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Well Drinking Water Fluoride Content and Dental Fluorosis in Al-Butana Region of Central Sudan

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Abstract: In this study the F^- ion concentration levels of 209 well water samples belonging to previous construction analysis (CA) and a total of 121 well water samples belonging to the current study (CS) in Al-Butana region of Central Sudan were investigated and located (mapped) using the geographical information system (GIS). The GIS-map indicates that the majority of F^- levels ranging between 0.5 and 1.5 mg/l dominates the northern part of the study area and the levels below 0.5 mg/l dominates the southern part of the study area whereas the levels above 1.5 mg/l are limited and are scattered, randomly, throughout the study area.

The results obtained revealed considerable spatial variations in the occurrence of fluoride even within the same community area, F^- levels ranging between 0.0 and 6 mg/l were found in boreholes drilled in Rufaa' Town. The majority of the investigated boreholes viz., 39.71% and 42.98% were found having F^- levels below 0.5 mg/l whereas only 0.96% and 3.3% were found beyond the level of 2.5 mg/l, for the CA and CS, respectively. The wide range of F^- levels (from 0 to 7 mg/l in the CA and from 0 to 2.6 mg/l in the CS) revealed the variability in the spatial distribution of F^- in the study area. 94.26% and 88.43% of the groundwater samples were found below the maximum recommended level of 1.5 mg/l set for F^- in drinking water by each of SSMO (2002) whereas only 5.75% and 11.58% were found in excess of this level, for the CA and CS, respectively. The decrease in the mean value of F^- in the investigated boreholes from 1.4 mg/l in the CA analysis to 0.6 mg/l in the CS analysis, indicates that F^- levels in the investigated boreholes has the tendency to decrease during pumping. Mottled teeth are widely observed among residents in the study area in spite of fluoride compliancy to SSMO standards. Therefore, dental fluorosis, in the study area, is not unlikely to occur.

Key words: Groundwater fluoride distribution, dental fluorosis, Al-Butana region, Sudan.

Introduction

Fluoride occurs in all types of rocks but the highest concentrations of F^- are found in water sources. Heavy clay soils, groundwater and lake water near volcanic areas can take up high levels of F^- from these rocks (WHO, 1984a).

Although water is the epidemiologically most important source of F^- in most areas, considerable exposure risk is also associated with the consumption of fish bones, canned meat, vegetables, grains and other staples, local salt, drinks (especially tea) and air (WHO, 1984b).

The most well-known and documented area associated with volcanic activity follows the East African Rift System from the Jordan valley down through Sudan, Ethiopia, Uganda, Kenya and Tanzania (Fawell et al., 2006).

Fluoride has beneficial effects on teeth, at optimal concentrations in drinking water, but excessive exposure to high F^- concentration in drinking groundwater, or in combination with exposure to F^- from other sources, can

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elevate the risk of a number of adverse effects. F^- affects, positively, the tissue composition of bone and tooth minerals by replacing the carbonate position (Ekstrand et al., 1988). Conversely, F^- affects, negatively, human health in many ways; staining the enamel teeth during secretory and/or maturation phase of the enamel (Linda, 2001), skeletal changes (Ekstrand et al., 1988), affects kidneys during the course of low-dose long-term exposure to F^- (Marier and Rose, 1977) and decreased ability to excrete F^- in urine and elevates the risk of developing fluorosis even at normal recommended limit of 0.7 to 1.2 mg/l (Banzal and Tiwari, 2006), impacts adult brain, with particular deficits in attention, auditory, retention, and physical dexterity and acuity as well as abnormal emotional states (Guo, 2001). If fluoride accumulates in the pineal gland during early childhood, it could affect pineal indole metabolism (Luke, 1997) and affects sexual maturation, calcium metabolism, parathyroid function, postmenopausal osteoporosis, cancer, and psychiatric disease (NRC, 2006a), playing a role in the widespread incidence of hypothyroidism (under-active thyroid) (NRC, 2006b), causes gastrointestinal complaints (Susheela, 1993) and mucosal abnormalities (Dasarathy, 1996). Moreover, it may cause a corrosive effect on the epithelial lining of the gastrointestinal tract (Susheela and Bhatnagar, 2002).

