Assessment of Groundwater Quality of Outer Skirts of Kota City with Reference to its Potential of Scale Formation and Corrosivity

NITIN GUPTA, S.M.NAFEES, M.K.JAIN and S. KALPANA

Environmental Chemistry Laboratory
P.G. Department of Chemistry, Govt. College, Kota, Rajasthan, India
guptanitin2002@yahoo.com

Received 16 October 2010; Accepted 17 December 2010

Abstract: Kota City is a prominent industrial and educational town of Rajasthan state, India. Mega industrial projects of cement, fertilizers, power plant, oil seed processing units are located nearby the city. The groundwater of study area is used in domestic as well as in industrial activities. It is worthwhile to know the water quality status and its effect on entity, which is exposed in practical use. A comprehensive assessment of water quality parameters in groundwater samples drawn from 24 different locations, 6 sites from each direction at outer skirts of Kota City of Rajasthan, India, in four seasons of years 2006 to 2008 was carried out. To find out the suitability and stability of water, various indices available to assess the scale formation and corrosivity was used. The Langelier saturation index (LSI) and Ryznar saturation index (RSI) were calculated and discussed with respect to saturation level.

Keywords: Water quality, Groundwater, Langelier saturation index, Ryznar saturation index

Introduction

Groundwater sources range over a broad spectrum of chemical quality, which reflects the history of water and the region of origin. The effect of water on the industrial equipment, piping system, utensils and other objects, appears in four forms: fouling, deposition, aggression and corrosion. Fouling is a complex phenomenon resulting from the accumulation of undesirable deposition on surface. Deposition is the phenomenon in which salts gets deposit on surface. Aggression is the dissolution of cement material comprising the conduits and retaining structures. Corrosion is the end result of electro chemical reaction between water and the metal components. Factors causing corrosion¹⁻³ include acidity,

hardness, high chloride concentration, dissolved oxygen and scale formation depends upon temperature, pH and concentrations of HCO_3^- , CO_3^{2-} , Ca^{2+} and Mg^{2+} . The occurrence of scale formation and corrosion in natural and processed waters can cause serious operational and cost problems in industries and drinking water supply systems⁴. It has been roughly assessed that in India direct loss due to corrosion is amounting Rs. 200 crore/annum. To evaluate the scale formation and corrosivity potential of water, so many indices are there but Langelier saturation index (LSI) and Ryzner saturation index (RSI) are the most famous CaCO_3 saturation indices, in which LSI determines whether water has tendency to precipitate or dissolve CaCO_3 and RSI estimates the quantity of the precipitated or dissolved amount of CaCO_3 . It is believed that supersaturated waters are scale forming whereas under-saturated waters are corrosive.

Kota City is a prominent industrial and educational town of Rajasthan state. Mega industrial projects of big industrial houses as DCM, CFCL, KSTPS, KS Oil *etc.* established their projects comprising the production facilities of cement, fertilizers, power plant, edible oil *etc.* nearby the city. Perennial River Chambal is the main water source for industries and agricultural activities but in lean season when canals are not flowing industries supposed to use groundwater in industrial activities. In the present study, the quality, potential of scale formation and corrosivity of twenty four groundwater samples collected from four different directions including six sites from each direction at outer skirts of Kota City of Rajasthan, India, in four seasons of years 2006 to 2008 were studied and the results were fully interpreted with respect to saturation level.

Experimental

Details about study area, sampling locations, sampling techniques and standard methods applied for analysis are as discussed below:

Study area

Kota City is centrally located in Hadoti Region. Over the years of industrial development Kota's name became synonymous with industrial town of Rajasthan as large industrial houses like KSTPS, DCM, instrumentation Ltd., Chambal fertilizers LTD., *etc.* have their units located at Kota.

Kota has good number of prominent industrial units, good network of railway lines, perennial sources of water and electricity. The Chambal River provides the irrigation, water supply and electricity to the whole Hadoti Region. It is well connected with all major cities of India by broad gauge railway system. National highway 12 Jaipur to Jabalpur and 76 Shivpuri to Pindwara pass through the city.

