THE RELATIONSHIP BETWEEN THE FLUORIDE LEVELS IN DRINKING WATER AND THE SCHOOLING PERFORMANCE OF CHILDREN IN RURAL AREAS OF KHARTOUM STATE, SUDAN

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ABSTRACT: Geogenic fluoride ion (F) contamination of groundwater has drawn worldwide attention due to its considerable impact on human health. In this study, the relationships between groundwater F levels, collected in the rainy and dry seasons from 16 rural areas in Khartoum state, Sudan, and the schooling performances of 775 primary school pupils, 315 boys and 460 girls, in 27 schools in these areas, were analyzed using the SPSS. The schooling performances were measured as the average score (%) [(100×average mark)÷total mark] and the high score prevalence (%) [(100×no of students scoring>70%)÷total no of students] for each of 8 subjects (Islamic studies I and II, Arabic, English, mathematics, sciences, history, and technology) and the overall score. The F level was found to be significantly negatively correlated with the average scores for 5 of the 8 subjects (range: r= –0.46, p<0.05 to r= –0.59, p<0.01), with the high score prevalences for 6 of the 8 subjects (range: r= –0.39, p<0.05 to r= –0.60, p<0.01), and with the overall score for both the average score (r= –0.51, p<0.01) and the high score prevalence (r= –0.48, p<0.05). On the basis of these results, we conclude that there may be an inverse relationship between the F level in drinking water and the schooling performance.

Keywords: Fluoride; Drinking water; Groundwater; Intelligence; Khartoum; Schooling performance.

INTRODUCTION

The quality of groundwater is very important in evaluating its utility in various fields such as the domestic public water supply and agriculture. In many parts of the world groundwater plays an important role as a primary drinking water source. In addition to the physical and bacterial characteristics of groundwater, its chemical properties determine its usefulness for domestic use. The assessment of the dissolved constituents is very important for the safety of drinking water. While some of ions dissolved in water at appropriate concentrations are essential for human health, e.g., iodine, others may result in toxicity when present at high concentrations.

The occurrence of the fluoride ion (F) in groundwater has drawn worldwide attention due to its considerable impact on human health. Sodium fluoride or sodium monofluorophosphate, in combination with added calcium, has been used for the treatment of age-dependent osteoporosis[1] but, although F was able to stimulate bone formation and increase bone density, the quality of the bone was decreased.[2] Riggs et al. concluded that F therapy increases cancellous but decreases cortical bone mineral density and increases skeletal fragility.[3] They concluded that under the conditions of their study that the F-calcium regimen was not an effective treatment for postmenopausal osteoporosis.[3]

Long-term exposure to elevated levels of F may cause dental, skeletal, and nonskeletal fluorosis.[4] The WHO has recommended a upper permissible limit guideline value for the F level in drinking water of 1.5 mg/L but notes that in

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developing national drinking water standards (or health-based targets) based on the guideline value, it will be necessary to take into consideration a variety of environmental, social, cultural, economic, dietary, and other conditions affecting potential exposure, as well as the default assumptions that are used to derive the guideline value.[1] They also note that F has been used in the artificial fluoridation of water supplies, usually at 0.5–1.0 mg/L, to promote dental health.[1] Several studies have shown caries reductions of up to 60% following drinking water fluoridation.[5]

However, although there is strong scientific evidence for the protective cariostatic effect of topical F application, the respective data for the systemic application of F via drinking water are less convincing.[6] F is neither an essential trace element for human health nor necessary for the development of healthy teeth and bones.[6]

Crippling skeletal fluorosis has been reported with a F intake approximately 15–20 mg/day over a 20-year period.[7] Elevated F concentrations have been found to be related to the prevalence of skeletal fluorosis in China.[8] In 1994, Freni reported evidence suggesting that exposure to F in drinking water may be associated with reduced fertility rates.[9]

