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Assessment of Groundwater Quality in Karakulam Grama Panchayath in Thiruvananthapuram, Kerala State, South India

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Abstract**—**Groundwater is vital to the livelihoods and health of the majority of the people, since it provides almost the entire water resource for domestic, agricultural and industrial uses. Groundwater quality comprises the physical, chemical and bacteriological qualities. The present investigation was carried out to determine the physicochemical and bacteriological quality of the ground water sources in the residential areas of Karakulam Grama Panchayath in Thiruvananthapuram district, Kerala state in India. Karakulam is located in the eastern suburbs of Thiruvananthapuram city. The major drinking water source of the residents in the study area is wells. The present study aims to assess the portability and irrigational suitability of groundwater in the study area. The water samples were collected from randomly selected dug wells and bore wells in the study area during post monsoon and pre monsoon seasons of the year 2014 after a preliminary field survey. The physical, chemical and bacteriological parameters of the water samples were analyzed following standard procedures. The concentration of heavy metals (Cd, Pb and Mn) in the acid digested water samples were determined by using an Atomic Absorption Spectrophotometer. The results showed that the pH of well water samples ranged from acidic to alkaline level. In majority of well water samples (>54 %) the iron and magnesium content were found high in both the seasons studied, and the values were above the permissible limits of WHO drinking water quality standards. Bacteriological analyses showed that 63% of the wells were contaminated with total coliforms in both the seasons studied. Irrigational suitability of groundwater was assessed by determining the chemical indices like Sodium Percentage (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), and the results indicate that the well water in the study area are good for irrigation purposes. Therefore, the study reveals the degradation of drinking water quality groundwater sources in Karakulam Grama Panchayath in Thiruvananthapuram District, Keralain terms of its chemical and bacteriological characteristics, and is not potable without proper treatment. In the study, more than 1/3rdof the well water samples tested were positive for total coliforms, and the bacterial contamination may pose threat to public health. The study recommends the need for periodic well water quality monitoring in the study area and to conduct awareness programs among the residents.

Keywords**—**Bacteriological, groundwater, irrigational suitability, physicochemical, potability.

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I. Introduction

WATER is the essential constituent of any form of life. On an average, a human being consumes about two litres of water every day and it account for 70% of the weight of human body. Not surprisingly, the unique properties of water make us feel that it is specially designed for the living organism and no other liquid can absolutely replace it [1]. Most of the water sources in India are being increasingly polluted due to industrial wastes, urban sewage and agricultural runoff. However, several steps have been taken on a broader front but the quality of the water resource seems to be far from satisfactory. Not only the surface water source, but the ground water also is polluted.

A study of water quality in any adequate system is fundamental to understand the water resource as it gives insight into the benefits to be gained from water management and the consequences of its mismanagement. Water quality has become a major global concern due to over increasing human developmental activities that over exploit and pollute the water resources on surface and ground water. Previous study [2] reported that the poor quality of the environment particularly in relation to drinking water and unsafe disposal of human excreta caused the persistence of diarrhoeal and dysenteric disorders even among the adult populations in Kerala. The present study was carried out in the selected stations of Karakulam Grama Panchayath of Thiruvananthapuram district, Kerala to assess the potability and irrigational suitability of ground water quality, which is the main source of drinking water of this area.

II. Materials and Methods

A. Study Area

The Karakulam Grama Panchayath is the area selected for the present investigation in Thiruvananthapuram district, Kerala. Karakulam is located in the eastern suburbs of the capital city. It covers an area of 25.01 sq.km and consisting of 23 wards having a population of 40503. Of these, 20184 are males and 20319 are females. The density of population is 1619 with an average literacy of 91.86%. According to its geography, this village can be called a hilly terrain. This land is a combination of high hills, valleys and water sources amidst the hills. The area lies close to Thiruvananthapuram Taluk and forms the southern region of Nedumangad Taluk and it comprises of Karakulam and Vattapara revenue villages. This region has high laterite content and hence forms 20

percent of the total agricultural region. About the inclined regions, most of their slopes lie between 15-20° and 65-70°. The most important specialty of the Karakulam Panchayath is those considerable portions of this Panchayath are rocky areas. The portion (4.5 km) of the river 'Killiyar' passes through this Panchayath. The major drinking water sources of the residents in the study area are open wells. Well water is also used for irrigation and domestic purposes.

