6	2.1	0.8	2.9	2.6
NO_3^{-} (mg/l)	45	45	50	56	38	36	16	32	38	52	26	84	124	47	34	31	13	26	32	43	21	69	105
Cl^{-} (mg/l)	250	1000	250	464	164	225	236	172	152	416	148	676	952	427	142	240	248	192	139	429	135	634	973
F^{-} (mg/l)	1	1.5	1.51	1	2.5	1.8	1.5	1.2	1.4	2.2	2.5	2.5	2.8	0.9	2.5	1.9	1.5	1.3	1.2	2.1	2.4	2.3	2.6
SO_4^{2-} (mg/l)	200	400	500	95	72	56	85	52	78	120	48	110	280	106	79	48	69	41	85	108	53	132	257
PO_4^{2-} (mg/l)	-	-	-	2	1.2	1.8	1.5	0.5	1	1.6	0.4	2.2	2.5	1.8	1.4	2.1	1.8	0.4	0.8	1.9	0.5	2	2.2
DO	-	-	-	2.0	1.2	1.8	1.5	0.5	1.0	1.6	0.4	2.2	2.5	1.8	1.1	1.6	1.5	0.6	0.9	1.4	0.4	2	2.3

CL: Colourless, S: Slightly, G: Greenish, Y: Yellowish, O: Objectionable, A: Algal

- (A) BIS (10500 - 2012) Standards - Acceptable Limit
- (B) BIS (10500 - 2012) Standards - Permissible limit in the Absence of Alternate Source
- WHO (2008) - World Health Organization's Guideline

Table 2 - Correlation Co-efficient Matrix of groundwater samples

Correlation	Seasons	Tur	TDS	EC	pH	TA	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe^{2+}	NH_3^{+}	NO_3^{-}	Cl^{-}	F^{-}	SO_4^{2-}	PO_4^{2-}	DO
Tur	Pre-Monsoon	1.000																	
	Post-Monsoon																		
TDS	Pre-Monsoon	0.659	1.000																
	Post-Monsoon	0.585																	
EC	Pre-Monsoon	0.659	1.000	1.000															
	Post-Monsoon	0.605	0.993																
pH	Pre-Monsoon	-0.503	-0.704	-0.704	1.000														
	Post-Monsoon	0.018	-0.538	-0.449															
TA	Pre-Monsoon	0.712	0.899	0.899	-0.545	1.000													
	Post-Monsoon	0.678	0.886	0.888	-0.383														
TH	Pre-Monsoon	0.535	0.927	0.927	-0.579	0.928	1.000												
	Post-Monsoon	0.480	0.915	0.914	-0.475	0.915													
Ca^{2+}	Pre-Monsoon	0.559	0.935	0.935	-0.524	0.889	0.956	1.000											
	Post-Monsoon	0.438	0.899	0.896	-0.506	0.869	0.955												
Mg^{2+}	Pre-Monsoon	0.598	0.981	0.981	-0.606	0.898	0.949	0.984	1.000										
	Post-Monsoon	0.454	0.960	0.949	-0.571	0.864	0.940	0.972											
Na^{+}	Pre-Monsoon	0.654	0.974	0.974	-0.712	0.870	0.874	0.846	0.919	1.000									
	Post-Monsoon	0.527	0.974	0.969	-0.592	0.861	0.885	0.858	0.918										
K^{+}	Pre-Monsoon	0.642	0.993	0.993	-0.664	0.874	0.907	0.939	0.985	0.954	1.000								
	Post-Monsoon	0.576	0.989	0.975	-0.562	0.847	0.904	0.904	0.968	0.944									
Fe^{2+}	Pre-Monsoon	0.900	0.679	0.679	-0.441	0.744	0.552	0.548	0.617	0.684	0.685	1.000							
	Post-Monsoon	0.896	0.685	0.690	-0.113	0.720	0.525	0.463	0.545	0.610	0.671								

