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Quality of groundwater in Kassena-Nankana district, Ghana and its health implications

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ABSTRACT

The potability of underground water from Kassena-Nankana District of Ghana was assessed using certified standard analytical methods. The water was hard with fluoride levels consistently lower than 0.5 mg/L. The mean physico-chemical quality of the water was average with borehole water slightly possessing better characteristics than water from hand-dug wells. Elevated levels of nitrite, nitrate, arsenic and lead were detected in few samples. The mean bacteriological quality of the underground water of the district was poor. The continuous consumption of the water without proper treatment may lead to health challenges such as: methaemoglobinaemia in infants, cardiovascular diseases, impaired renal function, impaired fertility, hypertension and arsenic toxicity. It is therefore important for the water to be treated before consumption to prevent health challenges.

Key words: underground water, physicochemical, bacteriological, *Escherichia coli*, arsenic, lead

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INTRODUCTION

The population of the world is ever increasing and water shortages are becoming worse. One of the most critical crises in developing countries is the lack of adequate potable water. The usual source of drinking water is from streams, rivers, wells and boreholes which are usually not treated [1]. Groundwater which used to be potable is becoming polluted because of increased human activities. Much of ill health which affects humanity, especially in the developing countries, can be traced to lack of safe and wholesome water supply [2]. It is therefore unfortunate that water which is important to life is one of the most poorly managed resources in the world [3].

Groundwater is a reliable source of water for the rural dwellers because it is often available all year round. It is more stable than surface water from streams and rivers which may dry up during the dry season. According to Kumar [4], groundwater accounts for more than half of safe drinking water in rural areas, where population is widely dispersed and the infrastructure needed for treatment and transportation of surface water does not exist. A number of potential groundwater contaminants exist, making it important that water from this source is tested regularly to ensure that it is still potable.

The major sources of water for the inhabitants of rural and semi-urban areas of Ghana are boreholes, wells, streams and rivers. Majority of the people from Kassena-Nankana District in Ghana depend solely on groundwater from borehole and open well sources for domestic water supply. However, available quality data on the groundwater resource in the district is scanty. The present study assessed the water quality of selected boreholes and hand-dug wells in the Kassena-Nankana District of Ghana. The results obtained were compared to the guidelines of the World Health Organisation [5] to assess the potability of the water from the studied boreholes and wells.

MATERIALS AND METHODS

2.1 Study Area

Kassena-Nankana District is located in the Upper East Region of Ghana and lies between latitude 10°30'N and 11°00'N and longitude 1°00'E and 1°30'E. The district has a rural setting with an area of 1675 km^2. The estimated population of the district in June 2011 was about 160000 people living in roughly 14000 dispersed compounds. There are two main seasons, the wet (June – October) and the dry (November – May). The climate is sub-sahelian and vegetation in these areas is dry guinea savannah characterised by short grass and some fire-resistant trees. The mean minimum temperature is 20°C and the mean maximum temperature is 41°C. The average annual rainfall is 900 mm [6]. The people of the district are mainly peasant farmers and their major crops are groundnut, millet, cowpea and green leafy vegetables. They keep small herds of livestock mainly cattle, goats, sheep, pigs, chicken and guinea fowls.

2.2 Sampling

A total of one hundred and twenty water samples were collected as follows: forty samples from boreholes and eighty samples from hand-dug wells. The boreholes were sampled four times each while the hand-dug wells were sampled eight times. The protocols for sampling underground water were adhered to and boreholes were sampled after pumping for at least 2 min [7, 8]. The hand-dug wells were all open and samples were collected at a depth of about 1 m below the surface of water. Sampling was done quarterly over a one-year period to take account of both rainy and dry seasons. Samples were collected into clean 1.5 L polythene bottles washed with detergent and later rinsed thoroughly with tap water and distilled water. Sampling bottles were further rinsed thoroughly with water to be sampled before sample collection. Water samples for the determination of heavy metals were preserved by adding 2ml concentrated HNO_3 per litre of water. Samples for bacteriological analyses were aseptically collected, kept in an ice chest and analysed within 6 h of collection. All other samples were kept in an ice chest, transported to the laboratory where they were kept in a refrigerator at a temperature of approximately 4°C and analysed within 48 h.