The district Kota lies between $24^{\circ}25'$ and $25^{\circ}51'$ North latitudes and $75^{\circ}31'$ and $77^{\circ}26'$ East longitudes with total area of 5203.94 Sq Kms. "Kota City" is located at extreme South of it at $25^{\circ}11'$ North latitude and $75^{\circ}51'$ East longitude occupying total area of 238.59 Sq Kms with average height 253.30 meters from sea level. The only perennial river "Chambal" originating from the hills of Western Madhya Pradesh passes through the district. According to 2001 census total population of district was 1568525 and according a survey estimated population for 2008 was 1836021. Kota District has Bundi on its West, Sawai Madhopur in the North, Chittorgarh in South West and Jhalawar in the South East and Baran in the East.

The climate of Kota varies from semi-arid to arid. The climate of Kota division is characteristic of South Eastern Rajasthan with a long and intensely hot summer, low rainfall and a short mild winter. The temperature normally varies from 7°C in January to

48 °C in May. The average annual precipitation in the area is approx 700 mm. The lithological units that constitute the Kota division are mainly those of upper Vindhyan system. The upper Bhandar sandstone covers wide areas on the North and parts of Southern sector are mantled by deccan trap flows. The Eastern parts of the central belt is occupied by the Suket Shales, while on the West there are rock out crops of Kaimur sandstone. Alluvium covers part of the area on the Northeastern parts.

Sampling locations and techniques

To find out potential of scale formation and corrosivity in groundwater of outer skirts of industrial and educational Kota City water samples were collected from 24 different selected sites in years 2006, 2007 and 2008 in all the four major seasons *i.e.* winter, spring, pre-monsoon and post-monsoon. The selection of sampling sites is done to give coverage to the largest area of outer skirts of Kota City in all the four directions, covering estimated points of high probability of groundwater pollution. Kota district map is shown on Figure 1 and sampling locations are shown in Figure 2. Six villages of prime importance from each direction were selected for study. The bore wells / hand pumps located in residential, commercial, agricultural and industrial area were selected for sampling. Before collecting groundwater samples the pipeline of bore wells / hand pumps were flushed for a sufficient period of time, so that actual sample can be collected which represents the actual quality of groundwater⁵. The samples were collected as composite samples, at every site samples collected from four different points and then mixed together. Sample collected in pre-cleaned good quality narrow mouth screw-capped polypropylene bottles of two-liter capacity and rinsed thrice with the water to be collected and then filled completely to avoid encroachment of any air bubble. Sample bottles screw-caped tightly and brought to the laboratory. The samples were preserved in refrigerator at 4 °C. Samples were protected from any out side contamination.

Figure 1. Calculated values of Langelier saturation index (LSI)

Figure 2. Calculated values of Ryznar saturation index (RSI)

Analytical methods

The analysis of groundwater samples was done using procedures of standard methods (APHA, 1995)⁶ and all analysis were carried out in triplicate. Water used in reagent / standard preparation is of Milli-Q and chemicals were of AnalR grade. The pH of sample was measured at site with the help of portable meter. Total alkalinity was estimated in laboratory by titration with standard hydrochloric acid. Total hardness and calcium hardness was measured by titration with standard EDTA and total dissolved solids was estimated by evaporation method. For calculation of indices temperature of water was taken 25 °C for all the samples so that impact of physicochemical parameters on potential of scale formation and corrosivity can be figure out.

Calculation of indices

Langelier saturation index (LSI)

It simply indicates the driving force for scale formation and growth in terms of pH as a master variable. It is purely an equilibrium index and deals only with the thermodynamic driving force for calcium carbonate scale formation and growth. It provides no indication of how much scale or calcium carbonate will actually precipitate to bring water to equilibrium⁷.

If LSI is negative: No potential to scale, water will dissolve CaCO_3 .

If LSI is positive: Scale can form and CaCO_3 precipitation may occur.

If LSI is close to Zero: Borderline scale potential.

In order to calculate the LSI, it is necessary to know the total alkalinity (mg/L as CaCO_3), the calcium hardness (mg/L as CaCO_3), the total dissolved solids (mg/L TDS), the actual pH and the temperature of the water (°C).

LSI is defined as:

$$\text{LSI} = \text{pH} - \text{pH}_s \quad (1)$$

pH is the measured water pH.

pHs is the pH at saturation in calcite or calcium carbonate and is defined as :

$$\text{pHs} = (9.3 + A+B) - (C+D) \quad (2)$$

Where

$$A = (\log_{10} [\text{TDS}] - 1)/10 \quad (3)$$

$$B = -13.12 \times \log_{10} (^{\circ}\text{C} + 273) + 34.55 \quad (4)$$

$$C = \log_{10} [\text{CaH as CaCO}_3] - 0.4 \quad (5)$$

$$D = \log_{10} [\text{total alkalinity as CaCO}_3]. \quad (6)$$

From analyzed data calculated LSI using equations (1) to (6).