Eleven sampling stations were randomly selected in the Karakulam Grama Panchayath after a field study. It includes eight open wells and three bore wells. The samples were (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11) selected based on the survey. Water samples were collected during post monsoon and pre monsoon season, from September 2013 to April 2014.

The physicochemical parameters analyzed include color, odor, temperature, pH, electrical conductivity, alkalinity, chloride, total dissolved solids, nitrate, sulphate, total hardness, calcium, magnesium, iron, sodium, potassium, fluoride, salinity, manganese, cadmium and lead. The physical, chemical and bacteriological characteristics were determined following the standard procedures in APHA [3]. The concentration of heavy metals Cd, Pb and Mn in the water samples collected during the pre-monsoon season were determined after acid digestion using an Atomic Absorption Spectrophotometer (Perkin Elmer, Pinnacle 900H). The bacteriological qualities of water samples were assessed by determining the Most Probable Number (MPN) of coliform per 100ml of sample according to standard methods of BIS (2003). Both total and faucal coliforms were determined by MPN technique. From the water quality data, irrigational suitability was evaluated based on the calculation of chemical indices like Sodium Percentage (%Na), Sodium Adsorption Ratio (SAR) [4] and Residual Sodium Carbonate (RSC) [5].

III. Results and Discussion

A. Physical and Chemical Characteristics

The physical characteristics like colour and odour of all water samples collected from the ground water sources in different stations of Karakulam Grama Panchayath were determined. The visual color examination of well water shows that the samples from S1, S6, S7, S8, S9, S10, S11 were pale yellow in colour and all the other samples were colorless, during both the post-monsoon and pre-monsoon seasons. The odour of well water samples collected was noted by sniffing and all the water samples except S2, S3, S4, S5 and S6 have unobjectionable odour during both the post and pre monsoon seasons. The disagreeable odours in water are due to the presence of microscopic organisms or decaying vegetation includes algae, fungi, bacteria, actinomycetes and weeds [6]. Water for drinking purposes should be free of objectionable odours. According to BIS (2003) standards [7], the potable water should be having a desirable limit of agreeable odour.

The results of physical and chemical parameters (temperature, pH, EC, alkalinity, total hardness, Ca, Mg, TDS, dhloride, sulphate, calcium, magnesium, iron, sodium, potassium, fluoride, manganese, cadmium and lead) of water samples collected from the study area are given in Tables I and II. The temperature recorded in the well water varied from 28^0C to 30^0C in post monsoon season and from 28^0C to 33^0C during pre-monsoon season. According to WHO (1984) standards [8], the desirable limit of temperature for drinking water is 20^0C.pH of well water samples are in acidic to alkaline range (5.43-7.32) during post monsoon, and pre monsoon seasons (5.98-7.47). According to WHO (1984) [8] and BIS (2003) [7], the desirable limit of pH for drinking is 6.5 to 8.5. The present study showed that pH of all the well water samples except S3 (5.93), S4 (6.47) and S9 (6.35) in post monsoon season were within the permissible limit of BIS standards.

In the present study, the electrical conductivity (EC) in the post monsoon season was within the range of 0.02 mS/cm to 0.32 mS/cm. A considerable variation was observed in the value of EC in pre monsoon season. The EC values were varied from 0.0087 mS/cm to 0.046 mS/cm. Based on the electrical conductivity (EC), the study revealed that samples collected in both the two seasons come under the excellent water quality and having low salinity with no detrimental effects on crops on irrigation.

Alkalinity of samples analyzed ranges from 50-160 mg/L during the post monsoon season and from 20-180 mg/L during the pre-monsoon season. The total alkalinity of sample S1 is higher than the standard prescribed limit for drinking water in post monsoon (160 mg/L) and pre monsoon season (180 mg/L).

