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Assessment of the Impact of Groundwater Fluoride on Human Health: A Case Study of Makindu District in Kenya

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Abstract

Assessment of human exposure to the naturally occurring fluoride in groundwater in Kenya has not being exhaustive. This study investigated the extent of human exposure to fluoride and its impact on human health in Makindu District, and evaluated the potential risk of using ground water contaminated by fluoride ion (F^-). The study used an ex post facto design and the data collection tools used were interviews, questionnaires, key informants and observation. Water from three boreholes and a spring in the study areas was analysed for pH, Total Alkalinity, Total Hardness, and concentrations of Fluoride, Chloride, Sulfate, Iron, Calcium, Magnesium, Sodium and Potassium. The collected data was analyzed using the Ms-Excel and Statistical Package for Social Sciences (SPSS). The results show that majority of the respondents relied on tap water from springs. Raw water from Makindu Spring, the main source of drinking water for Makindu Town, had fluoride concentration of 1.1 mg/L, which is below the WHO maximum allowable value of 1.5 mg/L. All the three boreholes covered during the study had fluoride concentration above the WHO maximum allowable value. This implied that the population that relied on boreholes as a source of water was exposed to health risk associated with high fluoride. 38.4% and 33.3% of the respondents, respectively from Kiboko Location and Makindu Location, had moderately to severely mottled enamel, an indication of the impact of fluoride in water. It is recommended that de-fluoridation systems should be introduced and that alternative sources of water be developed to mitigate the impacts of high fluoride water to the local communities.

Keywords: Dental caries; Environmental problem; Fluoride; Groundwater; Geology; Plaque

Introduction

Water is life and therefore, without water, man's existence on earth would be driven close to extinction. All biological organisms depend on water to carry out complex biochemical processes which aid in the sustenance of life. However, although water covers about 70% of the earth's surface, only 2.53% is fresh water while the remaining is salt water [1].

Groundwater is well thought-out to be the most vital natural and fresh resource on earth which is used for drinking and irrigation purposes. Groundwater quality studies become unavoidable since its poor quality may badly affect its users [2].

Fluoride is an ion of the chemical element fluorine which belongs to the halogen group. Fluoride is a common constitute of ground water where natural sources are connected to various types of rocks and to volcanic activities [3,4]. It occurs naturally in public water systems as a result of runoff from weathering of fluoride containing rocks and leaching from soil into groundwater [5]. Atmospheric deposition of fluoride containing emissions from coal fired power plants and other industrial sources can also contributes to amounts found in the water, either by direct deposition or by deposition to soil and subsequent runoff into water [3].

Fluoride has a significant mitigating effect against dental caries if the concentration is approximately 1.0 mg/L [6]. Fluoride prevents tooth decay by enhancing the remineralization of enamel that is under attack, as well as inhibiting the production of acid by decay causing bacteria in dental plaque [7]. Fluoride is also a normal constituent of the enamel itself, incorporated into the crystalline structure of the developing tooth and enhancing its resistance to acid dissolution. However, continued consumption of higher concentrations can cause dental fluorosis [8]. High fluoride concentrations are especially critical in developing countries, largely because of lack of suitable infrastructure for treatment [9]. High fluoride in water is a major health hazard in many parts of the world and it is known to cause dental and skeletal fluorosis, osteosclerosis, thyroid, kidney changes and cardiovascular, gastrointestinal, endocrine, neurological, negative effects if concentration is higher than 1.5 mg/l in drinking water [10,11].

Awareness of the environmental problem of fluoride in drinking water has been increased by the fact that skeletal abnormalities and dental fluorosis can be related to the level of fluoride intake [12]. In Kenya, cases of dental caries and dental fluorosis have been related to the amount of fluoride consumed mainly from drinking water, which for a large number of communities is obtained directly from boreholes or streams [13].

There is wide variation in fluoride levels in the natural waters of Kenya [14] with concentrations above and below the optimal range set by the World Health Organization for drinking water encountered [15] are encountered [16]. River waters generally have fluoride contents in the lower part of this range whereas ground waters show much higher levels [17,18].

Makindu District being in arid and semi-arid area, Calcium and Magnesium/carbonate concentration are high in the soils and rocks and appear to be good sink for the fluoride ion. Makindu District like any other arid region is prone to high fluoride concentrations. Here,

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groundwater flow is slow and the reaction times with rocks are therefore long. The fluoride contents of solution in water may increase during evaporation if solution remain in equilibrium with calcite and alkalinity is greater than hardness. Dissolution of evaporative salts deposited in arid zones may be an important source of fluoride [2].