2.3 Experimental Methods

Water samples were analysed by employing certified standard methods [7]. The pH of each water sample was determined in the laboratory within 6 h of sample collection using a calibrated Crison pH meter Basic C20 (Crison Instruments SA, Barcelona, Spain). Colour of samples was measured with DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA). Turbidity of the samples was determined using a DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA). A calibrated Crison conductivity meter Basic C30 (Crison Instruments SA, Barcelona, Spain) was employed for the determination of the total dissolved solids (TDS) of the water samples. Argentometric method was employed to determine chloride content. The sample was titrated at neutral conditions with a standard solution of silver nitrate using potassium dichromate as the indicator. The SPADNS colorimetric method was used to determine the level of fluoride ions in each sample, the zirconium-fluoride complex solution was read at 570 nm using DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA). Calcium, magnesium and total hardness were determined by the EDTA titrimetric method [7]. Sulphate ions were determined using a calibrated DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA) set to the wavelength of 450 nm. Nitrate ions were determined spectrophotometrically using DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA).

The levels of selected heavy metals in well water samples were analysed by atomic absorption spectrometry. Well water samples were examined for presence of total coliform and faecal coliform bacteria by multiple tube fermentation tests [9].

RESULTS AND DISCUSSION

The consolidated results of the physico-chemical characteristics of the water sampled from selected boreholes and hand-dug wells are presented in Table 1 and Table 2, respectively. The results were compared with the recommended limits for drinking-water set by the World Health Organisation [5].

3.1 Physical Characteristics

The pH of the boreholes samples ranged from 6.70-7.21, while that of the well samples ranged from 7.08-7.92. pH has no direct impact on consumers and no health-based guideline value has been proposed. However, the optimum pH in drinking-water is usually in the range 6.5-8.5 [5]. The pH of the underground water of Kassena-Nankana District falls within the optimum range in potable water.

The presence of colour in drinking-water makes is objectionable to the consumer. The off colour may be due to either metallic ions, such as iron and manganese; or dissolved organic matter [5, 10]. Most people can detect colour in drinking-water above 15 True Colour Units (TCU). However, no health-based guideline value is provided for colour in drinking-water [5]. The concentration of colour in well and borehole water samples in the district was consistently below the 15 TCU. It is therefore unlikely that consumers will find it objectionable on the basis of colour alone.

Table 1: Physicochemical characteristics of water from boreholes

Parameter	Minimum	Maximum	Mean	Std Dev	WHO Limit
pH	6.70	7.21	6.94	0.58	
Colour, TCU	2.50	5.00	4.50	2.05	15
Turbidity, NTU	0.01	3.49	0.73	1.47	5
Conductivity, µS/cm	314.11	562.09	407.04	133.69	
Suspended Solids, mg/L	1.10	3.02	1.74	1.32	
TDS, mg/L	146.13	269.96	192.60	69.86	1000
Total Alkalinity, mg/L	36.24	62.11	48.57	5.94	
Total Hardness, mg/L	180.08	424.66	277.63	88.98	
Nitrite (NO_2-N), mg/L	0.21	1.07	0.43	0.23	0.9
Nitrate (NO_3-N), mg/L	1.49	15.50	6.32	4.46	11
Bicarbonate, mg/L	13.68	26.66	19.67	2.41	
Carbonate, mg/L	8.28	18.60	12.87	1.57	
Chloride, mg/L	5.15	30.02	19.13	6.90	250
Fluoride, mg/L	0.01	0.37	0.25	0.16	1.5
Sulphate, mg/L	8.31	25.24	12.76	7.82	500
Phosphate, mg/L	0.06	0.39	0.16	0.18	2.5
Sodium, mg/L	17.85	38.02	29.55	8.55	
Potassium, mg/L	14.33	27.77	20.34	3.08	
Calcium, mg/L	53.98	126.65	86.58	26.48	200
Magnesium, mg/L	21.69	52.06	33.61	11.44	150
Iron, mg/L	0.01	0.30	0.05	0.07	0.3
Arsenic, mg/L	0.001	0.009	0.008	0.01	0.01
Copper, mg/L	0.001	0.08	0.05	0.03	2
Lead, mg/L	0.001	0.02	0.01	0.02	0.01
Zinc, mg/L	0.01	0.27	0.21	0.07	3

