Greener Journal of Environmental Management and Public Safety

ISSN: 2354-2276

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Research Article

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ABSTRACT

It is believed that the groundwater is a causal factor of several epidemiological diseases characterized people inhabited the southern suburb of Omdurman City since it is their only drinking water supply. In this study, 92 well water analyses were used to assess the quality of drinking groundwater in area of the study, mainly with respect to total dissolved solids (TDS), fluoride (F^-), total hardness (TH) and nitrate (NO_3^-). In addition, electric conductivity (EC), pH and the major cations (Ca^{+2}, Mg^{+2}, Na^+ and K^+) and anions (Cl^- and HCO_3^-) also were investigated. Coliform bacteria, as an indicator of faecal contamination, were tested as well. All of the parameters determined were compared to the local, regional and internationl standards and guidelines.

Results revealed that 27% of the wells having TDS levels in excess of the maximum recommended level of 1000 mg/l set by the Sudanese Standards & Metrology Organization (SSMO, 2002). Total hardness levels indicated that 72% of the samples classified as hard and very hard water. None of the wells studied found to have NO_3^- concentration above the maximum level of 50 mg/l set by SSMO whereas about 13% of the wells found having F^- concentration above the maximum level of 1.5 mg/l recommended by SSMO, indicating that, with the exception of NO_3^-, some wells showed drinking water analyses in excess of the standards set by the SSMO.

Keywords: groundwater quality, well, standards, Omdurman City.

INTRODUCTION

Over the past 50 years, the time in which machine-drilling wells were introduced in Sudan, symptoms of epidemiological diseases associated to the quality of drinking water were observed, e.g. cardiovascular mortality, atherosclerosis, urolithiasis, dental caries, dental fluorosis and kidney's failure. The natural mineral-contents of the drinking water e.g., TDS, TH, F^- and NO_3^- being accused of causing or partially contribute to these diseases. Among which, TH of drinking water has caught the attention of many researchers. According to USGS (2009), hardness in water is defined as the presence of multivalent cations. Revis *et al.* (1980) suggested that epidemiological and clinical incidence of atherosclerosis is higher in soft-water areas than in hard-water areas. However, Revis *et al.* (1981) concluded various studies and linked water softness to ischemic heart disease, hypertension, atherosclerosis, and to stroke. Again, however, it was also reported by Revis *et al.* (1981) that other studies do not confirm these observations to water softness.

Singh *et al.* (1993) documented that F^- in drinking water affects negatively or positively human health and, to far extent, influenced by the ambient temperature, alkalinity, calcium and magnesium contents of drinking water. In addition, it has been well demonstrated that there is a considerable degree of regularity in the antagonism between F^- concentration of drinking water and dental caries incidence. On the other hand, the excessive F^- administration on human is dental fluorosis (Cutress and Suckling, 1990) and skeletal fluorosis. Skeletal fluorosis was previously reported by Whyte *et al.* (2008) who confirmed that it can result from prolonged consumption of well water with more than 4 mg/l F^- in the drinking water. Furthermore, it has been reported that in human body the kidneys are probably the most crucial organ during the course low-dose long-term exposure to F^- (Abdellah, 2012b). Healthy kidneys excrete 50 to 60% of the ingested dose. Kidney malfunction can impede this excretion, thereby causing an increased deposition of F^- into bones and eventually causes skeletal fluorosis. Individuals with kidney disease have decreased ability to excrete F^- in urine and are at risk of developing fluorosis even at normal recommended limit of 0.7 to 1.2

mg/l (Banzal and Tiwari, 2006). Persons with renal failure can have a four-fold of spontaneous bone fractures and akin to skeletal fluorosis even at 1.0 mgF^-/l in drinking water (Ayoub and Gupta, 2006). As well, over ingestion of F^- also affects adult brain, with particular deficits in attention, auditory, retention, and physical dexterity and acuity as well as abnormal emotional states (Guo, 2001). In addition, F^- increases the production of free radicals in the brain through several different biological pathways; these changes have a bearing on the possibility that F^- act to increase the risk of developing Alzheimer's disease, furthermore, exposure to F^- in urine is associated with reduced performance, verbal, and full IQ scores before and after adjusting for confounders. If F^- accumulates in the pineal gland during early childhood, it could affect pineal indole metabolism (Luke, 1997). Recent information on the role of the pineal organ in humans suggest that any agent that affects pineal function could affect human health in a variety of ways, including effects on sexual maturation, calcium metabolism, parathyroid function, post-menopausal osteoporosis, cancer, and psychiatric disease. Moreover, F^- reduces the activity of the thyroid gland even at doses as low as 2 mg/kg, interfered with proper metabolism of cyclic-ATP and thus diminished cellular energy, fluoride disrupts enzyme system and it is progressively disrupts the sensitive G-proteins, these are the building blocks of body's hormone receptor (Abdellah *et al.,* 2012b).