Excessive F^- in groundwater can be avoided by defluoridation of drinking water and provision of alternative water sources such as surface water, rainwater and low-fluoride groundwater (Helmut and Redda, 1999). F^- can be removed from drinking groundwater by – adsorption, ion-exchange, coagulation-precipitation and membrane process (Meenakshi and Maheshwari, 2006). Clinical data also indicate that adequate calcium intake is directly associated with a reduced risk of dental fluorosis (Dinesh, 1998). Vitamin C also safeguards against dental fluorosis (Meenakshi and Maheshwari, 2006).

In Sudan, previous workers have reported that dental fluorosis was common among schoolchildren in Al-Butana region (Fadle, 2004). In Abu-deleig, area where drinking groundwater contains about 1.0–2.0 mg F^-/l dental fluorosis prevails especially among schoolchildren (Birkeland et al., 2005).

According to our observation, in past decades, communities in the study area completely relied on hand-dug shallow wells, as the main drinking water source. At that time, dental fluorosis was limited to certain communities. In recent decades, deep-tube wells were introduced and became the main groundwater source in the study area. Since then, dental fluorosis has spread widely and observed in other communities of the study area. Therefore, this study is conducted to investigate the following objectives.

1. To investigate F^- levels in drinking groundwater and dental fluorosis prevalence in Al-Butana region of Central Sudan.
2. To compare the results obtained (both CA and CS) with the local, regional and international standards and guidelines.

Materials and Methods

Study Location

The study area was divided, administratively, into three regions as follows.

1. The whole area of East of Gezira Locality, Gezira State.
2. The Western Administrative Units area of Umelghura Locality, Gezira State.
3. The Eastern Administrative Units area of Shark-el-Neel Locality, Khartoum. State (Figure 1).

Samples Collection

A total of 121 groundwater samples were collected from different boreholes of various communities using 250 ml plastic bottles, each bottle was rinsed with the targeted water 3–4 times before filling. Samples were collected directly from the outlet points of the well, where and when possible. In boreholes without outlet point, samples were collected from reservoirs or from the nearest water-tap to the groundwater source. After proper marking, the samples were immediately sent to the laboratory and kept in the refrigerator at 4°C pending analysis.

The spatial data of F^- levels were analysed using geographic information system (GIS) software (Arc View) and F^- distribution map has been produced. Basic statistics programme (Microsoft Excel Spreadsheet) was used to calculate mean, range and standard deviation of the obtained data.

Chemical Analyses of F^- Concentration

The analyses were carried out according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1998). In this analysis, fluoride concentration in groundwater samples 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 colourless complex anion $(ZrF_6)^{2-}$ and the dye. As the amount of F^- increases, the colour produced becomes progressively lighter and was compared with control samples containing different fluoride concentrations.