Total hardness is an important parameter of water quality. The desirable and permissible limits for hardness in drinking water according to BIS standards (2003) [7] range from 300 mg/L to 600 mg/L. The hardness of well water for post monsoon season ranged from 14 mg/L to 134 mg/L. And in pre monsoon, it ranged from 6 mg/L to 136 mg/L. The study thus clearly shows that the total hardness of all the ground water samples is within the standard limits. Calcium is a very important element influencing the flora of ecosystem, which plays a potential role in metabolism and growth [9]. The study reveals the concentration of calcium in the collected well water samples were found to be within the permissible limits of WHO (1984) [8] and BIS (2003) [7] standards for drinking water quality. The magnesium content of well water samples ranged between 12.4 mg/L to 91.52 mg/L during post monsoon, and from 15.2 mg/L to 91.91 mg/L during pre-monsoon season and was above the desirable limit for magnesium in drinking water (30 mg/L) by WHO standards (1984) [8]. Magnesium is a mineral that naturally occurs in rocks and soil and may be present due to underground pollution sources. Geographical features may be the reason for the presence of magnesium in the study area. Solids and rocks are the sources of magnesium especially from limestone; dolomite and gypsum. Increased intake of magnesium salts may cause a change in bowel habits (diarrhoea), but seldom causes hypermagnesaemia in persons with normal kidney function. Drinking-water in which both magnesium and sulfate are present in high concentrations can have a laxative

effect, although data suggest that consumers adapt to these levels as exposures continue [10].

In the present study the concentration of total dissolved solids (TDS) in ground water samples ranged from 138 mg/L to 402 mg/L during post monsoon, and 382.4 mg/L to 1590.74 mg/L during pre-monsoon season. It indicates that all the water samples have acceptable values. The moderately high values of TDS are observed in S6 of post monsoon, and S6 and S7 of pre monsoon season. In the groundwater samples analyzed, the chloride content varies from 8.69 mg/L to 39.76 mg/L during the study period. The study indicated that all the water samples in both post monsoon and pre monsoon seasons were within the permissible limits of BIS for drinking water quality.

TABLE I
CHEMICAL CHARACTERISTICS OF GROUNDWATER (POM)

Parameter	Sampling Stations										
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}
pH	6.9	7.13	5.93	6.47	6.63	6.55	7.32	6.93	6.35	7.18	7.02
EC (mS/cm)	0.02	0.025	0.033	0.156	0.174	0.32	0.296	0.135	0.212	0.318	0.208
Alkalinity (mg/L as $CaCO_3$)	100	130	120	90	60	50	130	60	120	160	90
Acidity (mg/L as $CaCO_3$)	15	15	30	15	15	15	10	15	30	20	15
Free CO_2 (mg/L as $CaCO_3$)	13.2	13.2	13.2	22	13.2	13.2	4.4	8.8	39.6	35.2	17.6
Total Hardness (mg/L as $CaCO_3$)	72	92	14	58	60	54	134	36	66	134	62
Ca^{2+} (mg/L as $CaCO_3$)	28.85	31.62	1.6	22.44	20.84	17.63	47.29	12.82	17.63	42.48	15.23
Mg^{2+} (mg/L as $CaCO_3$)	43.15	60.74	12.4	35.56	39.16	36.37	86.71	23.18	48.37	91.52	46.77
TDS (mg/L)	232	312	138	218	256	402	334	258	288	392	294
DO (mg/L)	7.31	7.96	11.05	8.78	8.45	6.82	7.804	13.65	7.804	13.82	14.47
Cl^- (mg/L)	25.56	22.72	14.2	11.36	17.04	39.76	11.36	17.04	22.72	25.56	25.56
NO_3^{2-} (mg/L)	6.28	5.64	2.74	2.49	8.27	15.8	9.67	9.74	1.59	1.3	1.28
SO_4^{2-} (mg/L)	14.93	17.84	10.46	12.18	20.25	19.56	19.04	30.89	13.04	14.24	16.81
Na^+ (mg/L)	12.8	17.9	6.9	10	15.1	38.7	11.4	8	9.6	9.8	9.7
K^+ (mg/L)	2.6	6	2.1	3	5.6	9.9	6.4	2.6	4.2	1	1.6
Fe (mg/L)	0.47	0.49	0.14	0.09	1.054	1.18	3.83	2.58	3.6	0.68	2.69
F^- (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Salinity (mg/L)	46.17	41.04	25.66	20.53	30.79	71.80	20.54	30.79	41.04	46.17	46.17