The value of turbidity of all the borehole water samples consistently fell below the maximum guideline of 5 NTU, while that of well water samples ranged from 0.51-19.10 NTU with a mean of 4.58 NTU. Approximately one out of every four well water samples from Kassena-Nankana District recorded turbidity levels higher than 5 NTU, especially during the dry season months of December to May. Turbidity in water may be caused by a combination of the following: suspended particles or colloidal matter, inorganic or organic matter, or minute air bubbles when water has high dissolved air content [5].

There is a direct relationship between the type and concentration of suspended matter and the turbidity and transparency of water [11]. In the present study, the mean value of suspended solids (SS) for hand-dug well samples (13.35 mg/L) was much higher than the mean value of SS for borehole samples (1.74 mg/L).

The level of total dissolved solids (TDS) is a good indicator of polluted water. It is an indication of the level of salts present in water [12]. WHO [5], did not propose any actual health-based value for TDS. However, TDS in drinking-water up to 600 mg/L is generally considered to be good; while consumers may find water containing TDS levels greater than 1000 mg/L objectionable. The measured values of TDS for borehole samples ranged from 146.13-269.96 mg/L with a mean of 192.60 mg/L, while the values for hand-dug well samples ranged from 192.77-791.08 mg/L with a mean of 439.60 mg/L. The underground water of the district is therefore classified as good on the basis of TDS.

There is a relationship between conductivity and the total concentration of dissolved ions in water [13]. The conductivity of underground water from Kassena-Nankana District ranged from 314.11-562.09 µS/cm for borehole samples; and 383.21-723.14 µS/cm for hand-dug wells. The conductivity levels of borehole samples were generally lower than the values recorded for well samples. The total alkalinity of the water samples from the district were within limits of acceptable standards for potable water. The samples from the boreholes generally recorded low total alkalinity values ranging from 36.24-62.11 mg/L, whilst samples from hand-dug wells gave values between 160.42-398.35 mg/L. WHO [5] did not propose any guideline for acceptable level of conductivity and alkalinity in drinking-water. This might be because the constituents have no direct link to adverse health impacts.

Table 2: Physicochemical characteristics of water from hand-dug wells

Parameter	Minimum	Maximum	Mean	Std Dev	WHO Limit
pH	7.08	7.92	7.44	0.14	
Colour, TCU	2.5	10.00	5.75	3.15	15
Turbidity, NTU	0.51	19.10	4.58	5.62	5
Conductivity, µS/cm	383.21	723.14	576.54	109.86	
Suspended Solids, mg/L	12.68	15.88	13.35	0.54	
TDS, mg/L	192.77	791.08	439.60	125.11	1000
Total Alkalinity, mg/L	160.42	398.35	261.87	113.32	
Total Hardness, mg/L	114.08	498.88	256.90	118.38	
Nitrite (NO_2-N), mg/L	0.10	0.25	0.22	0.07	0.9
Nitrate (NO_3-N), mg/L	0.07	12.40	8.23	3.67	11
Bicarbonate, mg/L	60.80	171.14	106.11	43.89	240
Carbonate, mg/L	37.43	117.52	65.70	28.23	
Chloride, mg/L	8.90	187.98	64.59	46.76	250
Fluoride, mg/L	0.05	0.81	0.61	0.42	1.5
Sulphate, mg/L	4.40	85.84	43.15	19.89	500
Phosphate, mg/L	0.01	0.05	0.01	0.01	
Sodium, mg/L	15.56	44.36	33.13	9.02	
Potassium, mg/L	12.87	32.45	24.56	3.26	
Calcium, mg/L	34.11	148.70	80.21	31.72	200
Magnesium, mg/L	14.56	61.09	31.96	12.54	150
Iron, mg/L	0.001	0.02	0.01	0.01	0.3
Arsenic, mg/L	0.001	0.15	0.03	0.32	0.01
Copper, mg/L	0.001	0.05	0.01	0.03	2
Lead, mg/L	0.001	0.05	0.03	0.02	0.01
Zinc, mg/L	0.01	0.30	0.04	0.08	3