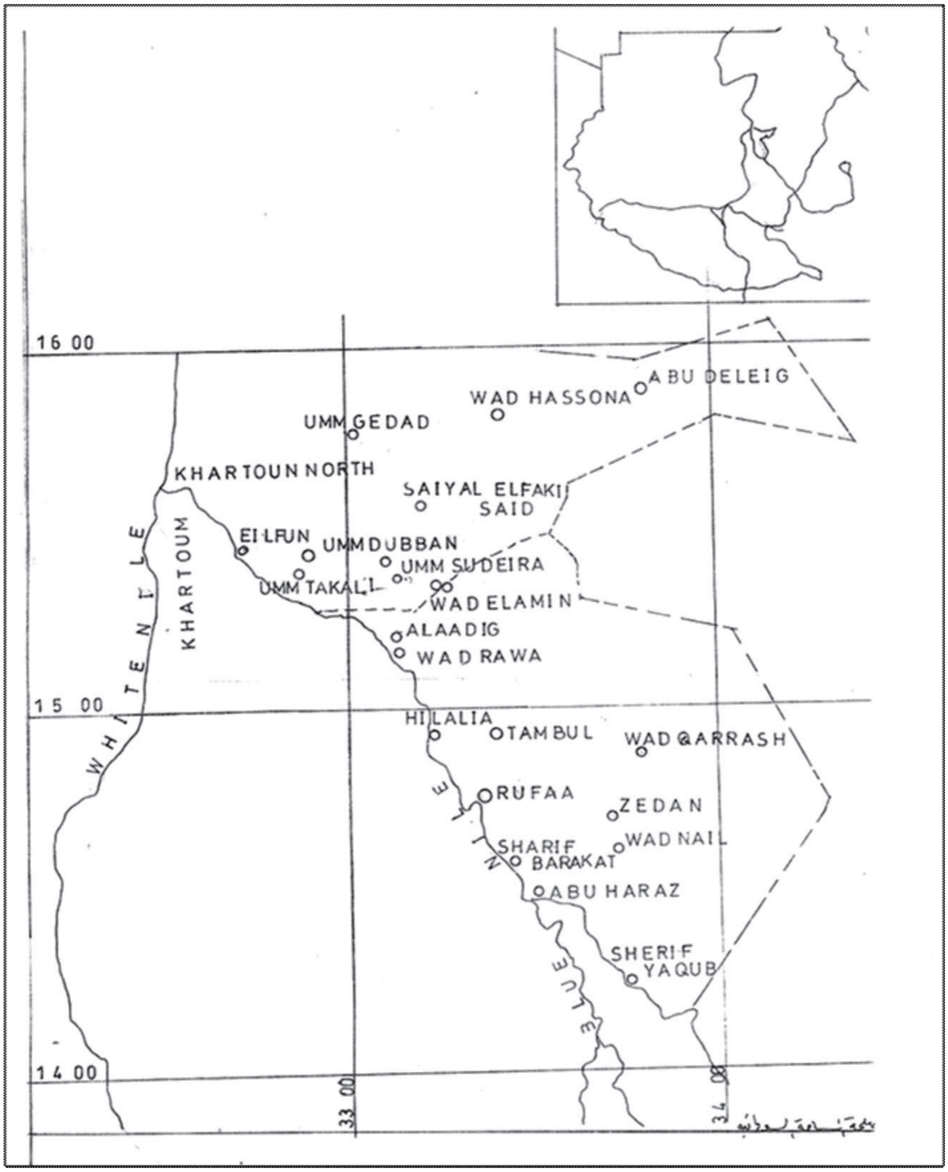

Figure 1: Location map of the study area, Al-Butana region of Central Sudan.
***Source:* Sudan National Survey Authority, prepared for the current study.**

Results and Discussion

Most of F^- levels in the investigated well water samples were found below the maximum recommended limit of 1.5 mg/l adopted by Sudanese Standard and Metrology Organization (SSMO, 2002) whereas boreholes exceeding the recommended limit are limited to locations scattered, randomly, throughout the study area. F^- levels, generally, vary among boreholes drilled in the same community area.

Distribution of F^- in the Study Area

According to GIS-map, the high F^- concentrations (above 1.5 mg/l) in the study area were observed in some boreholes scattered, randomly, throughout the study area. F^- levels ranging between 0.5 and 1.5 mg/l were observed in boreholes drilled in the Western and the Northern communities while F^- levels below 0.5 mg/l dominated the rest of the study area (Figure 2). The similarity of fluoride distribution in the different communities reflects, to large extent, the similarity of fluoride content in the Nubian Sandstone formation prevailing in the area.