TABLE II
CHEMICAL CHARACTERISTICS OF GROUNDWATER (PRM)

Parameter	Sampling Stations										
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}
pH	7.6	7.09	6.1	6.4	5.98	6.13	7.01	7.28	6.55	7.47	7.15
EC (mS/cm)	0.046	0.025	0.008	0.022	0.019	0.015	0.028	0.021	0.033	0.057	0.037
Alkalinity (mg/L as $CaCO_3$)	110	70	20	70	40	40	60	50	100	180	100
Acidity (mg/L as $CaCO_3$)	10	25	20	30	40	0	25	10	25	20	20
Free CO_2 (mg/L as $CaCO_3$)	8.8	17.6	30.8	30.8	39.6	22	8.8	8.8	22	8.8	13.2
Total Hardness (mg/L as $CaCO_3$)	108	48	22	36	22	20	32	44	74	136	72
Ca^{2+} (mg/L as $CaCO_3$)	39.27	12.82	2.4	16.03	5.61	4.8	10.42	14.42	17.63	44.08	16.83
Mg^{2+} (mg/L as $CaCO_3$)	68.73	35.18	19.6	19.97	16.39	15.2	21.58	29.58	56.37	91.91	55.17
TDS (mg/L)	384	791	597	592	993	1194	1590	393	588	382	387
DO (mg/L)	2.92	3.41	2.43	2.43	3.25	2.92	2.92	1.62	2.92	3.41	4.39
Cl^- (mg/L)	14.79	25.98	23.57	8.69	15.31	10.02	20.07	32.66	11.92	21.91	32.66
NO_3^{2-} (mg/L)	4.34	1.39	1.39	1.49	1.73	1.33	1.97	2.84	4.91	2.17	1.25
SO_4^{2-} (mg/L)	19.04	15.102	13.21	13.72	15.44	12.7	13.9	15.79	13.55	15.27	15.44
Na^+ (mg/L)	4.4	3.2	1.6	2.4	3.6	3	5	2.8	5	4.8	4.5
K^+ (mg/L)	3.8	3.1	1.8	2.4	3.5	3.6	2.3	1.0	5	1.3	2.4
Fe (mg/L)	2.49	5.109	0.98	1.32	5.89	1.21	0.78	6.27	4.85	6.47	4.29
F^- (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Salinity (mg/L)	26.73	46.92	42.57	15.72	27.67	18.12	36.26	58.98	21.55	39.58	58.98
Mn (mg/L)	0.011	BDL	0.003	BDL	0.034	BDL	BDL	BDL	BDL	BDL	BDL
Cd (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

In the present study the nitrate content of ground water samples collected from different stations varied from 1.286 mg/L to 15.8 mg/L during post monsoon, and from 1.06 mg/L to 4.34 mg/L during pre-monsoon season. The sulphate concentration in well water samples collected during the post monsoon ranged from 10.46 mg/L to 30.89 mg/L, and from

12.7 mg/L to 19.04 mg/L during the pre-monsoon season. Both the nitrates and sulphates contents in the wells of the study area are within the permissible limits of drinking water quality standards by BIS (2003) [7].

The concentration of sodium in well water samples ranged from 8 mg/L to 38.7 mg/L during post monsoon season, and 1.6 mg/L to 5 mg/L during pre-monsoon season. The potassium content in all the water samples collected from the study area ranged from 1 mg/L to 9.9 mg/L, and from 1 mg/L to 5 mg/L during post monsoon and pre monsoon season respectively. The present study showed that the sodium and potassium contents in well water samples of the study area are within the permissible limits for drinking water prescribed by WHO (1984). Fluoride is an active component that exists in both simple and complex forms. The fluoride content in water samples of the study area is below the detectable level in both the seasons.