Little is reported on the impacts on the human exposure to the fluoride particularly the local community and general public in Makindu District. The problem with continuing consumption of higher concentration of fluoride can cause dental fluorosis and in extreme cases skeletal fluorosis [9]. Research is therefore necessary in Makindu District, Makueni County, to provide information and representative data to the relevant environmental and health authorities, add to scholarly knowledge as well as create awareness among the general public about the impacts on human health caused by the fluoride in the environment.

The purpose of this study was therefore to investigate the occurrence of high fluoride in groundwater in Makindu District, determine the extent of the exposure of fluoride to the human population and assess the impact of fluoride in drinking water to human population in the area.

Material and Methods

Study area

The study was carried out in Makindu District which is located in Makueni County in the South eastern region of Kenya. It is located between 2°16' 30.00"S, 37°49' 12.00"E (Figure 1) and has an approximate area of 8000 km^2. It has an estimated population of about 121,934. Makindu District consists of four administrative locations namely Makindu, Nguumo, Kiboko and Twaandu locations.

The climate of the area is characterized by a bimudal low rainfall regime that falls mainly in the periods of February to April and October to December. The area falls within the arid and semi-arid ecological zone and has mean annual rainfall of approximately 600 mm and mean annual potential evaporation amounts to about 2300 mm. The annual mean temperature is about 27°C while the annual mean minimum temperature is about 16°C (Meteorological Department, Makindu, unpublished data).

Both perennial and ephemeral surface water sources are important elements in water supply in the study area. Several streams drain into the area, the major river being Kiumbi which is seasonal with many wells dug along its length. The geology of the area is characterized by two major geological and lithological systems, the Precambrian Basement system and the Younger Tertiary basaltic lavas. The Basement System rocks are mainly gneisses, schist, granulite and crystalline limestone of sedimentary origin. These rocks are poorly exposed and form the few scattered outcrops in the principal river-courses where a fairly continuous section can be recognized [19].

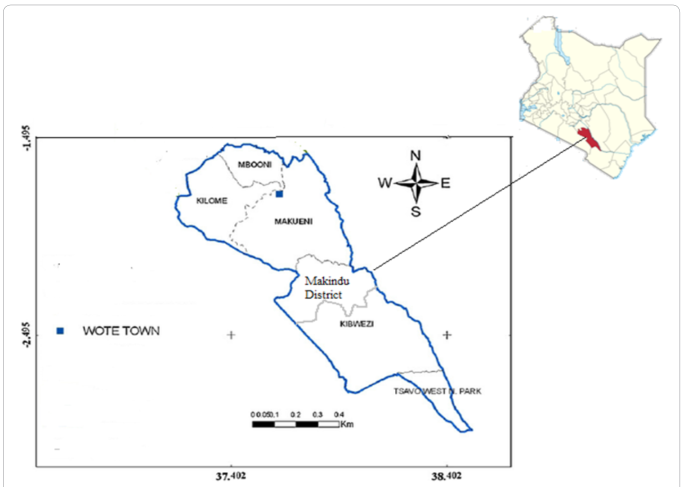

Figure 1: Map of Makueni County showing the location of Makindu District (Inset: Location of Makueni County in Kenya).

The 2009 population and housing census estimated the population of Makindu District as 121,984 with a population density of 0.067 persons per sq. Kilometer [20]. The district is therefore sparsely populated due to arid and semi-arid climate.

Makindu and Nguumo locations are supplied with water from the same source (Makindu Water and Sanitation Company, MAWASCO, water supply) while Kiboko and Twaandu Locations get water from Kikuu River. In addition, there are borehole water sources for the community in the two locations.

Research design

The study adopted an ex post facto design. This design is defined by Lammers and Badia as a non-experimental research technique [21]. The design is ideal for this study considering that the independent variables in this case cannot be manipulated by the researcher. The manifestations of the independent variables i.e., fluoride in groundwater, cannot be changed. The dependent variables are; dental carries, dental fluorosis, and skeletal fluorosis.

Study populations

The researcher purposively selected Makindu and Kiboko locations to represent the four locations in Makindu District. This is because Makindu and Nguumo Locations are supplied with water from the same source, which also applies to Kiboko and Twaandu Locations. The study targeted 286 individuals from Makindu Location and 112 people from Kiboko Location, determined by population thus a total of 398 individuals were interviewed. The sampling frame was. The sample size was determined from a total population of 66, 984 individuals using the formula proposed by Gay [22].

