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Assessment of Physicochemical Properties of Groundwater Sources from Some Selected Areas in Sokoto Metropolis, Nigeria

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Abstract:
The study investigates total of eight groundwater samples, two of the samples A and B are bicentenary dug wells, while others C, D, E, F, G and H are boreholes of between two to ten years old, all located in Sokoto metropolis. After the digestion of the samples with nitric acid, four heavy metals (Cd, Cu, Cr and Pb) were analyzed using Atomic Absorption Spectrometer (AAS). The results from the AAS revealed that 87.5%, 25%, 75% and 87.5% of the samples contained higher levels of Cd, Cu, Cr and Pb respectively than the prescribed limits set by WHO. The results also indicated that the TDS, TSS, Cl^-, NO_3^- and pH of all the samples were within the allowable permissible concentrations and pH range respectively set by WHO. About 62.5% of the samples contained DO slightly below the acceptable limits set by WHO, while 12.5% of the samples recorded BOD_5 values above the WHO permissible levels and the CO_3^- concentrations in all the samples were below the detection limits.

Keywords: *Physico-chemical properties, heavy metals, groundwater, Sokoto*

1. Introduction

Groundwater is indispensable vital natural resources that are found available in rocks and soil under the earth surface, this groundwater usually concentrates underground in sinkhole. It was estimated that about 97% of world freshwater that is potentially available for human use constitutes groundwater and it is an important source of drinking water in various places around the world. The sources of groundwater in most of the nations are found to be the largest water supplier for domestic and drinking purposes in many parts of the world, especially in areas without polluted free sources of surface water. In many localities around the world it may be the most economical water source and it is based on the fact that groundwater is usually considered to be of higher quality as well as relatively free from microorganism than surface water (World Health Organization, 2006).

However, this precious natural resources is vulnerable to many water pollutants such as heavy metal (As, Cd, Cr, Cu, Fe and Mn) contamination due to the geological location of the area as well as anthropogenic activity such as farming and industrial activity (Ackah et al. (2011); Chindo et al. (2013); Elangovan and Kumar (2013)). The higher nitrate and phosphate contents were found in the groundwater in India, Korea and Nigeria (Dahiya et al. (2007); Kangjoo et al. (2005)) and Aturamu (2012); Chukwu (2008) respectively. The higher concentration of fluoride and chloride in the groundwater in some places were equally noticed Arya et al. (2012) and Sayyed and Bhosle (2011) respectively. The agricultural activities and petroleum sector contributed heavily in the contamination of the groundwater with organochlorine pesticides, total petroleum hydrocarbons (TPH), total herbicides, polyaromatic hydrocarbons, volatile organic compounds (VOCS) and diesel hydrocarbon fraction (C_{10}-C_{40}) (Alshikh, 2011).

Therefore, this paper assessed the physico-chemical parameters (pH, DO, BOD_5, TDS, TSS, Cl^-, NO_3^-, CO_3^{2-}, Cd, Cu, Cr and Pb) of both bicentenary dug wells and boreholes of between two to ten years old, thereby finding whether are safe and fit for human consumption and food processing or otherwise.

2. Materials and Methods

Sokoto State located to the extreme northwestern part of Nigeria and lies between the longitudes and latitudes of 4^{0}8'E and 6^{0}54'E and12^{0}N and 13^{0}58'N respectively. It shares common boarders with Zamfara State to the east, Bebbi State to the southwest as well as Niger republic to the north. This State covered total land area of about 25,973 square kilometre and recorded population in 2005 (projected from the 2005 census) of about 4,244, 399 (census, 2005). The areas investigated are densely populated with people and economic activities are at increase. The sampling sites were code named A, B, C, D, E, F, G and H.