The concentration of heavy metals (Fe, Cd, Pb, Mn) were estimated in water samples show that total iron ranged from 0.09mg/L to 3.83 mg/L during post monsoon season and from 0.98 mg/L to 6.47 mg/L during pre-monsoon season. The water samples from S5 (1.05 mg/L), S6 (1.18 mg/L), S7 (3.83 mg/L) S8 (2.58 mg/L), S9 (3.6 mg/L) and S11 (2.69 mg/L) during post monsoon season shows high iron content. The iron content in samples from stations, S1 (2.49 mg/L), S2 (5.109 mg/L), S4 (1.32 mg/L), S5 (5.89 mg/L), S6 (1.21 mg/L), S8 (6.27 mg/L), S9, S10 (6.47 mg/L) and S11 (4.29 mg/L) during pre-monsoon season also show values above permissible standard limits (1 mg/L) by BIS (2003). The variation in the iron content is due to the geographic and soil morphological features. The increase in iron content intake may cause haemochromatosis (bronze diabetes) and may lead to different health problems [11]. Cadmium and lead contents were below detectable level in all the water samples analyzed. Manganese content was detected in the water samples from stations S1,S3 and S5 and it was below detectable level in the samples from other stations in the study area.

B. Bacteriological Quality of Groundwater

The results of total coliform and faucal coliforms count in the well water samples analysed during post monsoon and pre-monsoon are given in Figs. 1 and 2 respectively. The Most Probable Number (MPN) method is performed for the determination of coliform count and is commonly used as an indicator of potability of water. The results showed that the total coliform (TC) count and the faecal coliform count (MPN index per 100 ml) in well water of the study area ranges from 0 to 2400 during post monsoon season and from 0 to 1100 during pre-monsoon season. The MPN index values recorded are above the standard permissible level of 0/100ml for total coliforms prescribed by the BIS standards (2003). Also in pre-monsoon, 63% of the wells recorded the presence of faecal coliforms. According to WHO (1984) standards, the faecal coliform count in drinking water should be zero/100 ml. Therefore the findings of this study indicate that majority of wells in the study area are severely contaminated with pathogenic bacteria.

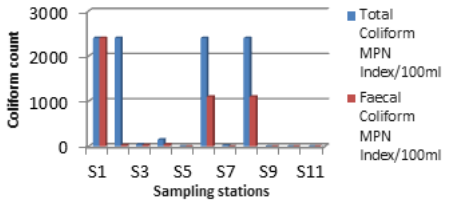

Fig. 1 Total Coliforms and Faecal Coliforms in Sampling wells (POM)

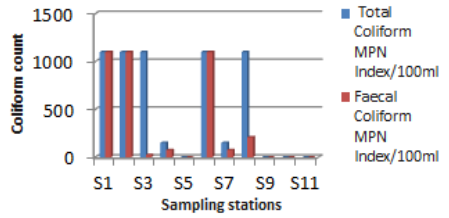

Fig. 2 Total Coliforms and Faecal Coliforms in Sampling Wells (PRM)

C. Irrigational Suitability of Groundwater

The irrigational quality is an important consideration in appraisal of salinity or alkali conditions in the irrigated area. Sodium Percentage (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Permeability Index (PI), have been used to classify and to understand the basic character of the chemical composition of ground water and its suitability for irrigation purpose. The results of irrigational quality indices in pre monsoon and post monsoon seasons are given in Tables III and IV. Based on the values obtained for the Sodium Percentage (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Permeability Index (PI) it was found that the ground water samples in the study area are suitable for irrigation purposes [12].

TABLE III
IRRIGATIONAL QUALITY INDICES OF GROUND WATER (POM)

Sampling Stations	Na%	SAR	RSC	PI
S_1	7.81	0.59	0.86	64.44
S_2	9.62	0.65	0.64	169.36
S_3	16.66	0.48	0.87	92.2
S_4	44.71	0.56	0.43	44.02
S_5	15.07	0.08	0.65	97.17
S_6	19.3	1.94	0.42	94.03
S_7	8.93	0.25	0.05	65.38
S_8	49.73	0.59	0.84	98.53
S_9	12.09	0.82	0.47	66.94
S_{10}	11.84	0.58	1.13	55.94
S_{11}	13.06	0.75	0.28	68.58

The results of the bacteriological quality of well water in the study area show that the water is contaminated with coliforms, and can be recommended only for drip irrigation in the case of leafy vegetables like lettuce, tomato.