Recently several reports have linked F in drinking water and intelligence.[10,11] In 1995, Li et al. measured the intelligence, by the China Rui Wen's Scaler for Rural Areas, of 907 primary school children, aged 8–13yr, living in areas in which the prevalence of fluorosis was either high (medium or severe) or low (slight or no).[12] The intelligence quotients (IQ) in the areas with low fluorosis were found to be higher than those in the high fluorosis areas (non-fluorosis area: n=226, IQ=89.9±10.4 (mean±SD); slight fluorosis: n=227, IQ=89.7±12.7; medium fluorosis: n=224, IQ=79.7±12.7; and severe fluorosis: n=230, IQ=80.3±12.9).[12] Another study in China involved 160 children randomly selected from each of two villages, one with a high drinking water F (4.12 mg/L), and one with a low drinking water F (0.91 mg/L).[13] The IQ, as measured by official intelligence quotient tests, was found to be lower in the high water F village compared to the low F village (97.69±13.00 [mean±SD] and 105.21±14.99, respectively). In 2006, a review article by Grandjean and Landrigan noted that F could cause neurotoxicity in laboratory animals and noted that high water F concentrations were associated with lower IQ in three studies from China.[14] However, Grandjean and Landrigan considered that these reports did not thoroughly consider possible confounders and that further in depth studies should be undertaken.[14] In 2012, Choi, Sun, Zhang, and Grandjean reviewed the findings of 27 studies from China and Iran and concluded that the results supported the possibility of an adverse effect of high F exposure on children's neurodevelopment.[11] In 2014, Grandjean and Landrigan classified F as a newly recognized developmental neurotoxicant, noting that a meta-analysis of 27 cross-sectional studies in children exposed to raised F concentrations in drinking water or food contaminated with F from coal burning suggested that they had an average IQ decrement of about 7 IQ points.[15] They considered that most of the studies, 25 from China and 2 from Iran, were unlikely to be affected by confounding.[15] Extremely high levels of F have also been reported to cause negative impacts on memory and learning in rodent studies.[16]

So far the evidence on the link between F and IQ from humans has come from endemic fluorosis regions. Some of the evidence is controversial due to several reasons such as lack of consideration of confounders such as nutritional status, socioeconomic status, iodine deficiency, and co-exposures to other known neurotoxicants, e.g., lead and arsenic. However, the studies appear significant enough to warrant additional research on the effects of F on intelligence. Therefore, more studies could help in interpreting the relationship between F in drinking water and IQ or IQ related properties. This is especially so because the brain power of the next generation is crucial to all of us.

IQ refers to a total score as measured by one of several standardized tests. IQ scores are used for educational placement, assessment of intellectual disability, and evaluating job applicants.[17,18] IQ scores have been studied as predictors of job performance and individual income. Several studies have agreed on a strong correlation between IQ and school performance.[19-21]

The present study was undertaken to assess the F level of groundwater and to explore its influence on school achievements of primary school children living in Khartoum state rural areas with a similar socioeconomic status. The results for primary school children, aged 6–14 yr, were used in this study because during this period brain development is rapid and vulnerable. However, while several published works have connected F and IQ,[11,14,15] none have considered F and school achievements. This study was conducted as a part of a project, which was designed to determine the chemical and physical properties of groundwater in Khartoum rural areas.

THE METHODS

The study area: The study areas include villages in different rural parts of Khartoum state, one of 18 states in Sudan (Figure 1).