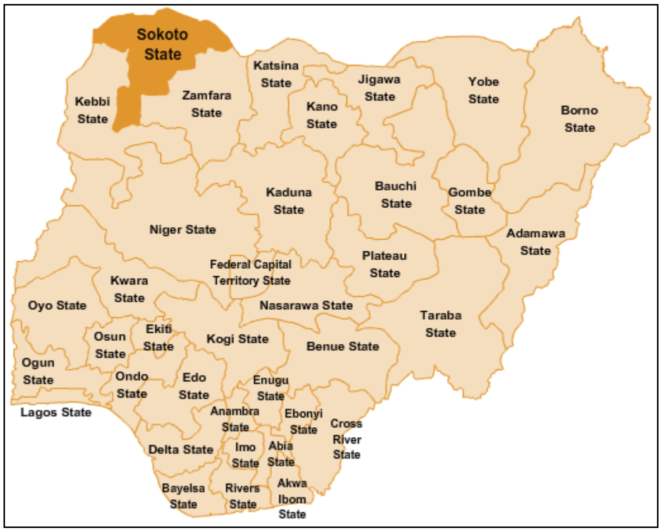

Figure 1: Map of Nigeria

2.1. Collection of Samples

Total of eight groundwater samples at different locations were randomly selected within Sokoto metropolis. The water samples were collected from these sources in August, 2014 between 7:00 am to 9:00 am local time in clean sterile 3.0 liter bottles. The water samples labeled A to H as follows:

Sample	Area	Source of water	Coordinates
A	Yarmarina area (Shehu Usmanu Danfodio's well)	Dug well	5^{0}14'38.22E, 13^{0}06'38.24 N
B	Yarmarina area (Shehu Usmanu Danfodio's well)	Dug well	5^{0}14'38.21 E, 13^{0}05'39.23 N
C	Sokoto State University, hostel area	Borehole	5^{0}12.41'E, 12^{0}54.95' N
D	Sokoto State University, staff quarters	Borehole	5^{0}12.41'E, 12^{0}54.95' N
E	Madorawa village	Borehole	5^{0}12.41'E, 12^{0}54.95' N
F	Hajiya Halima area	Borehole	5^{0}13'24' E, 13^{0}3'38" N
G	Diplomat area	Borehole	5^{0}24' E, 13^{0}39' N
H	Mabera area	Borehole	5^{0}26' E, 13^{0}31' N

Table 1: Description of the sampling areas

2.2. Sampling of Dug Well Water

A local well digger was used in this sampling; he entered the well, then a plastic bucket containing the sample bottles was lowered down to the well, he immersed each sample bottle to arm's length (about 15 cm) below the surface of the water and then removed the caps and then covered while below the water surface when the water filled the bottles and was pulled out of the wells.

2.3. Sampling of Borehole water

This was done by opening the borehole tap fully and the water was allowed to run to waste for 5 minutes, then the flow rate of the water was reduced significantly and then each of the clean sample bottle was filled and then covered.

All the samples collected were taken to the Laboratory at Usmanu Danfodiyo University, Sokoto within 3-4 hours for various analyses. The sample bottles were shaken vigorously for at least 25 times to obtain homogeneous water sample before any analysis.

2.4. Sample Treatment

The water samples were digested with nitric acid and filtered with Whatman No. 3 filter paper with pore size of 20 μm before taken to Atomic Absorption Spectrometer (AAS) for heavy metal analysis. Reagents of analytical grades were used throughout the analysis.

2.5. Heavy metals investigation

Four heavy metals (Cd, Cu, Cr and Pb) were investigated using Atomic Absorption Spectrometer (AAS) model 210 VGP as described by Christian, (2004).

2.6. Physicochemical

Parameters such as pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chloride (Cl^-), Nitrate (NO_3^-) and Carbonate (CO_3^{2-}) were investigated using standard methods.

2.7. pH

The pH of the water sample was measured using pH meter. The calibrated pH electrode was washed with distilled water, dried with filter paper and then inserted into the beaker containing the water sample in the laboratory and the pH value was recorded.

2.8. Dissolved Oxygen

200ml of the sample was transferred into a conical flask, 1ml of $KMnO_4$ solution was added to the bottom of the flask and 1ml of alkali iodide-azide solution was added in the same way as $KMnO_4$ solution, the flask was stoppered and shaken very well. Conc. H_3PO_4 and water were added thereafter. The released iodine was titrated with 0.025M thiosulphate. The measurement was done in triplicate

2.9. Biochemical Oxygen Demand

200ml screw-stopped incubator bottles were filled with the samples which were seated and incubated in the dark for 5 days at 20 ^{O}C. The DO levels of the samples were determined as in the DO determination above before and after the incubation. The BOD is then the difference between the two DO levels.