Variation of F^- Levels in Boreholes Drilled in the Same Community Area

Fluoride levels in boreholes drilled in the same community of the study area varied greatly (Table 1). The CA boreholes that were drilled in Ruffaa' and

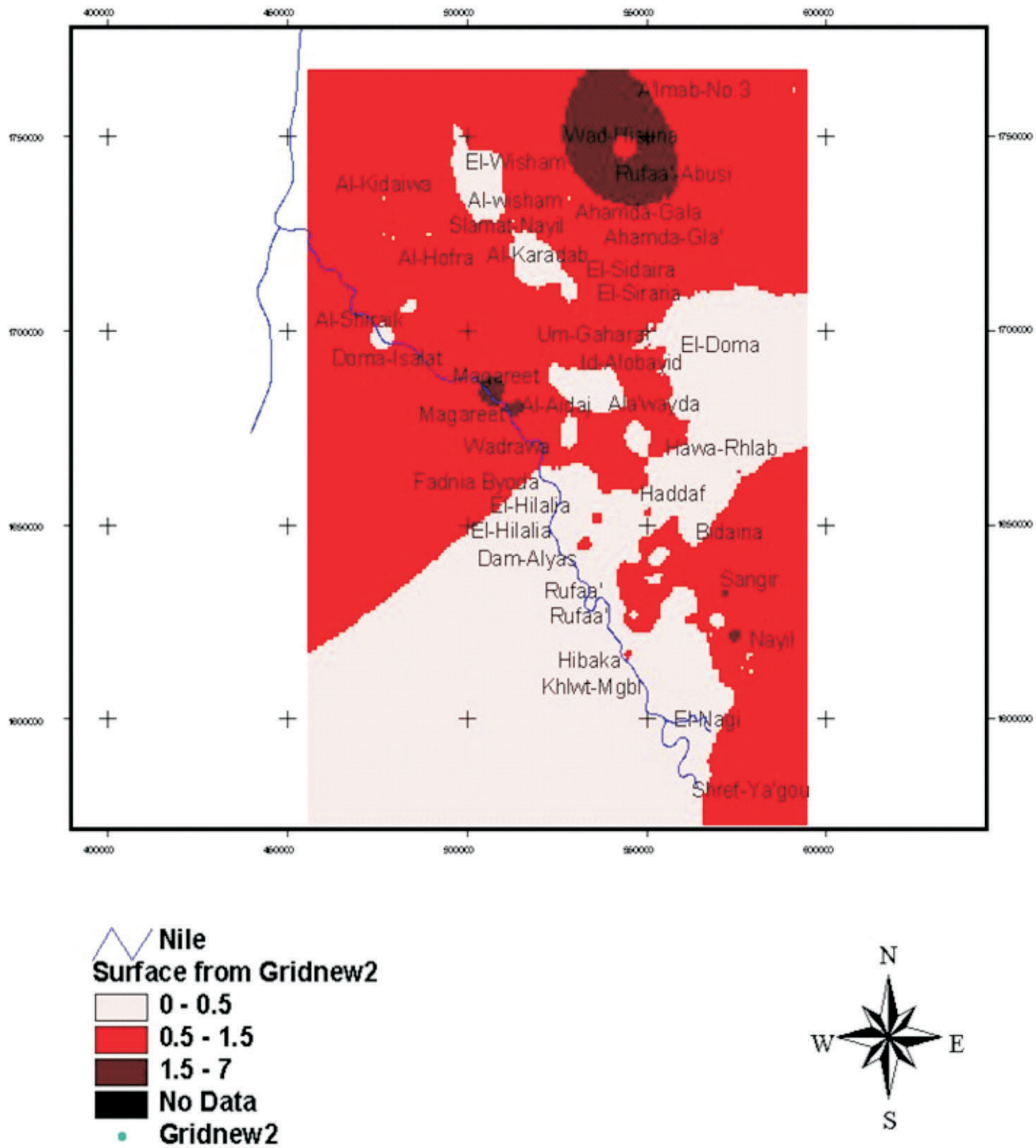

Figure 2: Distribution of flouride in the study area Al-Butana region of Central Sudan.

