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EVALUATING THE INFLUENCE OF FLUORIDATED WATER ON THE INTELLIGENCE LEVEL OF CHILDREN: ON THE PATH TOWARDS A GREENER FUTURE

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ABSTRACT: A cross-sectional study was carried out to investigate the impact of fluoridated water on the intelligent quotient (IQ) of primary school-going children. We used a random sampling approach for data collection purposes. A total of 376 respondents (10–16 years old) were chosen from areas with high and low levels of fluoride in drinking water (high fluoride group: 1.2–2 mg F/L [mean 1.7±0.3], n=205, mean age 12±2.1 years; low fluoride group: <1.2 mg F/L [mean 0.8±0.2], n=171, mean age 12.2±2.0 years). Several statistical tests, such as independent sample t-test, one-way analysis of variance (ANOVA), and post-hoc analysis, were used to assess the IQ level in the two groups. The results of ANOVA indicate a highly significant difference in the mean IQ levels of children in the different groups (*p* = 0.0001). The results showed that there is a negative correlation between IQ levels in children and the fluoride concentration in drinking water. These findings may help to further understand the harmful effects of fluoride on the IQ level of children, help overcome the problem of high fluoride concentrations in drinking water, and assist governments in strengthening policy making for the provision of safe drinking water.

Keywords: Administrative policies; Children; Fluoride; IQ level; Pakistan; Primary school,. Pakistan.

INTRODUCTION

Environmental and climate change issues have dominated throughout the world during the last few decades.[1-4] Environmental pollution has a negative impact on the environment, nature, and society at large.[5-9] Efforts are being undertaken to overcome these challenges.[10-14] However, a successful and seamless transition is highly dependent on coordinated efforts at numerous levels and on the participation of all the stakeholders.[15-20] Exposure to fluoride through an elevated fluoride concentration in drinking water is a big problem worldwide. A high concentration of fluoride in drinking water may cause a severe effect on the intellectual level of children. Many Asian and Latin American countries have reported drinking water fluoride levels exceeding the WHO recommended upper limit of 1.5 ppm (mg/L). It is noted, however, that WHO also allows lower country standards to be set and levels of 0.6 mg/L and 1.0 mg/L have been set by Senegal and India, respectively, with the Indian standard having the rider the "lesser the fluoride the better, as fluoride is

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injurious to health."[21,22] Research from Bangladesh by Wasserman et al. exposed the inverse relationship between fluoride in drinking water and the intellectual level of children.[23] The authors pointed out the limited amount of research done in this field and the limited awareness of the general public of the problem.[23] Two other studies, from Mexico,[24] and in Taiwan,[25] also showed a negative relationship between children's intellectual and fluoride exposure. However, both these studies had only small sample sizes (n < 100). In many communities of Mexico, people are exposed to fluoride in drinking water.[26] Naturally occurring element may have beneficial or harmful effects, with dose being factor. In many places, people depend on groundwater for survival and are at risk of being adversely affected by the fluoride concentration if this is high. When fluoride intake increases above a safe level, it may harm the body of human and the nervous system is particularly sensitive to being harmed *in utero* and the early years of development.[27] If a mother has a high intake of fluoride during pregnancy, this may adversely impact the child's intelligence quotient (IQ).[28]

Other studies have investigated fluoride's negative effect on the brain and explored the actions of protective agents.[29] Mother's exposure to high fluoride levels during the pregnancy adversely affected fetal cerebral function and neurotransmitters.[29] Spittle et al. did find any trend or relationship between fluoride and a child's IQ in 8 and 9 year-old- children in New Zealand who had been exposed to water fluoridated with 1 ppm fluoride for 0, 1–3, 4–6, and 7 years[30] and it is now considered that it is fluoride exposure *in utero* and in the early development years that is most important in the development of fluoride-induced neurotoxicity.[31] The current research aimed to investigate the association of fluoride and children's IQ level in the tribal areas of Pakistan (i.e., four villages of Kurram and Orakzai Agency). In this region, people mostly rely on the groundwater coming from the mountains. In this study, we investigated the effect of fluoride concentration and on children's IQ.

MATERIALS AND METHODS

Study design: In this study, the cross-sectional method was designed to analyze the effect of fluoride in drinking water on intelligence among primary school-going children (10–16 years old) in four villages of tribal areas (Kalaya, Ghotak Issa Khel, Sadda, and Ghunde Kaly). For ethical considerations, the local administration and luminaries were informed and the parents' consent was obtained after thoroughly explaining in detail the purpose of the study.