The use of the equation developed by Langelier made it possible to predict the tendency of natural or conditioned water to deposit calcium carbonate or to dissolve calcium carbonate. This is useful in predicting the scaling or corrosive tendencies of the water⁸. If the water dissolves calcium carbonate, the water is corrosive and has a negative value, if the water deposits calcium carbonate; it has a scaling tendency and a positive value.

Ryznar saturation index (RSI)

The Ryznar saturation index is an empirical method for predicting scaling tendencies of water based on a study of operating results with water of various saturation indices⁹.

$$\text{RSI} = 2 \text{ pHs} - \text{pH} = \text{pHs} - \text{Langelier's saturation pH}$$

This index is often used in combination with the Langelier index to improve the accuracy in predicting the scaling or corrosion tendencies of water. Calculated Ryznar saturation index (RSI) values can be construed as, RSI values in between 4.0 - 5.0, than water have heavy scaling tendency; between 5.0 - 6.0, light scaling; 6.0 - 7.0, little scale or corrosion; 7.0 - 7.5, corrosion significance; 7.5 - 9.0 heavy corrosion and higher than 9.0, water have tendency to make corrosion which is intolerable.

Results and Discussion

The sampling locations and there respective code along with numbering on Figure 2 is given in Table 1. Observations and results obtained from the physicochemical analysis of groundwater samples collected from 24 different selected sites in years 2006, 2007 and 2008 in all the four major seasons *i.e.* winter, spring, pre-monsoon and post-monsoon from outer skirts of industrial and educational Kota City are summarized in Table 2; calculated values of LSI and RSI are shown in Table 3; interpretation of LSI and RSI with respect to scale formation and corrosivity potential is given in Table 4 & 5 respectively. The observations summarized in Table 2 and calculated indices given in Table 3 are interpreted in a manner given below

Langelier saturation index (LSI)

Calculated values of Langelier saturation index (LSI) varied from 0.80 to 2.37 with an overall average of 1.52 for all the samples analyzed in four major seasons in year 2006; from 1.31 to 2.42 with an overall average of 1.95 for all the samples analyzed in four major seasons in year 2007; from 1.02 to 2.40 with an overall average of 1.75 for all the samples analyzed in four major seasons in years 2008 and the average values of three successive years varied from 1.19 to 2.40 with an overall average of 1.72. Use of groundwater without any treatment may result in such manner; in 2006 only one sample have slight scale formation tendency, four samples have moderate scale formation tendency and remaining nineteen samples have mild scale formation tendency.

Table 1. Sampling locations and codings of groundwater samples collected at outer skirts of Kota City

S.No.	Location	Code
1	Gangaycha	GWS/N/1
2	Notana	GWS/N/2
3	Rangpur	GWS/N/3
4	Bhim Mandi	GWS/N/4
5	Gamach	GWS/N/5
6	Tirath	GWS/N/6
7	Raipura	GWS/E/1
8	Borkhandi	GWS/E/2
9	Dhakar Kheri	GWS/E/3
10	Tather	GWS/E/4
11	Manpura	GWS/E/5
12	Kaithoon	GWS/E/6
13	Ranpur	GWS/S/1
14	Jagpura	GWS/S/2
15	Alaniya	GWS/S/3
16	Shankarpura	GWS/S/4
17	Dad Devi	GWS/S/5
18	Naya-Gaon	GWS/S/6
19	Nanta	GWS/W/1
20	Ganeshpal	GWS/W/2
21	Badgaon	GWS/W/3
22	Kunhadi	GWS/W/4
23	Balita	GWS/W/5
24	Sinta	GWS/W/6

Table 2. Water quality, physicochemical study of groundwater samples (Given values are average of the respective year)