NH_3^+	Pre-Monsoon	0.296	0.710	0.710	-0.321	0.734	0.745	0.687	0.704	0.765	0.679	0.338	1.000						
	Post-Monsoon	0.026	0.548	0.583	-0.307	0.494	0.568	0.621	0.588	0.633	0.483	0.135							
NO_3^-	Pre-Monsoon	0.669	0.985	0.985	-0.740	0.887	0.921	0.912	0.960	0.953	0.972	0.679	0.615	1.000					
	Post-Monsoon	0.554	0.982	0.959	-0.610	0.872	0.918	0.901	0.952	0.949	0.980	0.626	0.453						
Cl^-	Pre-Monsoon	0.590	0.978	0.978	-0.731	0.797	0.870	0.884	0.946	0.968	0.976	0.600	0.690	0.958	1.000				
	Post-Monsoon	0.483	0.973	0.963	-0.600	0.767	0.850	0.855	0.938	0.960	0.977	0.605	0.577	0.947					
F^-	Pre-Monsoon	0.611	0.430	0.430	-0.244	0.324	0.312	0.293	0.360	0.464	0.431	0.581	-0.024	0.511	0.449	1.000			
	Post-Monsoon	0.713	0.418	0.450	0.227	0.332	0.297	0.205	0.254	0.347	0.425	0.558	-0.250	0.429	0.366				
SO_4^{2-}	Pre-Monsoon	0.507	0.892	0.892	-0.587	0.690	0.774	0.849	0.901	0.817	0.925	0.599	0.436	0.897	0.897	0.476	1.000		
	Post-Monsoon	0.396	0.936	0.919	-0.533	0.739	0.860	0.874	0.937	0.869	0.952	0.515	0.451	0.949	0.936	0.407			
PO_4^{2-}	Pre-Monsoon	0.474	0.826	0.826	-0.419	0.729	0.715	0.725	0.793	0.874	0.818	0.543	0.871	0.751	0.832	0.247	0.700	1.000	
	Post-Monsoon	0.408	0.670	0.725	-0.039	0.587	0.552	0.538	0.572	0.698	0.590	0.544	0.794	0.550	0.660	0.253	0.557		
DO	Pre-Monsoon	0.978	0.561	0.561	-0.447	0.657	0.455	0.445	0.483	0.588	0.532	0.863	0.307	0.562	0.493	0.566	0.344	0.422	1.000
	Post-Monsoon	0.379	0.828	0.851	-0.373	0.703	0.724	0.750	0.778	0.861	0.769	0.507	0.864	0.750	0.834	0.171	0.742	0.928	

Very high positive correlation

TDS with EC, TA, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, NO_3^-, Cl^-, PO_4^{2-} & DO

There is no very high negative correlation, so
High negative correlation

pH with TDS, EC, Mg^{2+}, Na^+, K^+, NO_3^- & Cl^-

Very poor positive correlation

Tur with pH & NH_3^+

Very poor negative correlation

pH with Fe^{2+} & PO_4^{2-}

The factor analysis generated by three significant factors, which explained above 90 % of the variance in both seasons. From factor analysis the types of pollution generation as shown in *Table 4.*

Table 3 - Rotated Component Matrix of FA of groundwater samples

Rotated Component Matrix						
Parameters	Pre-Monsoon			Post-Monsoon		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Tur	0.297	**0.913**	0.206	0.246	0.125	**0.895**
TDS	**0.805**	0.350	0.478	**0.831**	0.392	0.388
EC	**0.805**	0.350	0.478	**0.774**	0.461	0.424
pH	**-0.703**	-0.264	-0.076	**-0.833**	0.084	0.325
TA	0.541	0.466	**0.632**	**0.700**	0.372	0.446
TH	**0.722**	0.230	0.566	**0.826**	0.355	0.267
Ca	**0.754**	0.218	0.529	**0.842**	0.380	0.178
Mg	**0.803**	0.265	0.506	**0.887**	0.359	0.220
Na	**0.737**	0.384	0.511	**0.809**	0.458	0.296
K	**0.820**	0.333	0.450	**0.865**	0.301	0.382
Fe	0.329	**0.847**	0.250	0.337	0.239	**0.797**
NH_3	0.322	0.040	**0.915**	0.360	**0.889**	-0.237
NO_3	**0.845**	0.379	0.360	**0.893**	0.253	0.357
Cl	**0.849**	0.278	0.410	**0.836**	0.397	0.286
F	0.430	**0.669**	-0.299	0.119	-0.084	**0.883**
SO_4	**0.907**	0.219	0.184	**0.857**	0.274	0.275
PO_4	0.513	0.215	**0.710**	0.223	**0.908**	0.307
DO	0.139	**0.940**	0.246	0.532	**0.810**	0.165
Eigenvalue	13.39	1.98	0.97	8.94	3.86	3.70
% of Variance	**74.37**	**10.98**	**5.38**	**49.65**	**21.44**	**20.55**
Cumulative %	74.37	85.35	**90.72**	49.65	71.09	**91.64**