Sample size and technique: A random sampling approach was used for data collection purposes. A total of 376 respondents were chosen with a 95% confidence interval having a 5% margin of error (Yamane, 1973). It was aimed to have 94 children selected for each of four groups (high and low fluoride, boys and girls). All these four villages were selected according to the concentrations of fluoride in the drinking water: fluoride level < 1.2 mg/L was considered low, and fluoride level 1.2–2 mg/L was considered high.

Selection criteria of the respondents (exclusion and inclusion): The children who were permanent residents of the areas, with shared culture and similar socioeconomic status and who were using the same underground water for drinking could be the part

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of the study. The children with disability or who migrated to the area from other tribal regions could not be a part of the study.

Fluoride estimation: For fluoride estimation, water samples were collected at all four villages from wells and streams that were confirmed by the inhabitants as being using as drinking water. New bottles were used for water sample collection, coded to represent a specific village, and then stored in an icebox to preserve all the characteristics. The electrode method (Thermo-Scientific Orion 4 star) was used to measure the fluoride level in water samples belonging to particular villages.

Intelligence estimation: Raven's Standard Progressive Matrices test[32] was used. This was initially developed in 1936 and contains 60 multiple choice questions in order of difficulty. All the questionnaire items have some difficulty and can differentiate the intelligence among children belonging to various villages. These were tasks like missing words, puzzles, or finding items to identify and complete tasks from the given choices. The aggregate scores were changed to percentile, and the particular grades were provided as follows:

Grade I: Intellectually superior (IQ score = 95%)

Grade II: Definitely above average (IQ score > 75%)

Grade III: Intellectually average (IQ score 75–25%)

Grade IV: Definitely below average in intellectual capacity (IQ score =25%)

Grade V: Intellectually impaired (IQ score of = 5%).

Statistical analysis: The data was coded and entered in Microsoft Excel spreadsheet software (Microsoft Inc., Redmond, WA., USA). In addition, we analyzed the data using Statistical Package for Social Sciences (SPSS) version 22 (SPSS Inc., Chicago, IL., USA). Several statistical tests, such as independent sample t-test, one-way analysis of variance (ANOVA), and post-hoc analysis, were used to assess the IQ in different fluoride concentration groups.

RESULTS

Sample characteristics: The descriptive information on demographics of children and fluoride concentration of water is provided in Table 1. There were more girls in both high and low F groups than the boys. There were 205 children in the high F group, while 171 children belonged to the low F group. The average age of children in both groups was about 12 years, and there were no significant differences in age. Similarly, the education of children's parents was below high school, with no significant differences across the two groups. The income level of households was close to the minimum wage rate in Pakistan. However, there was no significant difference in income levels in high and low F groups. In the low F group, the fluoride concentration in water was 0.8 mg/L, while it was significantly higher (1.7 mg/L) in the high F group.

The mean IQ levels of school children in the low and high F groups are reported in Table 2. The results revealed that children in the low F concentration group had a significantly higher IQ level (49.62) than those in the high F concentration group (35.14). The results of ANOVA indicate a highly significant difference in the mean

IQ levels of children in the different F groups (p = 0.0001). These results show that there is a negative correlation of IQ levels with fluoride concentration in water.

Table 1. Study parameters for all villages in the study areas [a]

Parameter	High fluoride group	Low fluoride group	p-value
No. of girls	110	98	
No. of boys	95	73	
Sum	205	171	
Age (years)	12 ± 2.1	12.2 ± 2.0	0.17[b]
Income (PKR/month)	18000 ± 250	18270 ± 340	0.12[b]
Parents' education (yea	9.2 ± 1.2	8.8 ± 1.1	0.15[b]
Water fluoride (mg/L)	1.7 ± 0.3	0.8 ± 0.2	0.03

[a]Values are reported for means ± SD for all parameters unless otherwise noted;
[b]The t-test was used to compare the differences between groups.

Table 2. Mean IQ levels of school children in low and high F groups

Fluoride concentration	Mean IQ levels	*f*-value	*p*-value
Low (<1.2 mg/L)	49.62 ± 12.15)	61.324	0.0001
High (>1.2 mg/L)	35.14 ± 15.40)		

The mean IQ levels among boys and girls in the two F concentration groups are reported in Table 3. We found that boys and girls have higher average IQ levels in the low F group than in the high F group. Further, the boys' IQ levels were higher than girls in both F concentration groups. Besides, we found no significant differences in the mean IQ levels of boys and girls within the same group. However, the mean IQ levels between low and high F groups differed significantly for boys and girls (p = 0.0001*)*. These results show that the effect of fluoride in water is not gender-specific, and there is a negative correlation between IQ levels and F concentration in water.