$n= N/(1+N(a)^2)$

Where 'n' is the sample size

'N' is the total number of individuals

'a' is the margin of error estimated at 5% (0.05).

$n=66,984/(1+66984(0.05)^2)$

$n=66984/168.46$

$n=397.625549091$

n=398 persons

Simple proportion was used to calculate the number of individuals for each selected location. Makindu location represents 72% of the sampling frame and so 72% of 398 whereas Kiboko location represents 28% of the sampling frame which is 112 persons. Out of the 398 individuals, there were three key-informants; two dentists and a health officer.

Data collection tools

Three main research tools were used in the data collection namely;

a questionnaire for the key-informants (i.e., the health officers), an interview schedule to collect information from community members and an observation schedule to record the mottled enamel and its intensity on selected individual. Cell phones were also used where necessary.

Ethical considerations

The respondents were briefed on the research and its importance and none was compelled to participate /complete the questionnaire but were allowed to do so at their will. The completed questionnaires were handled with a lot of confidentiality – so that no information about a respondent(s) leaked out.

Water quality sampling and analysis

Water samples were collected from Makindu Spring and three boreholes (Makindu, Kalii and Kiboko). The water samples were put in clean in one litre plastic containers and immediately transported to the laboratory for the analysis of pH, Total Alkalinity, Total Hardness, and Fluoride (F^-), Chloride (Cl^-), Sulfate (SO_4^{2-}), Iron (Fe), Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K) concentrations. The analysis was done following standard procedures as described in APHA [23]. The results were compared with WHO drinking water standards.

Data analysis

Analysis was done to determine the decayed, filled surfaces, missing teeth and mottled enamel. The residential data was also analyzed to co-relate exposure time of the fluoride and the mottled enamel/ dental fluorosis. The data was presented in form of charts, graphs and frequency distribution tables.

Results and Discussion

Respondents age, gender and academic qualification

The frequency and percentages of respondents' age are presented in Table 1. The respondents aged 15-19 years were 21.3% and 17% for Makindu location and Kiboko location respectively. In Kiboko, it was also noted that those aged 10-14 years were 17%. The least respondent were those aged 45-49 years (1.7%) for Makindu while for Kiboko it was those who were more than 59 years (3.6%). These results shows that there was a good distribution in age from 10 years to more than 59 years hence the researcher was able to gather information from a good representation of many age groups in the society.

	Makindu location		Kiboko location	
Age bracket	Frequency	Percentage	Frequency	Percentage
Less than 10	12	4.3	4	3.6
10 – 14	48	16.8	19	17
15 – 19	61	21.3	19	17
20 – 24	34	11.9	14	12.5
25 – 29	19	6.6	11	9.8
30 – 34	19	6.6	11	9.8
35 – 39	24	8.4	5	4.5
40 – 44	0	0	5	4.5
45 – 49	5	1.7	5	4.5
50 – 54	24	8.4	5	4.5
55 – 59	28	9.8	10	8.7
$\geq$ 60	12	4.3	4	3.6
Total	286	100	112	100

Table 1: Frequency and percentage proportion of different age bracket in Makindu and Kiboko locations.

	Makindu Location		Kiboko Location	
Gender	Frequency	Percentage	Frequency	Percentage
Male	186	65	70	62.5
Female	100	35	42	37.5
Total	286	100	112	100

Table 2: Frequency and percentage of respondent's gender.

	Makindu Location		Kiboko Location	
Academic level	Frequency	Percentage	Frequency	Percentage
Primary	143	50	67	59.8
Secondary	114	40	39	34.8
College	24	8.4	3	2.7
University degree	5	1.6	3	2.7
Total	286	100	112	100

Table 3: Educational level of respondents.

	Makindu location		Kiboko location	
District of birth	Frequency	Percentage	Frequency	Percentage
Makindu	191	66.8	56	50
Other	95	33.2	56	50
Total	286	100	112	100

Table 4: Respondent's district of birth.

	Makindu Location		Kiboko Location	
Period of stay in years	Frequency	Percentage	Frequency	Percentage
01-May	29	10.1	25	22.3
6 – 10	19	6.6	14	12.5
11 – 15	52	18.2	20	17.9
$\geq$ 15	186	65	53	47.3
Total	286	100	112	100

Table 5: Respondent's Period of stay in the location.

The respondents' gender is presented in Table 2 where it was found that majority of respondents were male with Makindu having 65% and Kiboko 62.5% as male. The female respondents were 35% and 37.5% for Makindu and Kiboko respectively. The males were relatively more than the females due to the fact that in the African setting, the males, being the heads of the family, opted to talk/respond to the research questions.