Wadrawa Towns revealed F^- concentrations ranging between 0.0–6.0 mg/l (SD = 2.1) and from 0.0– 1.6 mg/l (SD = 0.5), respectively, while boreholes drilled in the adjacently located villages of Bakrab and Sererya revealed F^- concentrations ranging between 1.0–2.6 mg/l (SD = 0.6), as obtained in the CS. Therefore, the distribution of F^- concentrations in the aquifer of the study area is greatly dependant on the availability and solubility of fluoride in the particular geological formation site where the groundwater has been hosted as it was previously reported by Ekstrand et al. (1988). The variation of groundwater F^- levels in the neighbouring boreholes may be due to the high electronegativity, which characterized the F^- ion. High electronegativity makes fluoride strongly coupled with metals and under normal conditions is rarely replaced with other ions (Ekstrand et al., 1988). Therefore, the high electronegativity of the F^- constricts migration of F^- through internal movement of groundwater to neighbouring boreholes.

Table 1: Variation of fluoride levels in well water sources in the study area

CA				*CS*	
Name of communities in the study area					
Rufaa' Town		*Wadrawa Town*		*Bakrab and Sererya villages*	
Date of drilling	*F^- levels (mg/l) (n = 7)*	*Date of drilling*	*F^- levels (mg/l) (n = 6)*	*Date of analysis*	*F^- levels (mg/l) (n = 7)*
1976	0.02	1968	0.7		1.4
1976	1.72	1968	1.0		2.4
1978	0.0	1976	1.6		2.6
1986	0.1	1984	0.0		1.0
1986	0.1	1984	1.2	2008	1.0
1986	6.0	1990	1.6		1.1
1986	0.2	NA	NA		1.6
Mean	1.5	NA	1		1.6
Range	0-6	NA	0-1.6		1-2.6
SD	2.1	NA	0.5		0.6

NA = not available; CA = Construction analysis; CS = Current study; SD = Standard deviation.

Statistical Analysis of F^- Levels in the Study Area

To make the picture more apprehensive than comprehensive, the data of fluoride concentrations were categorized in Table (2). The statistical analyses of fluoride concentration revealed that a total of 83 out of 209 boreholes (39.71%) and 52 out of 121 boreholes (42.98%) have F^- levels below 0.5 mg/l in CA and CS, respectively, whereas 86 boreholes (41.15%) and 39 boreholes (32.23%) boreholes are within the category of 0.5–1.0 mg/l in each of CA and CS, respectively. A total of 28 boreholes (13.39%) and 16 boreholes (13.22%) lie within the category of 1.0–1.5 mg/l for CA and CS, respectively. Eight boreholes (3.38%) and 7 boreholes (5.79%) are within the category of 1.5–2.0 mg/l for CA and CS, respectively. Only 2 boreholes (0.96%) and 3 boreholes (2.48%) are within the category of 2.0–2.5 mg/l for CA and CS, respectively. Not more than 2 boreholes (0.96%) and 4 boreholes (3.31%) are above the level of 2.5 mg/l in both CA and CS, respectively. Yasir (2004) reported that groundwater F^- levels in the study area ranged between 0.2 and 0.8 mg/l. Fadle (2004) reported F^- concentrations ranging between 0.4 and 3.0 mg/l for Khartoum State, 0.7 to 2.5 mg/l for Gezira state and 1.5 and 3.4 mg/l for Gedaref Town. Shomo (2007) reported a fluoride level range of 0.0–1.8 mg/l for southern Omdurman metropolitan area. Birkeland et al. (2005) found that fluoride

Table 2: Distribution of 209 CA-samples and 121 CS-samples in the study area of Al-Butana region according to their F^- levels