S.No.	Sample Code	Year 2006				Year 2007				Year 2008				Average of three years			
		pH	TDS	TA	CaH	pH	TDS	TA	CaH	pH	TDS	TA	CaH	pH	TDS	TA	CaH
1	GWS/N/1	7.60	674	314	159	8.03	468	240	87	7.85	479	225	100	7.83	540.2	259.4	115.0
2	GWS/N/2	7.78	1285	456	147	8.25	967	335	112	8.05	855	322	120	8.03	1035.8	370.5	126.4
3	GWS/N/3	7.63	964	549	156	8.20	866	403	116	7.80	1078	491	84	7.88	969.4	481.1	118.5
4	GWS/N/4	7.90	674	307	132	7.95	223	140	63	7.95	444	193	86	7.93	447.0	213.3	93.5
5	GWS/N/5	8.13	687	304	26	8.03	691	303	49	8.13	891	462	36	8.09	756.5	356.0	36.5
6	GWS/N/6	7.95	294	164	75	7.98	300	156	71	7.95	344	166	82	7.96	312.5	162.1	75.5
7	GWS/E/1	7.83	610	252	84	8.23	529	238	119	8.05	539	242	101	8.03	559.1	243.8	101.1
8	GWS/E/2	7.88	854	438	115	7.90	828	439	118	7.75	1017	359	195	7.84	899.9	411.6	142.8
9	GWS/E/3	7.88	740	336	104	8.05	556	320	74	7.98	493	257	86	7.97	596.4	304.2	87.9
10	GWS/E/4	7.78	736	286	136	8.40	723	257	82	8.30	713	287	86	8.16	724.0	276.7	101.1
11	GWS/E/5	7.95	833	331	120	7.98	732	308	115	8.13	978	395	124	8.02	847.9	344.7	119.3
12	GWS/E/6	7.93	603	330	152	7.98	619	216	74	7.88	496	233	84	7.93	572.8	259.7	102.9
13	GWS/S/1	7.45	473	251	153	7.90	359	153	67	7.70	443	168	93	7.68	424.7	190.6	104.3
14	GWS/S/2	7.73	586	223	130	8.03	295	132	76	7.43	477	192	169	7.73	452.6	182.3	124.8
15	GWS/S/3	8.10	529	230	125	7.93	400	165	61	7.78	400	172	63	7.93	443.1	188.8	82.9
16	GWS/S/4	8.00	764	375	228	8.05	354	161	56	7.95	411	176	64	8.00	509.8	237.0	115.5
17	GWS/S/5	7.63	509	227	146	7.83	564	209	168	7.70	540	218	139	7.72	537.6	217.8	150.6
18	GWS/S/6	7.73	526	227	144	7.95	392	198	123	7.80	397	242	99	7.83	438.4	222.3	121.8
19	GWS/W/1	8.28	524	189	116	8.00	307	138	88	8.00	320	142	89	8.09	383.8	156.4	97.4
20	GWS/W/2	7.85	551	221	116	8.08	528	232	56	8.03	504	229	56	7.98	527.4	227.3	75.6
21	GWS/W/3	7.70	454	230	88	7.90	397	166	73	7.90	372	160	71	7.83	407.4	185.3	77.5
22	GWS/W/4	7.95	509	340	82	8.25	624	281	42	8.08	523	266	43	8.09	551.8	295.5	55.7
23	GWS/W/5	7.98	300	147	40	8.10	335	151	46	8.10	360	166	44	8.06	331.4	154.5	43.0
24	GWS/W/6	7.90	627	304	39	7.98	551	324	56	7.70	666	386	57	7.86	614.8	337.7	50.3

TDS: Total Dissolved Solids, TA: Total Alkalinity, CaH: Calcium Hardness TDS, TA and CaH are in mg/L

Table 3. Calculated Indices of groundwater samples collected from outer skirts of Kota City (Indices are calculated from average values of the respective year)