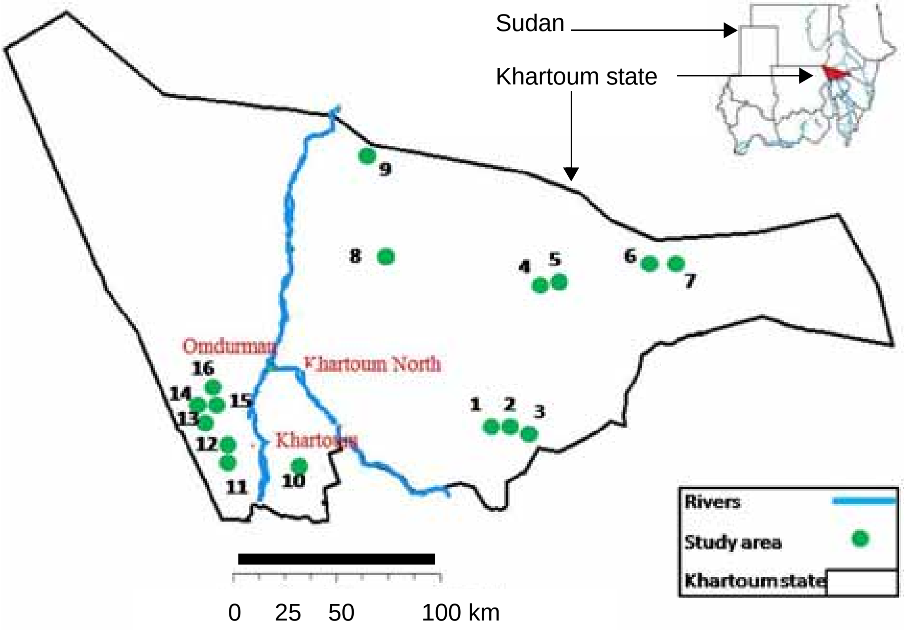

Figure 1. Location of the 16 groundwater wells in Khartoum state, Sudan, from which the samples were taken in the dry and rainy seasons giving a total of 32 samples. Blue lines=rivers, green circles=study areas, black line=border of Khartoum state.

These villages depend on groundwater as the main source of drinking water because of the lack of a central water supply. The main activities in these villages are agriculture and animal breeding. The villages lack any industrial and mining activities and are located away from high traffic roads.

The study area lies between longitudes 31.5 to 34 ºE and latitudes 15 to 16 ºN with an average annual rainfall which reaches 100–200 mm in the north-eastern areas and 200–300 mm in the northwestern areas. The temperature in summer ranges from 30 to 45ºC from April to June, and from 20 to 35ºC in the months of July to October. In winter, the temperature declines gradually from 25 to 15ºC between November and March.

Determination of fluoride: Samples of ground water from different rural areas in Khartoum state were collected and analyzed for fluoride in two different seasons (dry and rainy season). A GPS reading was recorded for each sampling well. Specifically, 32 samples of ground water, 16 for each season, were collected in polythene bottles. The sample bottles were cleaned and washed with acid water, followed by rinsing twice with distilled water, and then with the sample. The water samples collected were analyzed using SPADNS reagent as described by Standard Methods.[22]

Primary education examination system: Briefly, the education system in Sudan consists of two years of pre-primary education, eight years of primary education, three years of secondary level education, and at least four years of university education. The end of primary education cycle is marked by the primary school examination, which is used as a basis for the selection of pupils for secondary education. The examinations are set and organized by the educational authorities of each state. A certificate of primary school examination is issued by the Ministry of Education. The examined subjects are religions (two subjects each with 30 marks), languages (Arabic and English with 50 and 40 marks, respectively), mathematics (40 marks), sciences (2 subjects, each with 30 marks), and history (30 marks) giving a total of 280 marks. In this study, the data on school performance in the primary examinations were obtained from the Ministry of Education-Khartoum State. The results were confined to only the schools from the areas where the groundwater samples were collected. School children use the same source of drinking water whether they are at home or at school. The data include the results of 775 primary school pupils (315 boys and 460 girls) from 27 schools.

The results were analyzed by a method adopted by the Ministry of Education. Specifically the averages of all subjects were calculated for each school as a percentage of the average mark over the total mark using Microsoft Excel. Similarly, the high score prevalences of all the subjects were calculated as the percentages of number of students who scored more than 70% to the total number. It is worth mentioning that only students with high scores are able to join the model secondary schools in Khartoum state. The effect of the F level on schooling performance (average and high scores) was then investigated using SPSS.