It has been suggested that hardness gives palatability to water and moderately hard water containing sufficient calcium is essential for normal growth and health. However, high levels of hardness arising from elevated levels of magnesium sulphate are undesirable [10]. According to WHO [5], the levels of hardness in drinking-water is of no health concern. Consequently, no guideline for the acceptable level of hardness in drinking-water was proposed. Water hardness may be classified as soft (0-50 mg/L $CaCO_3$), moderately soft (50-100 mg/L $CaCO_3$), slightly hard (100-150 mg/L $CaCO_3$), moderately hard (150-200 mg/L $CaCO_3$), hard (200-300 mg/L $CaCO_3$), and very hard (over 300 mg/L $CaCO_3$) [10]. Borehole samples recorded total hardness levels ranging from 120.08-424.66 mg/L, whilst hand-dug well samples recorded total hardness levels ranging from 114.08-498.88 mg/L. In general, borehole and well water from the district can be classified as slightly hard to very hard.

3.2 The Anions

Intake of water containing excessive nitrite and nitrate ions may lead to health challenges especially in pregnant women and infants. At elevated concentrations, nitrate ion is known to cause cyanosis in infants [14] and digestive disturbance [15]; while nitrite ion may cause blue baby syndrome or methaemoglobinaemia in infants [16]. WHO [5] recommended that the level of nitrite ions in drinking water should not exceed 0.9 mg/L (NO_2-N). There was no record of exceedances to the WHO guideline for nitrite ion in water samples from hand-dug wells in Kassena-Nankana District. About 5 % of water samples from boreholes had level of nitrite beyond 0.9 mg/L. The levels of nitrate ions in all borehole samples were below the maximum limit of 11 mg/L [5]. About 15 % of the well water samples recorded nitrate ion levels higher than 10 mg/l. The highest concentration of nitrate recorded was 12.40 mg/L. The presence of high levels of nitrite and nitrate in some water samples might be as a result of use of inorganic fertiliser and manure in agricultural activities, and indiscriminate disposal of human and animal excreta [5].

Borehole and well water samples from Kassena-Nankana district had very low concentrations of phosphate ions. The levels of phosphate ion in borehole samples ranged from 0.06-0.39, whilst the concentration of phosphate ion in well samples varied from 0.01 to 0.05. There is no health-related proposed guideline for acceptable level of phosphate in drinking-water [5]. Similarly, groundwater from the district recorded low sulphate ion concentrations with borehole samples recording values between 8.31 and 25.24 mg/L, and well samples between 4.40 and 85.84 mg/L. It is unlikely that the levels of sulphate in drinking-water will exceed that for which it will be of health concern. Therefore, there is no proposed guideline for the preferable levels of sulphate in water. However, the presence of the anion in drinking-water at levels in excess of 500 mg/L may affect acceptability of water [5].

The levels of chloride in water may impact taste to it making it objectionable to consumers. There is no health-based guideline for chloride in drinking-water but levels above 250 mg/L may result in taste problems [5]. Water samples of boreholes and hand-dug wells in Kassena-Nankana District generally possessed chloride ion levels well below 250 mg/L. The chloride levels ranged from 5.15-30.02 mg/L and 8.90-187.98 mg/L for borehole and well samples, respectively.

Fluoride in drinking water may be beneficial or detrimental depending on its concentration and total amount ingested. It is beneficial particularly to infants and young children younger than 8 years for calcification of dental enamel when present within the permissible range of 0.5 to 1.5 mg/L, as the maximum acceptable level in drinking water is 1.5 mg/L [5]. The chronic and toxic effects of excessive intake of fluoride are usually observed as dental fluorosis, skeletal abnormalities that range from stiffness and rheumatism to a permanent crippling skeletal rigidity. It is a recommended essential substance in water for building healthy teeth when up to 1 mg/L [17]. Groundwater in Kassena-Nankana District is characterised by low fluoride ion concentrations. The concentrations in borehole samples varied from 0.01-0.37 mg/L while the recorded values for the well samples ranged from 0.05-0.81 mg/L. It is unlikely that these levels of fluoride in drinking-water will have adverse effects on health of consumers.