2.10. Total Dissolved Solids

This was measured using TDS can meter, this meter was adjusted using a standardizing solution. Thereafter, the meter electrode was washed with distilled water and then inserted into beaker containing the sample and the TDS reading was then taken. The measurement was done in triplicate.

2.11. Total Suspended Solids

This was done by using Whatman No. 41 filter paper of pore size 20 μm which was dried at 105 ^{O}C for 20 minutes. This filter paper was weighed and fitted into funnel. 50ml of the water sample was filtered and then the filter paper was dried again at 105^{O}C for 20 minute and cool in a desiccator and then re-weighed. The TSS was calculated the following equation.

$$\text{TSS (mg/l)} = \frac{W_s \times 10^6}{Vi}$$

W_s=Mass of the dried filter paper after filtration-Mass of the dried filter paper before filtration

Vi = Volume of the sample filtered

2.12. Chloride, nitrate and carbonate

All the groundwater samples were filtered through a 0.45-μm membrane filter and then Cl^-, NO_3^- and CO_3^{2-} ions were analyzed with ion chromatograph fitted with a conductivity detector.

3. Results and Discussion

3.1. Heavy Metals

Results obtained for the heavy metals analyzed are shown in table 1. The results indicated that about 87.5 % that is seven of the samples contained cadmium above the maximum permissible limit of 0.003 mg/l set by both National Industrial Standard (2007) and World Health Organization (2008). This might not be unconnected with the geological location of the area (Davison and Fischer, 2005). According to World Health Organization (2008) cadmium are found to accumulates mostly in human kidneys and also, found to have half-life between 10-35 years. United Nations Environmental Program (2010) reported that the main critical issues with cadmium accumulation in the kidneys are proximal tubular cell damage which resulted into an increased excretion of proteins in urine as well as skeletal damage. Also, the results revealed that 75% of the samples contained chromium well above the maximum permissible limit of 0.05 mg/l set by both National Industrial Standard (2007) and World Health Organization (2008). The high chromium contents in these ground waters could be due to the location of the water sources as reported by State Water Resources Control Board (2014) as well as leaching from the boreholes pipes. The World Health Organization, (2003) reveals that based on epidemiological studies there was a relationship between mortality due to the lung cancer and an occupational exposure to chromium (vi).

The results also, showed that 25% of the samples contained concentration of copper above the maximum permissible limit of 1.0 mg/l set by both National Industrial Standard (2007) and World Health Organization (2008) and this might be attributed to the location of the boreholes as reported by State Water Resources Control Board (2014) and could also be connected to the chemical composition of the pipes. According to California Environmental Protection Agency (2008) "Drinking water containing higher concentration of copper are related to the vomiting, headache, dizziness, diarrhea, epigastric pain, tachycardia, liver and kidney failure and death have resulted from copper toxicity World Health Organization (1998)". More so, the results exposed that 87.5% of the samples contained very significant concentrations of lead which were above the maximum permissible limit of 0.01 mg/l set by National Industrial Standard (2007) and World Health Organization (2008). These significant high concentrations of lead in these samples could possibly be attributed to many factors ranging from primarily the plumbing systems, service supply connections to home might contain trace amount of lead and to dissolution from natural sources as documented by World Health Organization (2011). According to the United State Department of Health and Human Services (2012) lead and lead compounds are reasonably anticipated to be human carcinogens.