RESULTS AND DISCUSSION

Fluoride level: The range for the F level was 0.14–2.07 mg/L in the dry season and 0.01–1.34 mg/L in the rainy season (Table 1). A statistically significant positive correlation (r=0.667, p<0.01) was observed between the F levels and the dryness of the season. Obviously, the relatively low F level during the rainy season was due to the dilution caused by the rain water. The highest level of F in the rainy season lies within the Sudanese and WHO standards.[1,23] However in the dry season it exceeded these standards. Although the F level not extremely high, frequent water drinking may occur due to several factors such as the rural human activities, arid conditions, and high temperatures. In addition, food products also contribute to the F intake as the people in these areas consume their own crops.[24] These crops may possibly accumulate F to considerable levels.

Table 1. Groundwater fluoride level (mg/L) in different rural areas

Area	Fluoride level (mg/L) in the rainy and dry seasons		
	Rainy season	Dry season	Average
1	0.01	0.14	0.08
2	0.28	0.91	0.60
3	0.50	0.50	0.50
4	0.44	0.44	0.44
5	0.92	1.03	0.98
6	0.72	1.59	1.16
7	1.34	2.07	1.71
8	0.14	1.00	0.57
9	0.29	1.11	0.70
10	0.60	0.91	0.76
11	1.00	1.00	1.00
12	0.67	0.76	0.72
13	0.60	1.32	0.96
14	0.08	0.60	0.34
15	0.37	1.13	0.75
16	0.38	1.05	0.72

Schooling performance (average score and high score prevalence): Using the Khartoum Ministry of Education's method, the schooling performance for the boys' and girls' primary schools in the 16 areas where the F samples were taken and were assessed by calculating the average score and high score prevalence for the 8 subjects of Islamic studies (I and II), Arabic, English, mathematics, sciences, history, and technology (food and health) and for the overall score (Tables 2 and 3). There were some differences in the 16 areas in the average scores and the high score prevalences for the subject and the overall scores. As seen in Table 2, the range for the average scores was 19–91%. The schools obtained reasonable percentages of ≥50% in the subjects of Islamic studies (I and II), history, and technology (food and health) and in the overall score while in the subjects of Arabic, English, mathematics, and sciences some of the averages were <50%. Table 3 shows that, in most of the subjects and in the overall score, extreme differences were present in the high score prevalences with a range of 0–100%. The range for Islamic studies I was 48–100%, for Islamic studies II 14–100%, for English 0–67%, for mathematics 0–48%, for sciences 6–100%, for history 18–100%, and for Arabic, technology (food and health), and the overall score 0–100%. Generally the schooling performance in these rural areas was poor compared to urban areas. There were also significant dropout rates in these rural areas,[25] which could reflect even lower schooling performances.

Table 2. Average score schooling performances (%) in the 8 subjects (Islamic studies [I and II], Arabic, English, mathematics, sciences, history, technology [food and health]) and the overall score

Area	School (boys and girls)	Average score = $\frac{100 \times \text{average mark}}{\text{total mark}}$ %								
		Islamic studies		Arabic	English	Mathematics	Sciences	History	Technology	Overall score
		I	II							
1	Boys	88	91	83	75	69	74	88	82	81
	Girls	90	71	74	42	40	72	83	64	65
2	Boys	72	90	76	62	63	88	84	77	76
3	Boys	68	62	50	45	19	66	71	51	52
4	Boys	78	82	74	57	49	76	91	83	72
	Girls	86	82	81	49	71	77	87	88	77
5	Boys	69	68	63	50	41	73	74	78	63
	Girls	84	74	67	41	64	74	73	81	68
6	Boys	77	68	66	39	44	44	64	56	57
	Girls	73	79	66	30	32	57	53	66	56
7	Boys	65	52	65	41	41	56	70	76	57
	Girls	80	70	74	49	40	58	70	70	63
8	Boys	82	73	75	48	47	70	73	65	66
	Girls	87	85	79	57	60	78	71	74	73
9	Boys	73	65	48	22	19	69	75	59	51
10	Boys	78	71	73	53	36	45	66	70	61
	Girls	82	60	74	47	37	51	58	68	59
11	Boys	78	76	62	60	43	70	81	67	66
	Girls	72	72	59	52	39	61	72	65	60
12	Boys	83	76	73	56	45	64	68	73	66
	Girls	88	80	80	55	54	70	76	79	72
13	Boys	73	59	54	34	28	52	62	56	51
	Girls	68	63	58	37	34	54	56	55	52
14	Girls	88	81	79	73	55	68	75	81	74
15	Boys	74	65	66	58	34	61	62	58	59
	Girls	86	85	80	60	57	71	75	82	74
16	Girls	86	77	73	49	31	65	59	66	62