F^- level category (mg/l)	*CA*		*CS*	
	Number of boreholes within the CA-class	*(%) of total within class*	*Number of boreholes within the CS-class*	*(%) of total within class*
<0.5	83	39.71	52	42.98
0.5–1.0	86	41.15	39	32.23
1.0–1.5	28	13.39	16	13.22
1.5–2.0	8	3.83	7	5.79
2.0–2.5	2	0.96	3	2.48
>2.5	2	0.96	4	3.30
Total	209	100.00	121	100.00
Study	CA		CS	
Mean	0.7		0.7	
Range	0.0 7.0		0.0–2.6	
SD	0.7		0.6	

SD = Standard deviation.

levels in Abu-Deleig area ranged between 1.0 and 2.0 mg/l. High concentrations of 5.2 mg/l, 15 mg/l, and 18 mg/l were reported in some Indian districts. Some of the highest F^- levels were recorded in wells in the African Rift System and the highest level of F^- was found in Lake Nakuru in Kenya which amounted to 2800 mg/l (Helmut and Redda, 1999). Abdel-Magid (1997) and Al-Redhaiman and Abdel-Magid (2002) reported that the F^- level of drinking and irrigation well water of Al-Gassim region of Central Saudi Arabia ranged between 0.7–3.1 mg/l and 0.2–1.5 mg/l, respectively. Xiangquan et al. (2010) found that the F^- levels in sandstone aquifers of Taiwan basin of China ranged between 1.5 and 2 mg/l.

Compliance of F^- Levels to Groundwater Standards

The applicability of local, regional and international drinking water standards and guidelines on groundwater F^- concentrations in the study area are presented in Table (3). F^- concentration levels for both CA and CS revealed that 94.26% (197 boreholes) and 88.43% (107 boreholes) of the well water samples are lying below the maximum permissible limit of 1.5 mg/l set by both of the SSMO (2002) and WHO (2008). However, no minimum recommended level of fluoride in drinking water was set by these standards. According to these guidelines, communities consuming groundwater with F^- concentrations below this level are out of risk in getting dental fluorosis. However, it may be indicated that avoidance of dental caries requires adequate fluoridation, depending on the prevailing ambient temperature . With respect to dental caries, these results do not point out whether the communities with F^- concentration in drinking water below this level are out of risk or not. Therefore, dental caries is expected among residents of the study area that are consuming groundwater that is devoid of any fluoride ion. Al-Redhaiman and Abdel-Magid (2002) indicated that the optimum level of F^- concentration in drinking water is deemed necessary to avoid dental decay and other manifestations associated with F^- deficiency. On the other hand, it may be observed that (Table 3) 5.75% (12 boreholes CA) and 11.58% (14 boreholes CS) of the well water samples are violating the maximum permissible limit of 1.5 mg/l set by SSMO (2002) and WHO (2008) and therefore, dental fluorosis and other diseases related to high fluoride consumption are expected among residents of these communities.

With respect to the Economic European Community standards and guidelines (EEC, 1992), a total of 64.11% (134 boreholes) and 61.15% (74 boreholes) of the well water samples examined have F^- concentration lying below the minimum recommended limit of 0.7 mg/l set by EEC (1992). 30.14% (63 boreholes) and 27.27% (33 boreholes) are lying within the 0.7–1.5 mg/l set by the respective standards while only 5.75% (12 boreholes) and 11.58% (14 boreholes) of the well water samples are lying above the maximum permissible limit of 1.5 mg/l for CA and CS, respectively.