Nitrate in drinking water is another hazardous warning contaminant, and has been frequently implicated in epidemiological studies concerning methaemoglobinaemia and cancer diseases. Cases of methaemoglobinaemia usually occur in rural areas, or in areas that rely on wells as primary source of drinking water. Methaemoglobinaemia was reported by WHO (1993) and Grignon (1997) that most often affects infants of less than six months of age when they consume drinking water containing more than 50 ppm. Infantile methaemoglobinaemia occurs when bacteria, either from soil or in the immature infant gut, converts NO_3^- to NO_2^-. Nitrite easily combines with foetal haemoglobin to form methaemoglobin, which cannot carry oxygen around the body (USEPA, 2010). Steps can be taken to prevent the child from becoming a victim of methaemoglobinaemia; residents of rural areas should have their water tested, especially if pregnant women or infants are consuming well water. If the well is contaminated, other alternative safe water sources such as bottled water, deeper well, or a water purification system, capable of removing NO_3^-, may be used for drinking (Jonathan *et al.,* 1987). Previous studies correlated between cancer incidence and groundwater NO_3^- contamination. On contrast, Payne (1993) found that the stomach cancer is highest in areas where groundwater concentration of NO_3^- is lowest and vice versa. Therefore, there is still no concrete evidence to associate NO_3^- contamination to stomach and gastrointestinal cancer (Forman *et al.,* 1985). However, study indicated that even at exposure levels of 111 mg/l, there were no adverse conditions in infants except for methaemoglobinaemia, and therefore, nitrate alone may not be the only cause of elevated regional gastric cancer mortality rates, but these may result from a number of other factors, such as high pesticide levels, presence of coliform bacteria and/or other groundwater contaminants, as reported by Abdellah *et al.* (2012b). Nitrate, nitrite and many nitroso compounds were reported by Tricker *et al.* (1989) to have a carcinogenic effect on urothelial cells. There is a positive association reported by Weyer *et al.* (2001) between the NO_3^- level in drinking water and bladder cancer and ovarian cancer, but an inverse association for uterine cancer and rectal cancer is observed. There is a direct association of the dietary intake of NO_3^- and the incidence of urothelial cancers (renal pelvis, ureter, urinary bladder, and urethra), but no association for prostate cancer, renal tumors or penile tumors has been found by Bjoern *et al.* (2005). However, results of epidemiological studies examining associations between cancer and nitrates in drinking water are inconclusive and are only circumstantial, as stated by USEPA (2010).

It has been reported that standards and guidelines for major cations and anions in drinking water were set on the based on taste considerations rather than the impact on human health (WHO, 1993) and thus higher values can be tolerated. However, excessive concentrations of Na^+ in drinking groundwater can be a health risk factor for those individuals on a low-sodium diet as reported by USGS (2005).

Bacterial contamination of drinking water has a direct and/or indirect effect on human health and the environment (Abdellah, 2012a). In general, Le Chevallier *et al.* (1991) associated the microbial growth in drinking water with rainfall and water temperature greater than 15°C, which is much lower than the average temperature in the study area. On the other hand, Abdel-Magid *et al.* (1984) attributed the absence of microbial contamination from groundwater to the complete protection from human and animal contact.

The continuous changes in groundwater chemical constituents' levels necessitate a frequent examination of groundwater quality before being used. Therefore, periodical analyses for drinking water wells are very important. Hence, this study is conducted to investigate the following objectives:

1. To assess the groundwater quality to be correlated with health problems noticed recently in the study area.
2. To compare the results with the local, regional and international standards and guidelines.

Study location, climate and population

The area under study is located at the western part of Khartoum State (southern suburb of Omdurman city). It is located between longitudes 32˚ 10´ – 32˚ 30´ E, and latitudes 15˚ 12´ – 15˚36´ N with an extent of approximately 400 km^2 (Fig 1).