Table 4 - Types of pollution generation from groundwater

Factor	Seasons	Physico-Chemical Parameters	Types of Pollution
1	Pre-Monsoon	SO_4, Cl, NO_3, K, TDS, EC, Mg, Ca, Na, TH & pH	Agricultural Pollution
	Post-Monsoon	NO_3, Mg, K, SO_4, Ca, Cl, TDS, TH, Na, EC, TA & pH	
2	Pre-Monsoon	DO, Tur, Fe & F	Domestic Waste Pollution
	Post-Monsoon	PO_4, NH_3 & DO	Industrial Pollution
3	Pre-Monsoon	NH_3, PO_4 & TA	
	Post-Monsoon	Tur, F & Fe	Domestic Waste Pollution

Hierarchical CA was performed on the factor scores obtained from FA using Ward's method with squared Euclidean distances. Results of CA are represented using dendogram for pre & post monsoons as shown in *figures 2-3 &* description of cases as shown in *Table 5*. Locations of same clusters have the similar pattern of the groundwater quality.

On the basis of Cluster analysis locations of Salem Corporation are divided as follows:

- Cluster I (Cases 2, 3, 5, 6 & 8) - ***Agricultural Pollution*.**
- Cluster II (Cases 1, 4, 7, 9 & 10) - ***Domestic Waste & Industrial Pollution*.**

Table 5 - Description of cases

Cases	Locations
1	Solampallam
2	Kasakanoor
3	Reddiyur
4	Gorimedu
5	Maravaneri
6	Kattuvalavu
7	Kitchipalayam
8	Dadagapatti
9	Pallapatti
10	Sivadapuram

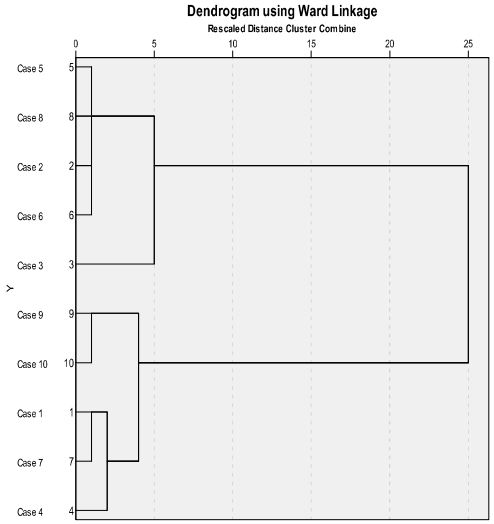

Fig. 2 - Dendrogram from CA (Pre-monsoon)

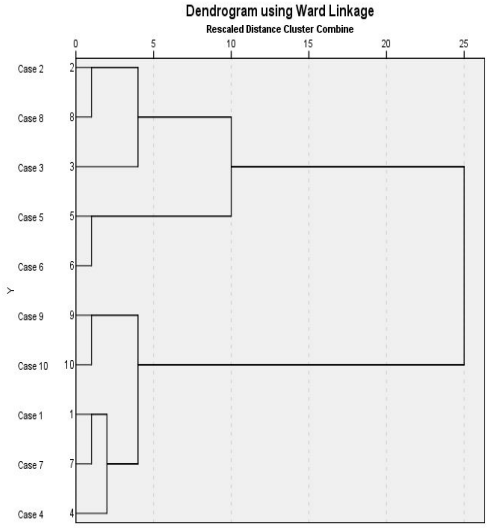

Fig. 3 - Dendrogram from CA (Post-monsoon)

VI. CONCLUSION

The present study has led to conclude that the quality of water samples studied were acceptable from the majority of the physicochemical parameters but as *turbidity, iron, ammonia and fluoride* values of all the samples were violating the desirable limit suggested by IS & WHO. So the water should be treated properly before its usage as drinking water to avoid probable adverse effects. Based on FA results were concluded that major water pollution threats are *Agricultural pollution, Domestic pollution & Industrial waste pollution*. Based on CA results, locations of Cluster I in Salem Corporation such as Kasakanoor, Reddiyur, Maravaneri, Kattuvalavu and Dadagapatti are strongly affected by *agricultural pollution* and locations of Cluster II in Salem Corporation such as Solampallam, Gorimedu, Kitchipalayam, Pallapatti and Sivadapuram are strongly affected by *Domestic & Industrial pollution.* Movement of groundwater into soil will affect the agricultural and other activities of Salem Corporation area due to presence of those pollutants. To control GW contamination by using several artificial recharge methods. Finally I conclude that, this paper helps to public should be made aware of drinking water quality. For the welfare of the human being, water quality should be assessed on the regular basis for drinking, agricultural and other purposes.

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