Table 4 shows the frequency distribution of IQ levels of school children according to the two F concentration groups. Results show that about three-quarters of children in the low F group had Grade III IQ scores. Further, about 20% of children in this group had a Grade IV IQ level. However, in the high F group, school children had lower IQ levels as the results showed that about 60% of children belonged to the Grade IV IQ level group. Further, about 40% of children belonged to Grade III in the high F group. These results show that there is a negative correlation between fluoride

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concentration and children's IQ levels. The one-way analysis of variance (ANOVA) showed that the differences in different IQ groups were statistically significant.

Table 3. Mean IQ Levels of boys and girls in the low and high F groups (IQ = Intelligence Quotient)

Fluoride concentration	Mean IQ level (boys)	Mean IQ level (girls)	t-value	p-value
Low (<1.2 mg/L)	51.52 ± 11.13[a]	48.02 ± 13.19[b]	0.43	0.665
High (>1.2 mg/L)	37.12 ± 14.17	34.32 ± 16.81	0.371	0.735

[a]The mean IQ levels between the boys in the low and high F groups were significantly different (p = 0.0001).
[b]The mean IQ levels between the girls in the low and high F groups were significantly different (p = 0.0001).

Table 4. Distribution of IQ levels of the sample of children. (F conc= fluoride concentration; Grade I=intellectually superior; Grade II=definitely above average; Grade III=intellectually average. Grade IV=definitely below average in intellectual capacity; Grade V=intellectually impaired)

Fluoride conc (mg/L)	IQ levels					f-value	p-value
	Grade I (?95) (%)	Grade II (95-75) (%)	Grade III (75-25) (%)	Grade IV (25-5) (%)	Grade V (?5) (%)		
Low (<1.2)	0	11 (5%)	166 (75.45) (%)	43 (19.55) (%)	0	108.843	0.00001
High (>1.2)	0	0	104 (40.62) (%)	152 (59.38) (%)	0		

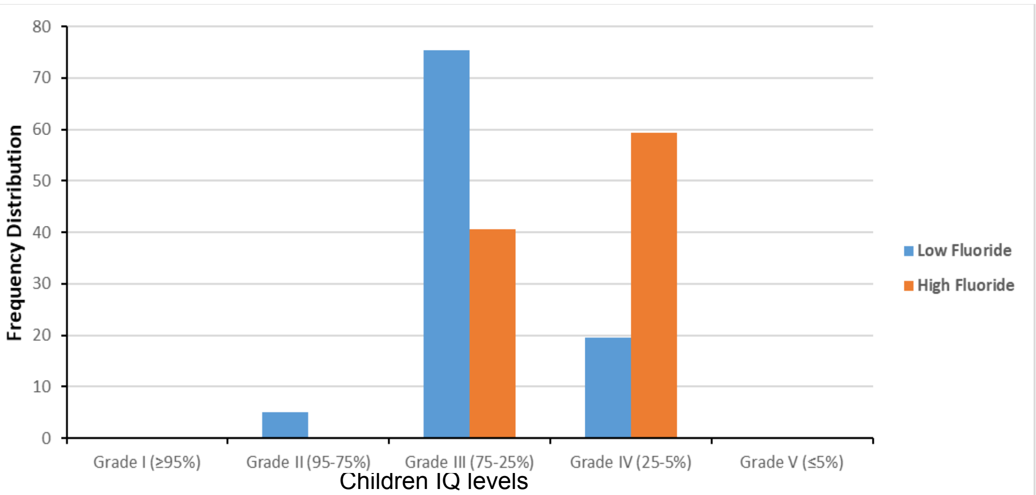

Figure 1. Frequency distribution of IQ in school children exposed to different fluoride concentration levels in the water.

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DISCUSSION

The present study of 376 children revealed that exposure to drinking water with a high fluoride concentration (1.2–2 mg/L) was associated with a significant lowering of IQ. This result indicates that long-term and early exposure to a high concentration to fluoride may lead to memory deficit. This is in contrast to a study by Eswar et al.of 173 school-going children, aged 12–14 years, in villages in the Davangere district, Karnataka, India, drinking water with high (2.45 mg/L) and low (0.29 mg/L) fluoride concentrations.[33] The authors found a trend toward lower IQ with high fluoride water but the difference was not statistically significant.[33] Other studies on humans have revealed that the developing brain is the ripest target for the disruption caused by fluoride poisoning. In the early stages of life, i.e., before the age of 6 years, the human brain is in the fastest developmental stage. Then, around seven and eight years, the basic structural development is completed. Therefore, taking F at a higher concentration before this stage may cause more damage.[34]