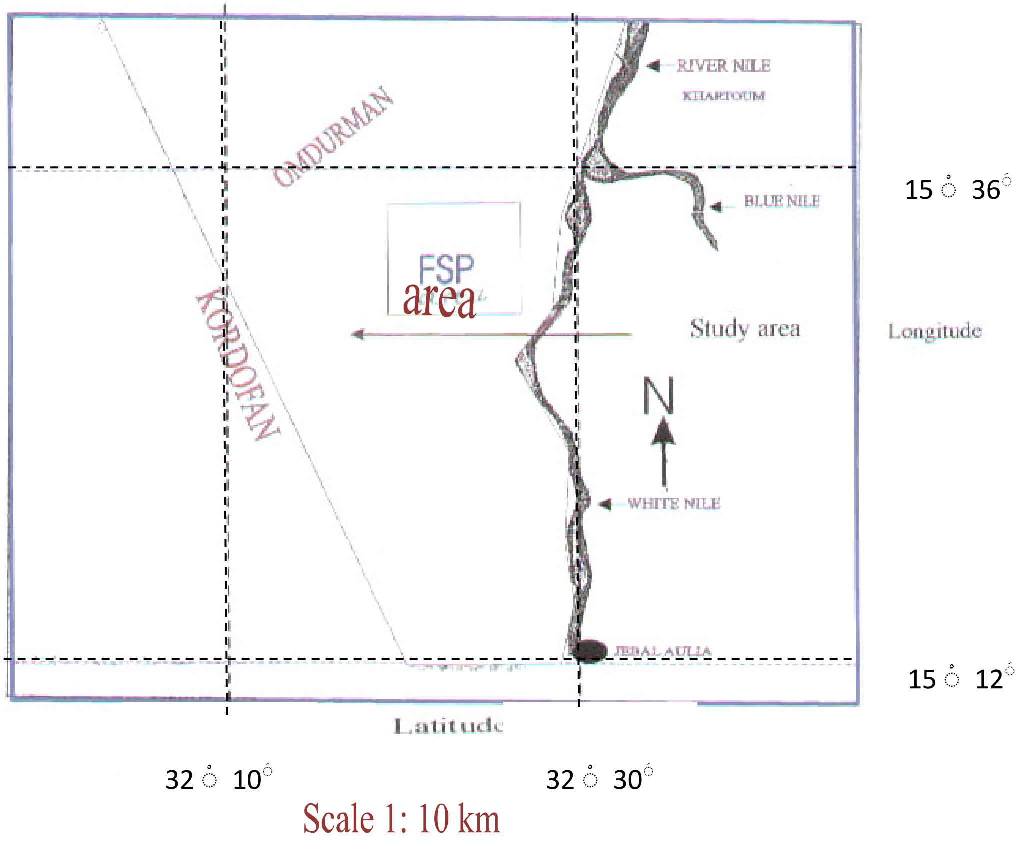

Fig: 1.1: Location map of the study area
FSP = Food Security Area
Source: GWWD (2002)

The climate of Khartoum State is arid with a hot long summer (7 months) and a cold dry winter. During the period from July to September, thunderstorms associated with the northwards movement of the intertropical convergence zone, produce rainfall with an annual average of 115.7 mm. The rainfall intensity increases to the south and decreases to the north of the region. The monthly rainfall records show that the maximum of the rainfall is during the period from July to September. The average annual temprature is 30˚ C with the highest monthly mean value during May 41.8˚ C and the lowest is during January (15.7˚ C). The wind direction is to the southwest durring May to September (speed 8 miles/h). However, the wind direction changes to the north during October to April (speed 9 miles /h). The monthly mean relative humidity is between 20 and 30 % from June to November and it jumps to 36 - 55 % from July to October. The monthly mean evaporation reaches its maximum (49 mm) during August and the minimum value (6 mm) during May.

Several villages are located in the study area with a total population of approximately 3500 persons. However, during the two past decades, there is a noticeable increase of migration to this region from other parts of Sudan as a result of draught that hit most of the western part of Sudan. The main occupations of the villagers are farming, livestock rearing and dairy products, with a small sector working in government institutions, private marketing sector and local markets.