The application of the limits of 0.6–1 mg/l for F^- concentration in drinking groundwater set by both SASO (1984) and GCCS (1993) to the examined well water samples revealed that only 27.75% (58 boreholes) and 27.27% (33 boreholes) of the examined well water samples are within the recommended levels of 0.6–1 mg/l in CA and CS, respectively. A total of 60.29% (126

Table 3: Comparison of F^- levels in the study area with the local, regional and international standards and guidelines

Standard name	*Recommended F^- limit (mg/l)*	*Class*	*CA (n = 209)*		*CS (n = 121)*	
			Number of boreholes within class	*% of total within class*	*Number of boreholes within class*	*% of total within class*
SSMO (2002) and	Up to 1.5	<1.5	197	94.26	107	88.43
WHO (1993)		>1.5	12	5.75	14	11.58
EEC (1992)	0.7–1.5	<0.7	134	64.11	74	61.15
		0.7–1.5	63	30.14	33	27.27
		>1.5	12	5.75	14	11.58
SASO (1984) and	0.6–1	<0.6	126	60.29	65	53.71
GCCS (1993)		0.6–1.0	58	27.75	33	27.27
		>1	25	11.96	23	19
USEPA (1976)	Up to 4	<4	207	99.04	121	100
		>4	2	0.96	0	0

boreholes) and 53.71% (65 boreholes) are lying below the minimum recommended level of 0.6 mg/l while only 11.96% (25 boreholes) and 19% (23 boreholes) are found above the maximum recommended guideline level in both CA and CS, respectively.

The examined well water samples revealed that a total of 99.04% (207 boreholes) and 100% (121 boreholes) are well below the maximum recommended level of 4 mg/l set for F^- in drinking water by the USEPA (1976) in both CA and CS, respectively. It has been noticed that only 0.96% (2 boreholes) of the data for CA are in excess of the maximum recommended level of 4 mg/l while none of the well water samples in CS have exceeded the maximum recommended level of 4 mg F^-/l set by the USEPA standard.

It is noteworthy that, the guidelines set by the various standards for the regulation of F^- concentration level in drinking water are conflicting. The considerable variation of standards set for the F^- level in drinking water is, in fact, dependant on a variety of factors, such as the availability of alternative sources of drinking water with an acceptable F^- concentration in a particular community. Tanzania, for example, has set the guideline for F^- in drinking water at 8 mg/l because most of their water supply has high F^- concentration levels whereas the United States has adopted a guideline of 4 mg/l for F^- because it has been found that more than 300 community water supply systems have F^- concentrations above 4 mg/l and that drinking water consumption is lower compared to the hot tropical regions (Helmut and Redda, 1999). Moreover, the adoption of F^- level guideline, in drinking water, is temperature dependant (CDPH, 2010). Despite the compliance of F^- concentrations, in most groundwater samples that were analysed in this study, to the local, the regional and the international standards, clinical features of dental fluorosis are widely observed among residents of the study area (Figures 3, 4 and 5).

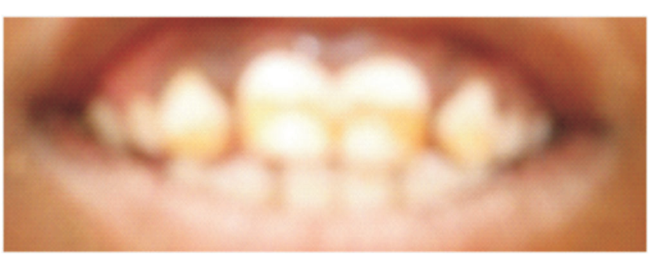

Figure 3: Obviously stained teeth of a 13-year old child lifelong resident in Kernos village during the year (2008) with 0.8 mg F/l in their drinking groundwater.

Figure 4: Partially stained teeth of a 13-year old child lifelong resident in Kernos village consuming drinking groundwater during the year 2008 containing 0.8 mg F/l.

Figure 5: White flecks with stain line equally drawn on maxillary central incisors of a 12-year old child lifetime resident in Alteragma village consuming drinking groundwater containing 0.25 mg/l fluoride (2008) and was previously (1971) containing 1 mg F/l.