3.3 The Cations

Sodium and potassium are normally present in water. Their normal levels in drinking-water are rarely high enough to pose any threat to health and no health-based guideline values have been derived [5]. Kassena-Nankana District recorded sodium concentrations ranging from 17.85-38.02 mg/L and 15.56-44.36 mg/L, in borehole and well water; respectively. Potassium is an essential element in human nutrition. The level found in borehole water ranged from 14.33-27.77 mg/L, while the concentration in well water ranged from 12.87-32.45 mg/L. According to WHO [5], potassium may cause some health challenges in susceptible persons. There is no conclusive evidence to associate sodium in drinking-water and the occurrence of hypertension. However, sodium levels in drinking-water higher than 200 mg/L may give rise to objectionable taste. It is unlikely that the low levels of sodium and potassium found in the underground water of the district should be hazardous to health.

Calcium and magnesium are important elements in human nutrition. Calcium is required for blood clotting and strong bones; while magnesium acts as a cofactor and activator of hundreds of enzymatic reactions [12] The presence of calcium and magnesium ions makes water hard. However, there is no evidence of adverse effects specifically attributable to these ions in drinking water [18]. Drinking-water may be a contributor to calcium and magnesium intake. However, there is no health-based guideline proposed for the levels of both metals in drinking water [5]. The mean levels of calcium and magnesium ions in borehole water samples were 86.58 mg/L and 33.61 mg/L, respectively; while the mean concentrations of calcium and magnesium ions in well water samples were 80.21 mg/L and 31.96 mg/L, respectively. It is unlikely that consumption of water with these levels of calcium and magnesium ions will have adverse effects on health.

Well water samples generally recorded very low total iron concentrations ranging from 0.001-0.02 mg/L with a mean value of 0.01 mg/L. Borehole samples on the other hand recorded values between 0.01 and 0.30 mg/L with a mean value of 0.05 mg/L. Iron, especially in the iron(II) oxidation state, is an important trace metal in human nutrition. Iron in water up to the concentration of 2 mg/L may be consumed without causing any negative impact on health. However, the taste and colour in water with iron concentration greater than 0.3 mg/L may make it objectionable to consumers. The levels of iron normally found in drinking-water are usually not high enough to cause health hazard. Therefore, no health-based guideline value is proposed for the trace metal [5].

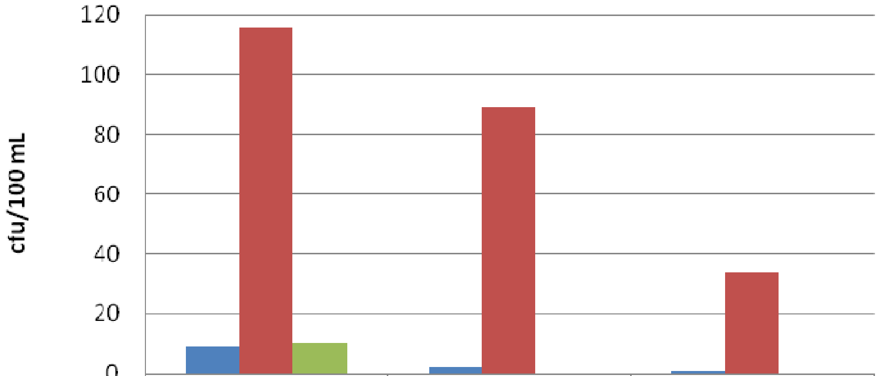
Arsenic is one of the chemicals with greatest health concern in natural water. It is not an important trace metal in human nutrition. High levels of inorganic arsenic compounds in drinking-water may lead to arsenic toxicity including cancer. WHO [5] set the provisional maximum level of allowable arsenic in drinking-water as 0.01 mg/L. The concentration of arsenic in the hand-dug well water samples was generally higher than the recommended maximum permissible limit of 0.01 mg/L [5]. The mean concentration of arsenic in borehole and well water samples were 0.008 mg/L and 0.03 mg/L, respectively. Prolong consumption of well water in the district without pre-treatment to lower the concentration of arsenic, may lead to arsenic toxicity. There is neither mining nor industrial activity in the district. Therefore, the high concentration of arsenic in groundwater of the district may be attributed to natural processes [19, 20]. It is therefore important for the water to be treated before consumption to lower the concentration of arsenic in it.