S.No.	Sample code	Name of sampling location	Year 2006		Year 2007		Year 2008		Overall average	
			LSI	RSI	LSI	RSI	LSI	RSI	LSI	RSI
1	GWS/N/1	Gangaycha	1.03	5.53	1.85	4.32	1.64	4.57	1.49	4.85
2	GWS/N/2	Notana	1.05	5.68	1.79	4.67	1.58	4.89	1.46	5.10
3	GWS/N/3	Rangpur	0.80	6.02	1.65	4.90	1.30	5.21	1.23	5.41
4	GWS/N/4	Bhim Mandi	1.42	5.05	2.18	3.59	1.88	4.20	1.78	4.37
5	GWS/N/5	Gamach	2.36	3.40	1.99	4.05	2.03	4.07	2.10	3.89
6	GWS/N/6	Tirath	2.03	3.90	2.10	3.78	1.98	4.00	2.03	3.89
7	GWS/E/1	Raipura	1.63	4.56	1.91	4.40	1.80	4.45	1.78	4.48
8	GWS/E/2	Borkhandi	1.29	5.29	1.31	5.29	1.02	5.72	1.19	5.46
9	GWS/E/3	Dhakar Kheri	1.46	4.96	1.81	4.43	1.78	4.42	1.67	4.62
10	GWS/E/4	Tather	1.31	5.15	2.20	3.99	2.04	4.23	1.84	4.48
11	GWS/E/5	Manpura	1.47	5.01	1.55	4.87	1.55	5.03	1.52	4.97
12	GWS/E/6	Kaithoon	1.36	5.21	1.91	4.16	1.73	4.42	1.63	4.66
13	GWS/S/1	Ranpur	1.01	5.43	2.04	3.81	1.66	4.39	1.53	4.62
14	GWS/S/2	Jagpura	1.40	4.93	2.19	3.65	1.06	5.31	1.51	4.70
15	GWS/S/3	Alaniya	1.78	4.53	2.07	3.78	1.89	3.99	1.89	4.16
16	GWS/S/4	Shankarpura	1.19	5.61	2.26	3.54	2.05	3.85	1.70	4.59
17	GWS/S/5	Dad Devi	1.25	5.13	1.42	4.99	1.36	4.98	1.34	5.04
18	GWS/S/6	Naya-Gaon	1.35	5.02	1.72	4.52	1.57	4.65	1.54	4.75
19	GWS/W/1	Nanta	2.08	4.12	2.08	3.84	2.06	3.88	2.06	3.97
20	GWS/W/2	Ganeshpal	1.58	4.69	2.10	3.87	2.06	3.90	1.89	4.21
21	GWS/W/3	Badgaon	1.54	4.62	1.97	3.97	2.00	3.90	1.83	4.18
22	GWS/W/4	Kunhadi	1.65	4.66	2.31	3.63	2.16	3.76	2.01	4.07
23	GWS/W/5	Balita	2.37	3.23	2.42	3.26	2.40	3.30	2.40	3.27
24	GWS/W/6	Sinta	1.96	3.98	1.86	4.26	1.49	4.72	1.76	4.34

Table 4. Interpretation of lengelier saturation index (LSI) test results

S.No.	Index	Appearance	Water condition Quality Issues
1	-4.00	Very Severe Corrosion	Conditioning required
2	-3.00	Severe Corrosion	Conditioning usually recommended
3	-2.00	Moderate Corrosion	Some conditioning is recommended
4	-1.00	Mild Corrosion	Need some conditioning
5	-0.50	Slight Corrosion	Should not / may need some conditioning
6	0.00	Balanced	Conditioning usually not recommended
7	0.50	Faint Scale Coating	Conditioning usually not recommended
8	1.00	Slight Scale / Encrustation	Some visual appearance concerns
9	2.00	Mild Scale / Encrustation	Should consider some conditioning
10	3.00	Moderate Scale / Encrustation	Should use some conditioning
11	4.00	Severe Scale / Encrustation	Conditioning usually required

Table 5. Interpretation of Ryzner saturation index (RSI) test results

S.No.	Saturation Index	Appearance / Description	Water condition comments
1	4.0 - 5.0 (Below 4.0)	Heavy Scaling	Non-Aggressive, Non-Corrosive
2	5.0 - 6.0	Moderate Scaling	Non-Aggressive, Non-Corrosive
3	6.0 - 7.0	Little Scaling	Slight Corrosion, Balanced Saturation
4	7.0 - 7.5	Non-Scaling, Corrosive	Aggressive, Under Saturation
5	7.5 - 9.0	Heavy Corrosive	Very Aggressive, Moderate Corrosive
6	9.0 and Above	Severe Corrosion	Extremely Aggressive, Highly Corrosive

In year 2007 groundwater quality change little bit and the analyzed samples exhibited the property as eleven samples have moderate scale formation tendency and remaining thirteen samples have mild scale formation tendency. In year 2008 eight samples have moderate scale formation tendency and remaining sixteen samples have mild scale formation tendency. The average of calculated LSI values for analyzed groundwater samples in successive three years interpreted in the way that five values were greater than 2.0 showing the moderate scale formation tendency and remaining nineteen values were in between 1.0 to 2.0 showing mild scale formation tendency.