3.2. Physicochemical parameters

Results for the physicochemical parameters are given in table 2. The results show that all the samples examined contained TDS, TSS, pH, Cl^- and NO_3^- within the acceptable limits of 500 mg/l, 10 mg/l, (6.5-8.5), 250 mg/l and 10 mg/l respectively set by both National Industrial Standard (SON, 2007) and World Health Organization (2008). This might be in connection with the nature of dug wells and boreholes investigated. However, it was reported that drinking water with high values of TDS is generally not harmful to human beings but high concentration of TDS may affect people suffering from kidney and heart related diseases (Geetha et al., 2008). Also, high contents of dissolve solids affect the density of water and reduce solubility of gases like oxygen, thereby decreasing the utility of drinking water (Maits, 2012). Also, irritation of the eye may result due to very low or high pH values, mucous membranes as well as the skin, equally it was reported that for the sensitive individuals, gastrointestinal irritation may also occur (World Health Organization, 2003). More so, toxicity due to chlorine in human has not been reported except in a case of metabolisms of the impaired sodium chloride metabolism and was documented that healthy individuals have ability of tolerating chloride intake in large quantities, if there is simultaneous intake of water World Health Organization (2006). Also, Drinking water containing nitrite (NO_2^-) in higher concentration was found to be carcinogenic in animals, and United State Environmental Protection Agency reported that the data available is not sufficient in justifying whether human exposure to nitrite and nitrate can cause cancer (Environmental and Occupational Health Services, 1997). In the same line nitrate (NO_3^-) in drinking water with a concentration above the maximum permissible level was reported to cause methenoglobinemia commonly called blue baby syndrome, a condition that effect children below the age of six month. This is due to the fact that the acid in the stomach of the children under six months is strong as for the older ones. Therefore, causing high conversion of nitrate to nitrite due to availability of the bacteria that can readily do the work (Self and Waskom, 2013). The results show that 62.5% of the samples contained DO slightly below the permissible limit of 7.0 mg/l set by National Industrial Standard (SON, 2007) and World Health Organization (2008). Also, 12.5% of the samples that is only one sample contained BOD_5 slightly above allowable level of 5 mg/l set by the National Industrial Standard (SON, 2007) and World Health Organization (2008). It was reported that water with lower values of dissolved oxygen imparts no good taste to water and also, drinking water with BOD_5 above the maximum prescribed limits are mainly due to microbial activities related to the dumps around the water sources (World Health Organization, 2004). The results also, revealed that all the samples contained CO_3^{2-} below the detection limit.

Sample	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Pb (mg/l)
A	**0.191** ± 0.02	**0.129** ± 0.02	**0.051** ± 0.01	**2.274** ± 0.01
B	**0.016** ± 0.01	**0.074** ± 0.01	**0.033** ± 0.03	**2.260** ± 0.03
C	**0.053** ± 0.02	ND	ND	ND
D	**0.024** ± 0.01	ND	**1.518** ± 0.02	**4.564** ± 0.03
E	**0.065** ± 0.03	**0.828** ± 0.04	**1.390** ± 0.03	**9.492** ± 0.02
F	**0.590** ± 0.02	**10.322** ± 0.02	ND	**4.1114** ± 0.01
G	**0.885** ± 0.01	**5.747** ± 0.01	ND	**1.899** ± 0.02
H	ND	**5.372** ± 0.03	ND	**6.692** ± 0.02
SON & WHO Std.	0.003	0.005	1.0	0.01