Samples and data collection

Ninty two (92) borehole water samples were used in this study for physico-chemical analysis, the first twenty one (21) samples were obtained directly from the field; they are used mainly for drinking, whereas the remaining seventy one (71) samples were obtained from different previous studies. The twenty one (21) water samples for chemical analysis were collected in polyethylene bottles whereas sixteen (16) water samples for bacteriological analysis were collected in 250 ml sterile glass bottles and they were then taken to the laboratory (Ambinet temprature 25˚C) and the analysis was carried out immediately.

Chemical and Statistical analyses

The determinations were carried out according to the standard methods for the examination of Water and Wastewater (APHA, 1998). Electric conductivity (dS/m at 25ºC) in groundwater samples was measured by Beckman Solu Bridge type equipment. To convert the EC readings to TDS, the results for the EC dS/m were multiplied by 640. Calcium and Mg^{+2} were determined by complex metric titration using ethylene diamine tetra acetic acid (EDTA). Sodium and K^+ was determined photo metrically by flame photometer (Model: PFP7, Serial No. 15027, Jenway-England). Chloride was determined by titration using standard silver nitrate solution and potassium chromate (5% solution) as an indicator. Bicarbonate was determined by titration against 0.05 N standard sulphuric acid (H_2SO_4) to pH 4.5 using phenolphthalein and methyl orange as indicators. Fluoride was determined by Alizarin Visual method, this method is based on the reaction between F^- and a zirconium-dye lake. Fluoride reacts with Dye Lake, dissociating a portion of it into a colorless complex anion $(ZrF_6)^{2-}$ and the dye. As the amount of F^- increases, the color produced becomes progressively lighter or of different hue. Fluoride determined visually by comparing with control samples containing different F^- concentrations. Nitrate was determined by cadmium reduction method according to APHA (1998). Nitrate is reduced almost quantitatively to nitrite (NO_2) in the presence of cadmium. The NO_2^- thus obtained is determined colorimetrically using instrument Model specord 40-analytikjena spectro-photometer (Germany).

According to the WHO (1993), total coliform number was determined by membrane filtration method (MF). 100 ml water samples were filtered through the membranes using sterile forceps, the membrane filters were placed in the petri dishes on the pads which were saturated with membrane lauryl broth medium. The dishes were placed in an incubator at 37˚C for 24 hrs. Thermo tolerant (fecal) coliforms were determined also by membrane filtration method, but incubation was done at 44 ˚C. Basic statistics program (Microsoft Excel Spreadsheet) was used to calculate mean, range and standard deviation of the obtained data.

RESULTS AND DISCUSSION

Table (1): Physical, chemical and bacteriological characteristics of well water samples (n=92) in the southern suburb of Omdurman area, as compared to local, regional and international standards.

Constituent/ property	Mean N=92	Range	SD*	SSMO (2002)	% of Samples above	SASO (1984)	% of Samples above	GCCS (1993)	% of Samples above	WHO (1993)	% of Samples above	USEPA (1976)	% of Samples above	EEC (1992)	% of Samples above
TDS, mg/l	707	97-2600	559	1000	18	1500	10	1000	30	1000	30	500	52	1500	15
Ec., ds/m	12	0.2-5.2	1	NS	NS	2.3	11	1.6	16	NS	NS	NS	NS	2.3	21
pH	7.8	7-9	0.5	6.5-8.5	66	6.5-9.2	0.0	6.5-8.5	66	6.5-8.5	66	6.5-.8.5	66	6.5-8.5	66
TH (asCaCO3)mg/l	272	34-295	58	NS*	NS	500	0.0	500	0.0	500	0.0	NS	NS	NS	NS
Ca^{+2} mg/l	49	8-276	98	NS	NS	200	1	200	1	NS	NS	NS	NS	200	1

Table 2 continues

Mg^{+2} mg/l	34	2-122	24	NS	NS	150	0.0	150	0.0	NS	NS	NS	NS	50	18
Na^{+} mg/l	202	15-100	210	200	28	NS	0.0	200	28	200	28	NS	NS	175	49
K^{+} mg/l	11	5-32	6	NS	NS	NS	0.0	NS	0.0	NS	0.0	NS	NS	12	32
Cl^{-} mg/l	186	5-1038	217	250	23	600	8	400	16	250	23	250	23	200	23
SO4^{-2} mg/l	159	4-625	164	250	23	400	10	250	23	250	23	250	23	250	23
NO^{3-} mg/l	0.4	0-25	3	50	0.0	<45	0.0	<45	0.0	<50	0.0	<45	0.0	<50	0.0
HCO^{3-} mg/l	332	97-803	164	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F^{-} mg/l	0.9	0-1.8	0.5	1.5	18	0.6-1	46	0.6-1	46	1.5	18	4.0	0.0	1.5	18
Total coliform (MF/100 ml)	-	-	-	(-)Ve	-	(-)Ve	-	(-)Ve	-	(-)Ve	-	(-)Ve	-	(-)Ve	-

SD=Standard deviation, NS=No standard.