The research sought to establish the academic qualification of respondents, in order establish their literacy level and the results are presented in Table 3. Majority of the respondents Kiboko (59.8%), Makindu (50%) had primary Education as their highest level of Education. This was followed by secondary Education at 40 % (Makindu) and 34.8 %(Kiboko). The academic level with least frequencies was the University degree level with 1.6% and 2.7% for Makindu location and Kiboko respectively. This shows that, all respondents had basic education which could help them give reliable responses.

District of birth and period of stay in the study area

Table 4 shows the proportion of those who were born in and outside the study areas. In Makindu, majority (66.8%) were born in the district while 33.2% were born in other districts, whereas in Kiboko the number of those born within and outside the district was the same (50%). The respondents who were born in other districts resided in the study areas at the time of the research. This show that the respondents were in a better position to give reliable information concerning water sources in the study area.

The frequency and percentage of respondents who have lived in the study area for different periods are presented in Table 5. Majority (65%) had stayed in Makindu for more than 15 years while 47.3% had stayed in Kiboko for the same number of years. It is assumed that this length of stay was good enough to give reliable results for the study.

Main sources of water

The main sources of water in the study area, are presented in Figure 2. Majority, 80% and 68% respectively, of the respondents in Makindu and Kiboko relied on tap water from the spring. This was followed by those who relied on borehole water, 10% and 21% respectively in Makindu and Kiboko. The third important source was rain water, accounting for 8% in both locations. The rivers were least sited source of water with 2% and 3% in Makindu and Kiboko respectively.

Physiochemical characteristics of water

The physiochemical characteristics of selected water sources in the study area are presented in Table 6. The water quality characteristics varied differently between the three sources, Makindu Spring, Makindu borehole, and Kiboko borehole, with on average Makindu Borehole recording the highest values. In Makindu Borehole chloride, total hardness, total alkalinity, sulfate and magnesium values were above the WHO guidelines. Chloride concentration was lowest in Makindu spring (28 mg/L) whereas total hardness and total alkalinity were highest in Makindu borehole (700 and 851 mg $CaCO_3$/L respectively). Iron concentration was generally low with concentration below detection limit of 0.01 mg/L, except in Makindu borehole (0.07 mg/L). pH values were within the range of WHO guidelines and calcium was lower than WHO guideline value in the three water sources.

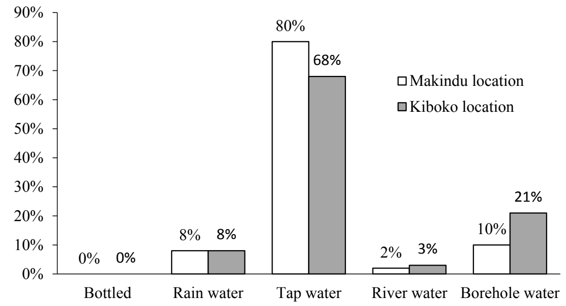

Figure 2: Percentages of respondents using different water sources in Makindu and Kiboko locations.

Parameter	Makindu Spring (Raw)	Makindu Borehole	Kiboko Borehole	WHO Guidelines
Chloride (mg/L)	28	260	144	250
Total Hardness (mg $CaCO_3$/L)	260	700	260	500
Total Alkalinity (mg $CaCO_3$/L)	408	851	348	500
pH	8.53	7.3	8.17	6.5-8.5
Sulphate (mg/L)	57.1	622	50	450
Iron (mg/L)	<0.01	0.07	<0.01	0.3
Calcium (mg/L)	48	70.8	6	100
Magnesium (mg/L)	34	122.4	2.7	100
Sodium (mg/L)	110.5	193	272	200
Potassium (mg/L)	12		0.4	

Table 6: Chemical characteristics of water from Makindu Spring (Raw) and Makindu Borehole and Kiboko Borehole and the WHO guidelines for drinking water. Bolded values are above WHO guidelines.

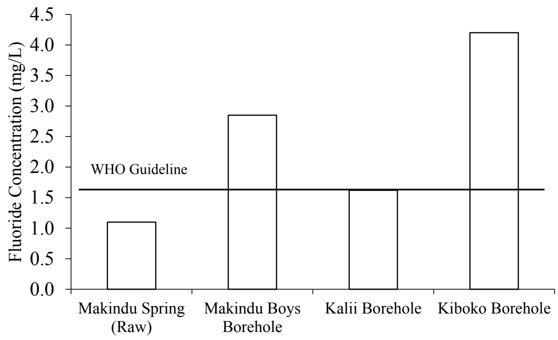

Figure 3 Fluoride concentrations in water from different water sources within the study area.