Table 2: Heavy metals concentrations of groundwater from different areas

Values are expressed as (mean ± SD) of triplet measurements; ND = Not detected

Sample	pH	TDS (mg/l)	TSS (mg/l)	DO (mg/l)	BOD (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	CO_3^{2-} (mg/l)
A	6.7 ± 0.01	125.2 ± 0.01	7.2 ± 0.03	6.9 ± 0.01	2.2 ± 0.02	8.1 ± 0.01	4.6 ± 0.03	ND
B	6.7 ± 0.01	117.1 ± 0.01	9.3 ± 0.03	6.1 ± 0.01	5.2 ± 0.03	5.8 ± 0.03	7.2 ± 0.02	ND
C	7.0 ± 0.03	52.5 ± 0.01	2.2 ± 0.01	7.1 ± 0.02	2.5 ± 0.01	1.5 ± 0.03	1.2 ± 0.03	ND
D	7.1 ± 0.01	41.2 ± 0.01	1.1 ± 0.01	6.9 ± 0.01	3.8 ± 0.02	0.7 ± 0.01	0.8 ± 0.03	ND
E	7.0 ± 0.01	30.3 ± 0.01	1.4 ± 0.02	7.2 ± 0.03	1.9 ± 0.01	0.8 ± 0.02	1.2 ± 0.01	ND
F	6.5 ± 0.02	33.5 ± 0.01	2.2 ± 0.02	7.1 ± 0.01	2.3 ± 0.01	10.8 ± 0.01	1.8 ± 0.02	ND
G	6.5 ± 0.03	44.7 ± 0.01	1.3 ± 0.01	6.9 ± 0.02	2.2 ± 0.03	0.6 ± 0.03	0.8 ± 0.01	ND
H	7.2 ± 0.02	53.4 ± 0.01	1.4 ± 0.03	7.1 ± 0.01	2.1 ± 0.01	2.1 ± 0.01	1.0 ± 0.01	ND
NIS&WHO	6.5-8.5	500	10	7.0	5	250	10	-

Table 3: Physicochemical properties of the groundwater from different areas

Values are expressed as (mean ± SD) of triplet measurements; **TDS**= Total Dissolved Solids; **TSS**= Total Suspended Solids; **DO**= Dissolved Oxygen; **BOD**= Biochemical Oxygen Demand.

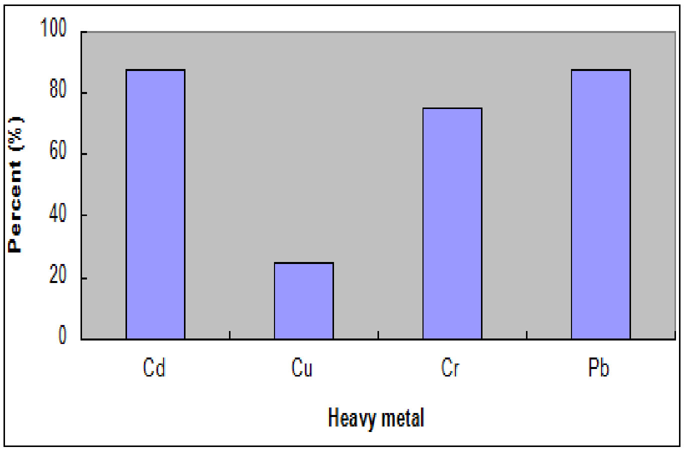

Figure 2: Percentage of the samples having heavy metals greater than maximum prescribed limits of WHO and NIS.

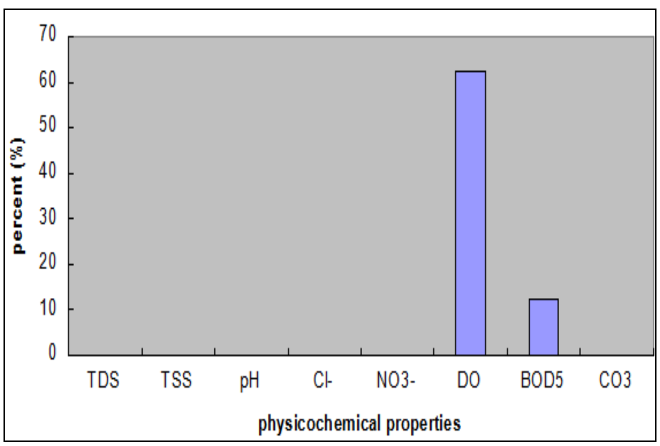

Figure 3: percentage of the samples having physicochemical properties greater than the maximum permissible limits of WHO and NIS.

4. Conclusion

The results of the analyses have revealed that the groundwater investigated are less polluted in terms of physical parameters, however highly polluted with respect to heavy metals, suggesting that the contamination might be of geological origin. Therefore, in light of this high heavy metal contents as well as high levels of dissolved oxygen and biochemical oxygen demand, this paper deduced that none of the groundwater sources analyzed is fit or healthy for human consumption and food processing. Also, not all the groundwater sources should be taken as a direct source for a portable water, suggesting that there should be a geochemical survey before siting any groundwater source (borehole or hand dug well) as well as taken into consideration the anthropogenic pollution sources that could be close to the siting area.