This study indicates a neurotoxic effect on the children while drinking water with a high fluoride content. According to Cheng and colleagues, animal experiments proved that fluoride may affects the IQ level and damage brain function.[35] Many studies have been conducted on animals,[36] and these have elaborated the possible mechanisms for the neuro-hazardous effects of fluoride at the fetal stage.[37] When the structural development of the brain is in process at this time more of the ingested fluoride is retained in the body.[38] The level of fluoride retention is increased in children (80–90%), compared to adults for whom approximately 50% of the ingested fluoride remains in the body.[38] If fluoride is present in the blood, it makes some lipid-soluble complexes that cross the blood-brain barrier and are accumulated in the cerebral tissues. The central nervous system is adversely affected by penetrated fluoride complexes through various neurotoxic mechanisms, i.e., free radical generation, inhibition of antioxidant and mitochondrial energy enzymes, and glutamate transporter inhibition.[39]

It was found, in the Zhao county of Heilongjiang province in northeastern China, where the intake of fluoride is high, that when pregnant mothers have exposure to a higher concentration of fluoride, the infants have neurobehavioral development impairment and agonistic developmental muscle tension abnormalities. Agonistic muscle tension is often affected when brain damage occurs, which is consistent with the results of Liu et al. and Wang et al.[40,41] In our follow-up study, we have conducted this research in the northern area of Pakistan, i.e., Koram agency and Orakzai agency. Our results reveal that there is a negative correlation between exposure to fluoride and IQ level. These findings are consistent with those of Trivedi et al. who found that the children in a high drinking water fluoride area (5.55±0.41 mg/L) had a significantly lower IQ (91.72±1.13) compared to children from a low drinking water fluoride area (2.01±0.09 mg/L) whose mean IQ was 104.44±1.23.[42] The WHO reported that as the fluoride concentration increased, it affected the IQ level more vigorously. Li and colleagues conducted a study which found that as the fluoride passes through the blood-brain and placental barriers, it had the potential to damage brain development in the fetus.[43] It was found to be harmful for brain functionality in the children when the fetus was *in-utero* and in a developmental stage.[43] Our results are also in line with the results of Li et al. and support our

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hypothesis. In other words, our results highlight the significant effect of fluoride, at a concentration of ≥1.2 mg/L in drinking water, on the IQ of children. In some studies, fluoride is the primary factor affecting the IQ level[40] Similar to the findings of Trivedi at al, our results show a significant inverse relationship between the level of fluoride in drinking water and IQ.

CONCLUSIONS

In conclusion, there was a significant inverse relationship between the level of fluoride in drinking water and children's IQ levels. However, other factors such as social, cultural, economic condition, environmental and nutrition factors may also affect the IQ level of children. Secondly, an excessive intake of fluoride in drinking water, particularly during pregnancy and the early years of development, may adversely affect human health. To provide for the overall well-being of people, especially children, access should be provided to clean safe drinking water. Governments, local bodies, policy makers, and other stakeholders should play an active role in ensuring fluoride-safe drinking water is available for drinking and cooking. All drinking water sources, such as private wells, water borings, and municipal water supply lines, should be identified, tested, and regularly monitored in all fluoride-high drinking water areas and localities.

LIMITATIONS AND ADMINISTRATIVE POLICIES

We found that the lack of awareness among the local population about the phenomena of fluoride toxicity created some difficulties in explaining the purpose of the study which affected the data collection. We found that some medical-related personnel had only a limited knowledge of about fluoride and sometimes misunderstandings were present. even. We found a high level of fluoride in the drinking water of some of areas studied and note that the previous literature concludes that overuse of fluoride can be harmful to the human body. The long-term exposure to excessive fluoride will increase the risk of dental fluorosis, skeletal fluorosis, and nonskeletal fluorosis including neurological diseases. As a result of the study we suggest some policies that might be considered by local administrations to create more awareness among the local populations about fluoride use and its effects. It would be helpful to arrange training about fluoride for the local dentists and other medical personnel, which might create a better understanding and knowledge about fluoride use and its effects. The local administration needs to provide an alternate source of filtered and safe drinking water for the local population when the level of fluoride in drinking water is high. The concerned department should introduce and initiate fluoride-safe drinking water supply schemes by identifying safe water sources and ensuring the operation and maintenance of the water supply schemes. These water supply schemes should meet the government standards for the long-term sustainability of supplying fluoride-safe drinking water in all high-fluoride drinking water areas.

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