Table 3. High score prevalence schooling performances (%) in the 8 subjects (Islamic studies [I and II], Arabic, English, mathematics, sciences, history, technology [food and health]) and the overall score

$$\text{High score prevalence} = \frac{100 \times \text{number of students scoring} >70\%}{\text{total number of students}}\ \%$$

Area	School (boys and girls)	Islamic studies I	Islamic studies II	Arabic	English	Mathematics	Sciences	History	Technology	Overall score
1	Boys	100	100	100	67	33	100	100	100	100
	Girls	100	50	50	0	0	50	100	0	0
2	Boys	64	100	79	24	36	91	88	70	65
3	Boys	57	19	10	14	0	43	52	5	5
4	Boys	73	82	55	27	18	73	100	100	55
	Girls	95	100	100	5	48	81	95	100	86
5	Boys	57	54	36	7	7	57	61	68	32
	Girls	75	69	19	0	0	63	88	44	19
6	Boys	54	31	23	0	8	15	23	8	0
	Girls	55	100	36	0	0	18	27	27	9
7	Boys	48	14	19	10	10	19	52	57	10
	Girls	80	51	62	18	10	25	49	51	27
8	Boys	84	58	79	11	21	47	68	53	42
	Girls	93	96	81	19	26	81	48	63	59
9	Boys	67	17	0	0	0	50	83	17	0
10	Boys	78	56	56	33	0	22	33	33	33
	Girls	88	24	53	24	18	6	24	59	24
11	Boys	75	88	25	25	6	50	100	38	31
	Girls	55	64	9	9	0	27	45	27	9
12	Boys	93	70	53	25	13	33	45	63	28
	Girls	100	77	83	22	20	40	63	70	50
13	Boys	66	29	26	6	3	20	40	20	14
	Girls	51	46	33	10	8	21	18	33	13
14	Girls	92	73	73	58	27	50	62	65	54
15	Boys	65	42	43	30	15	35	28	23	27
	Girls	92	91	82	32	34	47	64	86	57
16	Girls	87	74	61	16	5	37	29	39	26

Fluoride levels and schooling performances: The average F levels and the schooling performances (average scores and high score prevalences) were analyzed using SPSS as shown in Tables 4–7, respectively. Negative correlation coefficients were found for the average score for all the subjects and for the overall score, with the result being statistically significant in five out of the eight subjects and in the overall score (Tables 4 and 5).

Table 4. Association between the average drinking water fluoride (mg/L) and the average score schooling performances (%) in the 5 subjects of Islamic studies I and II, Arabic, English, and mathematics

Parameter	Subject				
	Islamic studies		Arabic	English	Mathematics
	I	II			
Pearson	–0.50†	–0.47*	–0.32	–0.46*	–0.33
Significance (2-tailed)	0.008	0.013	0.11	0.016	0.097
N	27	27	27	27	27

*Correlation is significant at the 0.05 level (2-tailed), †correlation is significant at the 0.01 level (2-tailed).