TABLE IV
IRRIGATIONAL QUALITY INDICES OF GROUND WATER (PRM)

Sampling Stations	Na%	SAR	RSC	PI
S_1	11.92	0.13	0.13	46.93
S_2	16.22	0.63	0.84	156.38
S_3	3.91	0.60	0.20	179.55
S_4	10.49	0.85	0.54	91.19
S_5	15.18	0.75	1.02	44.62
S_6	6.63	7.44	2.25	58.18
S_7	14.15	0.39	0.48	97.11
S_8	11.46	0.88	0.89	251.60
S_9	14.44	0.67	0.61	73.08
S_{10}	12.74	0.19	1.21	51.03
S_{11}	12.26	1.74	0.32	71.09

IV. CONCLUSIONS

The study revealed the pollution of open wells and bore wells in the study area with high content of iron and magnesium. In addition, majority of open wells in the Karakulam Grama Panchayath are contaminated with total coliforms and faecal coliforms. The groundwater sources in the study area are suitable for irrigation purposes. The study results vividly point out the need of proper treatment of groundwater for drinking and domestic purposes. Iron removal can be accomplished by exchanging the iron for sodium. The most common processes include aeration, ozonation and the use of catalytic carbon may be effective in iron removal. The magnesium hardness can be removed by using powdered or liquid chemicals and ion exchange softening units. To avoid bacterial contamination, wells should be constructed at a distance of 7.5 to 15 m away from the septic tank. In addition, it is suggested to conduct periodic well water quality monitoring and awareness programs among the residents in the study area. Proper groundwater management measures are necessary to restore the declining water quality in the Karakulam Grama Panchayath in Thiruvananthapuram district, Kerala.

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REFERENCES

[1] E. K. Berner, and R. A. Berner, Global Water Cycle: Geochemistry and Environment, Prentice-Hall, New Jersey (Pub), Englewood Cliffs, 1987, 12 (7).
[2] P. G. K. Panicker, and C. R. Soman, Health Status of Kerala: Paradox of Economic Backwardness and Health Development. Centre for Development Studies, Thiruvanathapuram, (1984).
[3] APHA. Standard Methods for the Examination of Water and Wastewater, 20th Edn. American Public Health Association, Washington DC, U.S., (1995, 1998, 2012).
[4] D. K. Todd, Groundwater Hydrology. Wiley, Canada, (2001), pp. 280-281.
[5] F. M. Eaton, Significance of Carbonate in Irrigation Waters. Soil Science, 39, (1950), pp. 123-133.
[6] S. A, Abbasi, Water Quality Sampling and Analysis, 1998.
[7] BIS, Bureau of Indian Standards, Indian Standards Specifications for Drinking Water, IS: 10501. (2003). pp. 2-6.
[8] WHO, Guidelines for Drinking Water Quality: Recommendations, World Health Organisation, Geneva, (1984).
[9] V. Ravindar, C. H. Ravinder, and K. Vijaya Rao, Groundwater Pollution due to Dumping of Municipal Solid Waste at Warangal, Ind. J. Environ. Protec., 25 (6), (2005), pp: 523-526.
[10] WHO, Calcium and Magnesium in Drinking Water: Public Health Significance, J. Cotruvo, J. Bartran (Eds), World Health Organization, Genenva, (2009).
[11] A. S. Fauci, E. Braunwald, D. L. Kasper, S. L. Hauser, D. L, Longo, J. L. Jameson, J. Loscalzo, (Eds). Harrison's Principles of Internal Medicine, 17th Edn. Vol. I, (2008). pp. 2429-2433.
[12] BIS, Bureau of Indian Standards. Guidelines for the Quality of Irrigation Water. IS: 11624, (1986).