5. References

i. Ackah, M., Agyemang, O., Anim, A. K., Osei, J., Bentil, O., Kpattah, L., Gyamfi, E. T. and Hanson, J. E. K. (2011). Assessment of groundwater quality for drinking and irrigation: The case study of Teiman-Oyarifa community, Ga East municipality, Ghana. Proceeding of International Academy of ecology and Environmental Sciences, vol. 1(3-4), 186-194.
ii. Alshikh, A. (2011). Analysis of Heavy Metals and Organic pollutants of Groundwater samples of south Saudi. Life Science Journal, vol. 8(4), 438-441.
iii. Arya, S., Kumar, V. and Sharma, S. (2012). Analysis of Water Quality Parameters of Groundwater in and around Diamond Cement Industry, Jhansi, central India. International Journal of Current Research, vol. 4(03), 75-77.
iv. Aturamu, A. O. (2012). Physical, Chemical and Bacterial Analyses of Groundwater in Ikere Township, southwestern Nigeria. International Journal of Science and Technology, vol. 2 (5), 301-308.
v. Califonia Environmental Protection Agency (2008). Puplic Health Goals for Copper in Drinking Water, 22. Retrieved on 28/04/2015 from www.epa.gov/waterscience/criteria/copper/draftupdatefs.htm.
vi. Census (2005). Nigeria Census 2005 figures. Retrieved on 28/04/2015 from http://www.africamasterweb.com
vii. Chindo, I. Y., Elisha, K., Ishaku, Z. and Ephrain, D. A. (2013). Physicochemical Analysis of Groundwater of selected Areas of Dass and Ganjuwa Local Government Areas, Bauchi state, Nigeria. World Journal of Analytical Chemistry, vol. 1(14), 73-79.
viii. Christian, G. D. (2004). Analytical Chemistry, 6th edition. John Wiley & Son Inc, Washington. Retrieved on 29/04/2015 from www.wileyonlinelibrary.com.
ix. Chukwu, O. (2008). Analysis of Groundwater Pollution from Abattoir waste in Minna, Nigeria. Research Journal of Dairy Science, vol. 2(4), 74-77.
x. Davison, B. and Fischer, R. S. (2005). Groundwater Quality in Kentucky. Cadmium, information circular 9, series 11, 1-2. Retrieved 29/04/2015 from www.uky.edu/kgs/water/gnet/gnet.htm.
xi. Dhiya, S., Singh B., Gaur, S., Garg, V. K. and Kushwaha, H. S. (2007). Analysis of Groundwater Quality using fuzzy synthetic evaluation. Journal of Hazardous material, vol. 147, 938-946.
xii. Elongovan, N. S. and Kumar, Dharmendra, M. (2013). Assessment of Groundwater Quality along the Cooutum river, Chennai, Tamil Nadu, India. Journal of Chemistry vol. 2013, 10.
xiii. Environmental and Occupational Health Services (1997). Facts on Nitrate and Nitrite in Drinking Water. Trenton New Jersey, 6.
xiv. Retrieved 29/04/2015 from www.state.ng.us/health/eoh/hhazweb/nitrate.pdf.
xv. Geetha, A., Palanisamu, P. N., Sivancumar, P., Ganaesh, Kumar, P. and Sujatha, M. (2008). Assessment of Underground Water
xvi. Contamination and Effects of Textile Effluents on Noyyal River Basin In and Around Tiruppur Town, Tamilnadu. E-Journal of Chemistry, 5(4), 696-705.
xvii. Kangjoo, K., Natarajan, R., Hyun-Jung K., Seok-Hwi, K., Gab-Soo, H., Seong, T. Y., Baohua, G., Min, J. C. and Sang-Ho, L. (2005). Evaluation of Geochemical Processes Affecting the Groundwater Chemistry based on mass balance approach: A case study in Namwon, korea. Geochemical Journal, vol. 39, 3557-369.
xviii. Maiti, S. K. (2004). Handbook of Methods in Environmental studies, Water and Waste Water Analysis.Vol. 1, ABD Publishers Jaipur. Retrieved on 29/04/2015 from www.ismdhanbad.ac.in/cv/cv-skmaiti.pdf.
xix. Nigerian Industrial Standard (2007). Nigerian Standard for Drinking Water Quality. Standard Organization of Nigeria, Lagos, 15-16. Retrieved on 23/04/2015 from http://www.ng-puplications-nigerian-standards-for-drinking-water-quality.pdf.
xx. Sadiq, I. S. and Malami, S. (2009). Comparative study of the effects of tannery effluents on two major streams in Sokoto State, Nigeria. Nigerian Journal of Basic and Applied Sciences, 17(1), 48-52.
xxi. Sayyed, J. A. and Bhosle, A. B. (2011). Analysis of Chloride, Sodium and Potassium in Groundwater samples of Nanded city in Mahabharata, India. European Journal of Experimental Biology, vol. 1(1), 74-82.
xxii. Self, J. R. and Waskom, R. M. (2013). Nitrate in Drinking water. Facts and Sheet No. 0.517; Crop series/soil Colorado State University, 1. Retrieved on 28/04/2015 from www.ext.colostate.edu.
xxiii. State Water Resources Control Board (2014). Hexavalent Chromium. Ground Water Information Sheet, Division of Water Quality, GAMA program, 3. Retrieved on 27/04/2015 from http://www.waterboards.ca.gov/water_issues/progrms/gama/doc/coc_hexchromcr6.pdf.
xxiv. United Nations Environmental Program (2010). Final Review of Scientific Information on Cadmium. Version of December, 6-7. Retrieved on 28/04/2015 from http://www.unep.org/hazardoussubstances/cadmium
xxv. United State Department of Health and Human services (2012). Lead in Drinking Water and Human blood lead levels in the United State: Morbidity and mortality, weekly report. Supplement, vol. 61, August 10, 4. Retrieved on 28/04/2015 from www.cdc.gov/mmwr/pdf/other/su6104.pdf.
xxvi. World Health Organization (2003). Chromium in Drinking Water: Background development of WHO Guidelines for Drinking-water Quality. WHO/SDE/WSH/03.04/04. Retrieved on 28/04/2015 from