Exposure to lead may cause cardiovascular diseases, impaired renal function, impaired fertility and hypertension. The provisional maximum allowable concentration of lead in drinking-water is 0.01 mg/L [5]. The level of lead in borehole water ranged from 0.001-0.02 mg/L, with a mean of 0.01 mgL; while water from hand-dug wells recorded lead concentration ranging 0.001-0.05 mg/L, with a mean of 0.03 mg/L. The presence of lead in the underground water of the district was probably due to the use of pesticides [21]. Prolong consumption of the water without lowering the lead concentration below 0.01 mg/L may be hazardous to health.

Copper and zinc are both essential trace elements that may be present in water. Water from borehole and hand-dug wells in the Kassena-Nankana District were characterised by low copper and zinc concentrations. The district recorded copper levels ranging from 0.001-0.08 mg/L and 0.001-0.05 mg/L, in borehole and well water; respectively. The concentration of zinc ranged from 0.01-0.27 mg/L and 0.01-0.30 mg/L in borehole and well water, respectively. The health-based maximum allowable concentration of copper in drinking-water is 2 mg/L [5]. No health-based guideline has been proposed for zinc in drinking-water. However, water containing zinc at concentrations above 3 mg/L may be objectionable to consumers.

3.4 Bacteriological Characteristics

The importance of microbiological quality of drinking-water cannot be over-emphasized in relation to water borne diseases [22]. The level of total coliform in water is generally used as an indicator of cleanliness and effectiveness of disinfection. The detection of total coliform in water at levels greater than 10 cfu/100 mL is an indication that the water needs to be treated. The use of *Escherichia coli* (*E. coli*) as an indicator of faecal pollution in drinking-water is well established. It is absolutely important that drinking-water must never contain any faecal indicator organism [5].



	Total coliform	Faecal coliform	E. coli
Borehole	9	2	1
Well	116	89	34
WHO Std	10	0	0

Figure 1. Indicators of bacterial contamination

The mean levels of bacterial indicator of contamination for borehole and well water samples are presented in Figure 1. It is obvious that the underground water in Kassena-Nankana District possessed poor bacteriological characteristics. Water from hand-dug wells generally possessed worse bacteriological quality than borehole water. In general underground water in the district may have negative impact on health if consumed without treatment. The level of sanitation in Kassena-Nankana district is poor and open defecation is common. Moreover, a large population of livestock is reared on free range basis [23]. These may be the cause of the poor bacteriological characteristics of underground water in the district.

CONCLUSION

This study revealed that underground water in Kassena-Nankana District, Ghana is hard with fluoride level below 0.5 mg/L. The mean physico-chemical quality of the water was average with borehole water slightly possessing better quality than water from hand-dug wells. Elevated levels of nitrite, nitrate, arsenic and lead were detected in few samples. This might be as a result of use of inorganic fertiliser, manure and pesticides in agricultural activities; and indiscriminate disposal of human and animal excreta. The mean bacteriological quality of the underground water of the district was poor. The continuous consumption of the water without proper treatment to lower the parameters in excess, may lead to health challenges such as: methaemoglobinaemia in infants, cardiovascular diseases, impaired renal function, impaired fertility, hypertension and arsenic toxicity.

It is recommended that the Kassena-Nankana District Assembly and Community Water and Sanitation Agency (CWSA) regularly monitor the underground water of the district. Moreover, appropriate steps should be taken to properly treat and disinfect the underground water to make it safer for consumption.

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