The results of the analysis for the samples (Table 1) revealed a wide variation in salt concentration. Total dissolved solids, ranged from 97 to 2600 mg/l with an average value of 707 mg/l. Comparison with the recommended standards and guidelines for salinity of drinking water revealed that 18%, 10%, 30%, 30% 52%, and 15% of the samples studied are above the limits set by SSMO, SASO, GCCS, WHO, USEPA, and EEC, respectively. The level of TDS in the water samples investigated varied significantly (large standard deviation value is 559 mg/l). The data presented in table (1) indicate that only 43% of the samples comprised the best quality water (TDS < 500 mg/l) as set by the USEPA, whereas 30 % of the water samples have TDS values between 501 and 1000 mg/l, 13% have TDS values between 1001 and 1500 mg/l which comply with the standards and guideline limits for drinking water set by SSMO, SASO, GCCS and WHO. On the other hand, high salinity water samples (TDS =1501 -2000 mg/l) and (TDS >2000 mg/l) are 4 % and 10 % of the samples, respectively. Electrical conductivity, generally, reflects salinity and ranged from 0.2 – 5 ds/m with an average of 1.4 ds/m, (Table 1). Therefore, according to the standards and guideline limits for drinking water listed in table (1), high salinity water, as shown by some of the samples, is considered unsuitable for drinking but could be used for irrigating crops with good salt tolerance such as date palm trees (Clark *et al.,* 1963; Raveendran and Madany, 1991; Al-Redhaiman and Abdel Magid, 2002). However, in some areas utilization of moderately saline drinking water is inevitable due to economic technical, social, cultural and political considerations (Hesponhol and Prost, 1994). According to Al-Redhaiman and Abdel Magid (2002), the high salinity of some of the water samples studied may be attributed to various reasons including over exploitation, excessive pumping, weathering of salt bearing materials , runoff water and agricultural drainage water. The tested water samples have pH values ranging within the limits of the local (SSMO), regional (SASO and GCCS) and international (WHO, USEPA and EEC) guidelines. Total hardness (TH) as $CaCO_3$ ranged between 34 and 295 mg/l, Table (1); with none of the water samples being above the 500 mg/l limit set by SASO, GCCS and WHO. According to Viessman and Hammer (1985), water hardness of more than 300- 500 mg/l is considered excessive for a public water supply and results in high soap consumption as well as objectionable scale in heating vessels and pipes. Moreover, many consumers object to water harder than 150 mg/l, a moderate figure being 60 – 120 mg/l thus including the optimum limit of 100 mg/l recommended by SASO (1984). Calcium concentrations ranged between 8 – 276 mg/l with only 1% of the well water samples studied falling above the standard limits of 200 mg/l recommended by SASO, GCCS and EEC. Mg^{+2} concentrations ranged between 2 – 122 mg/l with none of the samples above the standard limit of 150 mg/l set by both SASO, GCCS. However, 18 % of samples studied are above the 50 mg/l standard limit set by the EEC. Sodium (Na^{+}) concentrations ranged between 5 – 1000 mg/l with 28 % of the samples falling above each of the SSMO, GCCS and WHO standard and guideline limits of 200 mg/l. Potassium (K^+) concentrations ranged between 5 -32 mg/l, the EEC regarded 12 mg/l as the highest permissible limit for K^+. Chloride (Cl^-) concentrations ranged between 5 – 1038 mg/l with 23 % of the water samples studied have Cl^- concentrations above the limit of 250 mg/l set by SSMO, WHO, USEPA and EEC standard limits. According to Raveendran and Madany (1991), the WHO guidelines for Na^+ (200 mg/l) and Cl^- (250 mg/l) are based on taste considerations rather than the impact on human health and thus higher values can be tolerated. However, the concentration of Na^+ and Cl^- in wells water are alarming. High Na^+ levels in drinking water are physiologically undesirable. Patients with certain diseases require water with low Na^+ concentrations, and well water with high Cl^- levels exhibits a detectable salty taste when Na^+ rather than Ca^{+2}or Mg^{+2} are the predominant counter-ion (Lambert, 1972). The high levels of Na^+ and Cl^- ions in some wells water could be attributed to the significant amounts of these ions being carried by flushing runoff during rain storm in this region of saline soils (Abdel Magid *et al.,* 1984 and AL-Redhaiman and Abdel Magid, 