www.who.int/water_sanitation_health/dwq/chemicals/chromium.pdf.

xxvii. World Health Organization (2003). Guidelines for Drinking Water. Water Quality, 2nd Edition, Vol. 2, Geneva, 1. Retrieved on 28/04/2015 from www.who.int/water_sanitation_health/dwq/gdwq2v1/en/index2.html.

xxviii. World health Organization (2006). Chloride in Drinking Water. Word Health Organization: Guidelines for Drinking Water Quality, 4. Retrieved on 28/04/2015 from www.who.int/water_sanitation_health/dwq/gdwq0506.pdf.

xxix. World Health Organization (2006). Protecting Ground Water for Health. Managing the Quality of Drinking Water Resource. T. J. International (ltd), padstow, cornwall, Uk, 4-6. Retrieved on 28/04/2015 from www.who.int/water_sanitation_health/publications/PGWsection1.pdf.

xxx. World Health Organization (2008). Drinking Water Quality, 3 rd edition incorporating 1st and 2nd addenda, vol. 1. Retrieved on 23rd/04/2015 from http://www.who.int/water-sanitation-health/dwg/fulltext.pdf.

xxxi. World Health Organization (2008). Cadmium in: Guidelines for drinking water-water quality, 3rd edition incorporating 1st and 2nd addenda, vol. 1, 318-319. Retrieved on 23rd/04/2015 from http://www.who.int/water-sanitation-health/dwq/GDW12rev1and2.

xxxii. World Health Organization (2011). Cadmium in Drinking Water. Background document for development of WHO guidelines for Drinking-water Quality: WHO/SDE/WSH/03.04/08, REV/1. Retrieved on 28/04/2015 from http://www.who.int/water_ sanitation_health/publications/2011/9789241548151_annex.pdf.