The fluoride concentration in water from different sources is presented in Figure 3. All the three boreholes had fluoride concentration above the WHO maximum allowable value of 1.5 mg/L. Kiboko Borehole had the highest concentration of 4.2 mg/L followed by Makindu Boys Borehole with concentration of 2.85 mg/L. Kalii Borehole had the lowest fluoride concentration (1.62 mg/L) among the threey. Raw water from Makindu Spring, the main source of drinking water for Makindu Town, had fluoride concentration of 1.1 mg/L, which is well below the WHO maximum allowable value.

Discussion

The high fluoride concentration in groundwater indicate the population that use boreholes as a water source (10-20%) are exposed to health risks associate with high fluoride. According WHO there is wide variation in fluoride levels in the natural waters in Kenya, with concentrations above and below the optimal range set by the WHO for drinking water. However, river waters generally have fluoride contents in the lower part of this range whereas ground waters show much higher levels Thus the exposure to fluoride in Makindu District is likely to be more severe to the population that uses water from groundwater sources [24].

Impact of fluoride in drinking water to human population

The third objective of this study was to determine the impact of fluoride in drinking water to human population in Makindu District. To achieve this objective the respondents were requested to indicate their condition of teeth. The results of responses are presented in Figure 4.

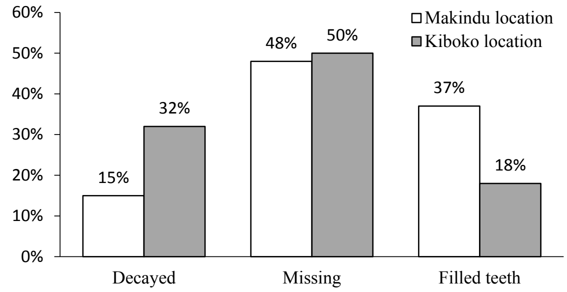

Figure 4: Percentages of respondents with different teeth conditions in Makindu and Kiboko locations.

Majority of the respondents from Kiboko and Makindu Locations had missing teeth (50% and 48% respectively). The percentage of respondents with decayed teeth was 15 and 32 and those with filled teeth were at 37 and 18 respectively in Makindu and Kiboko Locations. There are several factors that may cause the three teeth condition in humans including sugar rich diet, accidents, hereditary and level of teeth care among others but consumption of high fluoride water may also cause or exacerbate the occurrence of some the condition.

The study sought to establish the intensity of mottled teeth among the respondents and the responses are presented in Table 7. Most of the respondents from Kiboko and Makindu (38.4% and 33.3% respectively) had moderately to severely mottled enamel. These results show the impact of fluoride in water. The results agrees with Dean [24] who argued that the severity of mottled enamel condition is generally characterized as ranging from very mild to severe, is related to the extent of fluoride exposure during the period of tooth development. Mild dental fluorosis is usually typified by the appearance of small white areas in the enamel; individuals with severe dental fluorosis have teeth that are stained and pitted ("mottled") in appearance. In human fluorotic teeth, the most prominent feature is a hypomineralization of the enamel. The results also agree with Elvove who argued that dental fluorosis is caused in human being consuming water containing 1.5mg/1 or more fluoride, particularly from birth to the age of eight. Mottled enamel usually takes the shape of modification to produce yellow brown stains or an unnatural opaque chalky white appearance with occasional striations patting. The incidence and severity of mottling was found to increase with increasing concentration of fluoride in drinking water.

Comparison between the two locations shows a difference in the intensity level of mottled teeth. Makindu had relatively higher number of respondents with moderately severe to severe mottled teeth (31%) compared to Kiboko (20.1%). In contrast, Kiboko had relatively higher number of respondents with very mild to mild mottled teeth (23%) as compared to Makindu (16.7%). This difference maybe as a result of difference in fluoride concentration levels in water sources in the two locations.

	Makindu location		Kiboko location	
Intensity	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Very mild	5	1.7	6	5.3
Mild	43	15	20	17.9
Moderately	95	33.3	43	38.4
Moderately severe	57	19.9	17	15.2
Severe	33	11.5	6	5.3
Total	286	100	112	100

Table 7: Frequency and percentage of different levels of mottled enamel among the study respondents.