2002). The SO_4^{-2} concentrations ranged between 4 - 625 mg/l with 23% of the samples are above (250 mgl/l) set by SSMO, GCCS, WHO, USEPA and EEC standards, whereas 10% of samples are above SASO standard limits of 400 mg/l. Viessman and Hammer (1985) indicated that the taste threshold for SO_4^{-2} lies between 300 – 400 mg/l for most persons. Nitrate (NO_3^-) concentrations ranged between 0 and 25 mg/l with all of the water samples studied thus falling below the limit of 50 mg/l set by SSMO, WHO and EEC standards. In view of the SSMO, WHO and EEC standards and guidelines which suggested the limit of 50 mg/l NO_3^- as the highest tolerable NO_3^- content in drinking water, all of the water samples examined in this work, fall within this limit and, therefore, pose no health hazards with respect to their $NO3^-$ level. This is an indication that there are no NO_3^- sources such as nitrogen rich fertilizers and manures applied at liberal rates by farmers in the study area (Amr, 2000). Bicarbonate (HCO_3^-) concentrations, ranged from 97 -803 mg/l, this high level is attributed to the presence of limestone in deep soil layers and consequently in groundwater (Raveendran and Madany, 1991; AL-Redhiman and Abdel Magid, 2002). High standard deviation values (Table 1) indicated that significant variations exist among the water samples examined with respect to their HCO_3^- content. Some of the results of this study are supported by previous evidence reported by other investigators (Abdel Magid *et al.,* 1984). Eighty-seven (87) water samples were examined for F^- concentration showed that F^- concentrations ranged between 0 and 1.8 mg/l with only 46% of the samples were above the SASO and GCCS maximum permissible limit of 1 mg/l, but no sample is above the USEPA standard limit of 4 mg/l. The SSMO, WHO and EEC standard limits for F^- is 1.5 mg/l, therefore, only13% of the samples are above the standard limits of 1.5, whereas 80% of drinking water samples examined have F^- concentrations lying well below the recommended permissible limit of 1.5 mg/l, which means that supplemental fluoridation to the optimum level is deemed necessary to avoid dental decay in water consumers (Al-Khateeb *et al.*, 1991). Conservatively, this study suggests putting in mind the climatic conditions when recommending supplemental fluoridation in such arid areas. It is important to state that Abdellah *et al.* (2012b) suggested the level of 0.3 mg/l to be the minimum concentration of F^- in drinking groundwater in order to prevent dental caries, and the level of 0.6 mg/l as the maximum concentration in order to prevent dental fluorosis. No bacterial contamination observed in water sampled directly from by vendors using donkey/horse carried barrels or other containers that are taken from the same well. This may be attributed to the excessive use of water-flushing during the afternoon, the time in which the samples have been collected.

CONCLUSION

1- There are considerable variations among the examined samples with respect to their physical and chemical constituents. Some of the obtained data were in good agreement while others are either above, below or not meeting the local, regional and international standards or guideline limits for water quality.

2- Nitrate concentration levels of the water samples examined pose no health hazards to the public health since they lie well below the maximum permissible limit of the respective standards used in this study.

3- The concentration levels of F^- in wells water are acceptable since 80% of the samples studied have F^- concentrations lie well below the upper recommended permissible limit of 1.5 mg/l suggested by the SSMO, WHO and EEC standards guidelines.

RECOMMENDATIONS

1- Continuous assessment of groundwater quality on routine basis is imperative and better management is warranted to reduce the deterioration of aquifer water quality.

2- Regardless of the economic, social and water availability and scarcity status, it may be recommended that boreholes with low grade and deteriorating drinking water quality may be abandoned or closed.

3- Efficient legislations and sanitation measures should be scientifically enacted to safeguard good quality water for human consumption, and the concern authorities should be strictly adhered to implement these legislations.

ACKNOWLEDGEMENT

The authors acknowledge the assistance of all those who contributed to this study.

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