Tendency of Fluoride Concentration During Long Discharge Time

The comparison between F^- concentrations in the CS of well water samples with those in CA of the same well water samples demonstrated that the daily pumping rate or abstraction of water from wells decreases F^- concentrations in groundwater of the study area (Table 4).

Conclusion

Based on the results of the present investigation the following conclusions may be drawn:

1. F^- concentration in groundwater of the study area is sporadically distributed and is mainly affected by the availability and solubility of fluoride in rock formation where groundwater is being hosted.
2. Different neighbouring boreholes vary considerably in their F^- level even in the same community area and it generally decreases with pumping rate.

Table 4: The tendency of decrease of groundwater F^- levels during discharge time in some boreholes in the study area, Al-Butana region (*n*=26)

Name of village or town	*Date of drilling (CA)*	*F^- level in CA (mg/l)*	*F^- level in CS (2008) (mg/l)*	*F^- Total decrease (mg/l)*	*% decrease*
Gozelahamda	1976	0.3	0.1	0.2	67
Sayal-Attay	1988	0.5	0.4	0.1	20
Wadennour	1971	0.4	0.3	0.1	25
Damgadkrem	1972	0.7	0.6	0.2	29
Elteragma	1971	1.0	0.3	0.8	80
Abugalfa	1978	0.4	0.3	0.2	50
Sharafa-brkat	1987	0.3	0.2	0.1	33
Umhiryzat	1971	1.0	0.5	0.6	60
Almegareet-1	1972	1.8	1.0	0.8	44
Tamboul-1	1978	0.9	0.8	0.1	11
Banat	1978	0.7	0.2	0.6	86
Aidaj	1978	2.0	1.9	0.1	5
Fadniabyoda*	2001*	0.7*	0.9*	0.2*	29*
Sialesawra	1990	1.4	0.6	0.8	57
Altikalat	1986	1.4	0.5	0.9	64
Amara-Ali	1971	1.0	0.6	0.5	50
Gurra-tay	1993	0.8	0.1	0.7	88
Hillat-Idrees	2001	1.0	0.6	0.5	50
Doma-Isalat	2001	0.8	0.5	0.3	38
Alwan Ibrahim	1999	0.9	0.4	0.5	56
Mstfa-Fadni	1973	1.1	0.5	0.6	55
Alfadnia-North	1998	1.5	1.2	0.3	20
Umdwanban	1970	1.6	1.1	0.5	31
Umdwanban	1978	1.4	1.1	0.3	21
Rufaa-2	1986	0.2	0.0	0.2	100
Rufaa-3	1986	6.0	0.6	5.4	90
Ahamda-fresh	1999	7.0	2.5	4.5	64
Mean	1983	1.4	0.6	0.8	50
Range	1970-2001	0.2-7	0.0-2.5	0.1-5.4	5-100
SD	11	1.7	0.6	1.1	25

* In this borehole F^- level in CS > in CA

3. Despite the compliancy of F^- level in drinking groundwater to the maximum permissible limit for F^- (1.5 mg/l) set by the SSMO, mottled teeth (dental fluorosis) were obviously observed among residents in the study area.

Recommendations

It may, therefore, be recommended that:

1. Each country, imperatively, calculate its own optimal level of F^- in drinking water, based on the dose-response relationship of F^- in drinking water with the level of caries and dental fluorosis. Climatic conditions (ambient temperature), dietary habits of the population and other possible F^- exposures need to be considered in adopting these recommendations (Ayyas et al., 2004).
2. The study strongly recommends avoiding consuming drinking ground water with F^- concentration in excess of the SSMO and the WHO guideline limits especially those who are suffering kidney malfunctioning and that decision makers are advised to enforce safe limits for F^- in drinking water based on climatic conditions.
3. In case of any collapse or technical problems associated with the optimal F^- level, a substitutive borehole should be drilled in the vicinity in order to minimize the risk of the spatial variability in the distribution of F^- in underground water.

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