Ryzner saturation index (RSI)

Calculated values of Ryzner index (RSI) varied from 3.23 to 6.02 with an overall average of 4.82 for all the samples analyzed in four major seasons in year 2006; from 3.26 to 5.29 with an overall average of 4.15 for all the samples analyzed in four major seasons in year 2007; from 3.30 to 5.72 with an overall average of 4.41 for all the samples analyzed in four major seasons in years 2008 and the average values of three successive years varied from 3.27 to 5.46 with an overall average of 4.50. Use of groundwater without any treatment may result in such manner; in 2006 only one sample have little scale formation tendency, eleven samples have moderate scale formation tendency and remaining twelve samples have heavy scale formation tendency. In 2007 only one sample have moderate scale formation tendency and remaining twenty three samples have heavy scale formation tendency. In 2008 four samples have moderate scale formation tendency and remaining twenty samples have heavy scale formation tendency. The average of calculated RSI values for analyzed groundwater samples in successive three years interpreted in the way that four values were less than 5.0 showing the heavy scale formation tendency and remaining four values were in between 5.0 to 6.0 showing moderate scale formation tendency.

Conclusion

From the present study of groundwater, it can be concluded that the groundwater of outer skirts of Kota city are having scaling tendency in comparison to corrosion tendency, hence the water required some conditioning before use. The use of groundwater without treatment may results in precipitation of calcium carbonate as it is visually seen in bottom of utensils used by residents of the area. Rapid urbanization and indiscriminate disposal of solid waste¹⁰ and domestic effluents¹¹ causes depletion in quality of nearby surface water bodies¹² and alter the physicochemical properties of water¹³⁻¹⁵. Percolation of such polluted water in groundwater table results in changing the behavior of water towards its scale formation and corrosivity. Hence to prevent the pristine quality¹⁶ of groundwater at outer skirts of Kota city, pollution control measures should be taken immediately.

References

1. Aiman E Ai-Rawajfeh and Ehab M. Al-Shamaileh, *Desalination*, 2007, **206**, 322 - 332.
2. Snoneyink V L and Jenkins D W, *Water Chemistry*, John Wiley and Sons, New York, 1980.
3. Wranglen G, *Introduction to Corrosion and Protection of Metals*, London, UK, Chapman and Hall, 1985, 236-238.
4. Loewenthal R E, Morrison I and Wentzel M C, Control of corrosion and aggression in Drinking Water Systems. The 1st IWA Conference on: Scaling and Corrosion in Water and Wastewater Systems, Cranfield University, UK, 25 – 27, March 2003.
5. Madhavi A and Prasad Rao A, *J Environ Biol.*, 2003, **24(2)**, 187-192.
6. APHA, AWWA, WPCF, *Standard Methods for Examination of Water and wastewater*, Washington, D.C. 2005, U.S.A., 19th Edn., 1995.
7. Langelier W F, *J AWWA*, 1936, **28**, 1500-1521.
8. Kemmer, Ed, *The NALCO Water Handbook*, McGraw-Hill, New York, 1979, 4-13.
9. Ryzner John W, *J AWWA*, 1944, **36(3)**, 472 - 481.
10. Gopalasamy V, Damodharan V and Kanakasabai V, *Polln Res.*, 2002, **21(3)**, 285-291.
11. Reddy R C, Kelkar P S, Rao R R and Pande S P, Eutrophic Status of Hussainsagar Lake in Hyderabad. *J Inst Engrs India* (Environ Engng Div), (Sept), 2002, **83**, 14-19.
12. Chandrasekhar J S, Lenin Babu K and Somasekhar R K, *J Environ Bio*, 2003, **24(3)**, 223-227.
13. Chatterjee Pinaki Ranjan and Raziuddin M, *Nature Env Polln Technol.*, 2003, **2(2)**, 171-172.
14. Pejaver Madhuri, Somani Vaishali and Borker Mangala, *J Ecobiol.*, 2002, **14(4)**, 277-281.
15. Maya S, *Nature Env Polln Technol.*, 2003, **2(3)**, 289-294.
16. Report of the Third World Academy of Science; Safe Drinking Water: the Need, the problem, Solution and Action Plan, High-Level Conference on Science and Technology, Dubai, 27 - 30 October, 2002.