Table 5. Association between the average drinking water fluoride (mg/L) and the average score schooling performances (%) in the 3 subjects of sciences, history, technology and the overall score

Parameter	Subject			
	Sciences	History	Technology	Overall score
Pearson	–0.53†	–0.59†	–0.30	–0.51†
Significance (2-tailed)	0.005	0.001	0.158	0.007
N	27	27	27	27

*Correlation is significant at the 0.05 level (2-tailed), †correlation is significant at the 0.01 level (2-tailed).

Similarly, negative correlation coefficients were found for the high score prevalences for all the subjects and for the overall score, with the result being statistically significant in six out of the eight subjects and in the overall score (Tables 6 and 7).

Table 6. Association between the average drinking water fluoride (mg/L) and the high score prevalence schooling performances (%) in the 5 subjects of Islamic studies I and II, Arabic, English, and mathematics

Parameter	Subject				
	Islamic studies		Arabic	English	Mathematics
	I	II			
Pearson	–0.59†	–0.35	–0.47*	–0.41*	–0.39*
Significance (2-tailed)	0.001	0.078	0.014	0.034	0.045
N	27	27	27	27	27

*Correlation is significant at the 0.05 level (2-tailed), †correlation is significant at the 0.01 level (2-tailed).

Table 7. Association between the average drinking water fluoride (mg/L) and the high score prevalence schooling performances (%) in the 3 subjects of sciences, history, technology and the overall score

Parameter	Subject			
	Sciences	History	Technology	Overall score
Pearson	–0.60†	–0.46*	–0.22	–0.48*
Significance (2-tailed)	0.001	0.016	0.265	0.012
N	27	27	27	27

*Correlation is significant at the 0.05 level (2-tailed), †correlation is significant at the 0.01 level (2-tailed).

Considering the results of the Tables 4–7, which were found to be related to each other, significant correlations undoubtedly exit between the drinking water F level and the schooling performances in all the subjects except for one, technology, which might be due to the nature of the subject. Thus, school children exposed to F may have an increased risk of low schooling performance. Taking into account the positive correlation between the schooling performance and IQ as reported in literature, it follows, logically, that the IQ of school children in the studied areas is similarly affected by the drinking water F levels. Thus, it is not only endemic high drinking water F regions that have low IQ[11,14,15] but also areas with F levels within and slightly higher than the WHO recommended range.[1]

There may be several reasons why some studies have found that F in not a neurotoxicant.[11,16,26] Firstly, the F level in the fluoridated water could have been be adjusted to give a lower level than the allowable upper limit. Secondly, there are considerable geographical and climatic differences between the areas with fluoridated water and the regions with endemic high drinking water F levels. Consequently, the consumption of water is significantly higher in hot regions, resulting in the accumulation of more F. This is consistent with the studies by Linhares et al., who also considered that nail clippings were a more sensitive biomarker than urinary F for assessing long-term exposure to F,[27] and by Ramadan and Hilmi who noted that with a given drinking water F concentration the prevalence and severity of fluorosis seems to increase with increasing mean daily temperature. After considering the mean temperatures in Sudan, Ramadan and Hilmi recommended that the upper permissible level of F in potable water in Sudan be set at between 0.32 and 0.35 mg/L, and that for Khartoum State with a mean temperature of 36.8ºC the upper permissible F level be 0.33 ppm.[28] Thirdly, F neurotoxicity depends on the level and duration of exposure and the presence of predisposing and protective factors such as nutritional status, iodine deficiency, and exposure to other known neurotoxicants (e.g., lead or arsenic) as has been described in the literature.[10] In this respect, exposure to heavy metal neurotoxicants is not likely to contribute to the low school performance found in the present study as there is no heavy metal pollution in Khartoum State in areas other than those in industrial and roadside locations.[29,30]

CONCLUSION

In summary, the results of this study suggest that there may be an association between the fluoride level in drinking water and the schooling performance of children. This result may be applicable to children in other areas with conditions similar to those of the study areas. Consequently the upper permissible drinking water fluoride level needs to be revised downwards to minimize the effect of fluoride on children neurodevelopment.

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