	Makindu location		Kiboko location	
Frequency	**Frequency**	**Percentage**	**Frequency**	**Percentage**
< 2 times per day	176	61.5	62	55.4
≥ 2 times per day	110	38.5	50	44.6
Total	286	100	112	100

Table 8: Percentages of frequency of tooth brushing in a day by the respondents.

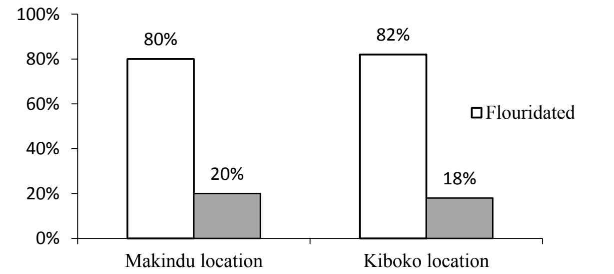

Figure 5: Percentage of respondents using fluoridated and non-fluoridated toothpaste in the study area.

	Makindu Location		Kiboko Location	
Reason	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Check up	26	9.1	19	17
Dental problem	147	51.4	61	54.5
None	113	39.5	32	28.5
Total	286	100	112	100

Table 9: Visit to dental clinics.

Variables	Value	df	Asymp. Sig. (2-ided)
Pearson Chi-Square	14.0[a]	4	0.007
Likelihood Ratio	7.21	4	0.025
Linear-by-Linear Association	4.21	1	0.04
N of Valid Cases	398	--	--

[a] 10 cells (100.0%) have expected count less than 5. The minimum expected count is .07.

Table 10: Chi-Square test values to establish the association between ground water fluoride and ill-effects on human population in Makindu District.

Mitigation measures against the ill-effects of fluoride in ground water

The last objective was to determine the possible mitigation measures against the ill effects of fluoride. The researcher sought to establish the frequency of teeth brushing by the respondents and the results are presented in Table 8.

It was observed that 61% and 55.4% of the respondents from Makindu and Kiboko respectively, brushed their teeth about twice per day and those brushing more than two times a day were respectively 38.5 and 44.6%. This shows that the respondents were serious in taking care of their teeth.

The researcher further sought to establish the type of tooth paste used and the responses are presented in Figure 5.

It was found out that majority of the respondents (80% and 82%) use fluoridated tooth paste. This seems to be a mitigation strategy applied by the residents against the ill effects of fluoride. These results are in line with [6] who argued that fluoride has a significant mitigating effect against dental caries if the concentration is approximately 1.0 mg/L). However, given that the water in this area has high fluoride the use of fluoridated toothpaste should be deemphasized since it does not serve the purpose of enhancing dental health especially given that exposure of higher concentrations of fluoride can cause dental fluorosis.

Table 9 shows the frequency of visit to dental clinics in the past year for different reasons. Majority of the respondents had visited (71.5% and 60.5%) with dental problems or for checkup. This shows that the residents were conscious of the need for dental care and also that dental services were available in the area.

Hypothesis of the research

The hypothesis of this study is that the groundwater fluoride may be higher than the recommended World Health Organization upper limit of 1.5mgli hence leading to ill-effects on human population in Makindu District. This hypothesis was tested using Chi-Square test. This test was necessary because it tests association and statistical dependence. By this test the researcher was able to establish whether there was a significant association between the ground water fluoride in Makindu District and ill – effect on human population. The Chi-square results were presented in Table 10.

These results imply that there is an association between the ground water fluoride in Makindu District and ill – effect on human population since all the P-values are less than 0.05 at 95% confidence level. The results therefore imply that, each of the independent variable namely; exposure, extent, impact and mitigation is statistically associated with ill-effect on human population.

Conclusions and Recommendations

Based on the findings of this study it can be concluded that the water source for Makindu District which is mainly tap water from the spring and borehole exposed the respondents to fluoride. This is because of high fluoride concentration in groundwater was well above the WHO maximum allowable levels of 1.5 mg/L.

It was observed that the population had stained/mottled enamel teeth which resulted from the intake of excess levels of fluoride during the period of tooth development. The study also found out that for the respondents to mitigate the dental problem they used tooth paste which was fluoridated as well as attending dental clinics in case of dental problem.

Based on the findings of this study it is recommended that the responsible authorities should introduce de-fluoridation systems to remove fluoride from water supplied to the community and that alternative sources of water should be developed for the population depending on the boreholes with high fluoride water. In addition, public awareness initiatives on the effect of consumption of high fluoride water should be initiated by the local authorities Government and other stakeholders.

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