Original Research Article

Heavy metal assessment in domestic water sources of Sikuda and Western division located in Busia district, Uganda.

Abstract

Human beings especially in developing countries depend on different water sources for domestic purposes. Water sources found near agricultural areas and mining activities, may end up contaminated and hence not suitable for human consumption. This study aimed at determination of the economic activities carried out near the water sources of Busia district; investigation of the presence and concentration of selected heavy metals in the water sources; and investigation of the likely health effects brought about by the consumption of water polluted with heavy metals by the population in Busia district. Water samples from twenty-nine point water sources were collected during wet and dry seasons, and analyzed for the presence of some selected heavy metals using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP – OES). Information concerning health issues of the respondents were collected using the questionnaires. The concentrations (mg/l) as expressed in terms of mean ± standard deviation in domestic water sources including streams, ponds, protected springs, shallow wells and boreholes were within the acceptable range for copper, lead and mercury while arsenic values were above the acceptable limits according to WHO and EAC standard limits. Abdominal pains and diarrhea were the most reported common diseases that affected the population who consumed water polluted with heavy metals. The study recommended that Government officials especially from the Ministry of Health should carry out awareness about safe water uptake to avoid diseases that result from consuming contaminated water. In addition, there should be constant monitoring about the concentration levels of heavy metals in domestic water sources in order to avoid or scale down the spread of diseases due to consumption of water contaminated with heavy metals. The residents should be encouraged to use tap and shallow wells for domestic purposes since they contain small traces of heavy metals as compared to other water sources.

Key Words: Agricultural Production; Domestic Water Sources; Heavy Metal Contamination; Mining

Introduction

Water is recognized as a necessity to sustain life and has to be adequate, safe and accessible to all humans (WHO, 2017). Studies carried out in the world today show that both surface and groundwater are contaminated with toxic elements including heavy metals such as arsenic (As), Copper (Cu), lead (Pb), Mercury (Hg), cobalt (Co) and cadmium (Cd) (Omara et al., 2019; Tomašek et al., 2022).

Heavy metals are regarded as serious pollutants to water ecosystems because of their toxicity, ability to be incorporated into food chains (Cavin, 2017), non-biodegradable and bioaccumulation causing them being persistent and thereby causing long term effect on the environment (Singh et al., 2011). Heavy metals are toxic at low concentrations, and they occur naturally as components of the earth's crust (Lenntech, 2004). Studies show that exposure of elevated levels of heavy metals in human beings results into spontaneous abortions, damaged kidneys, severe neurological symptoms, seizures, mental disturbance (Park & Zheng, 2012), slow growth and development, cognitive impairment of the central nervous system, and abnormal heart beat in human beings (Azeh Engwa et al., 2019; Jaishankar et al., 2014; Mitra et al., 2022). Human beings are exposed to heavy metals through intake of food, drinking water and breathing contaminated air (Balali-Mood et al., 2021).

Activities such as application of fertilizers, herbicides and pesticides in agriculture; extraction activities like mining and quarrying; infrastructure construction, maintenance and use; erosion and weathering generate particles and wastes (Akhtar et al., 2021; WHO, 2017), which may contain heavy metals (Ferreira Da Silva et al., 2004). The heavy metals may leach out in uncontrolled manner into the surrounding water environments resulting into their elevated levels including domestic water sources (Fashola et al., 2016; Coelho et al., 2015). The local geology and climate also determine the occurrence of heavy metals in groundwater sources released as a result of water - rock interactions and weathering processes (Tomašek et al., 2022). Climatic factors like change in precipitation, humidity and evapotranspiration can also, directly or indirectly affect the quality of water sources through dilution of lake, river or stream water (Akhtar et al., 2021).

The population of Busia district in eastern Uganda utilizes water sources from both surface and ground water. Surface water sources are lakes, rivers, ponds and streams; and groundwater sources exploited are protected springs, deep boreholes and shallow wells (Nsubuga et al., 2014). The district is also characterized by small-scale agricultural production, artisanal and small scale mining, settlement construction, farming and industrialization (Barasa et al., 2016; UBOS, 2017). Agricultural production involves use of manure and fertilizer to improve on productivity (Njuguna & Rutebuka, 2003). Gold mineralization is extracted by artisanal and small scale miners from auriferous quartz veins and from sulfide quartz veins (Mbonimpa et al., 2007). Artisanal and small-scale miners also employ mercury to form an amalgam that is burnt in open air to extract gold from the ore. These activities coupled with the natural processes of weathering of bedrock, erosion and flooding are among the many sources of heavy metals to domestic water sources yet there is limited or no literature detailing the elemental concentration including that of heavy metals in the domestic water sources of Busia district, Eastern Uganda. This study therefore aimed at determining the different economic activities undertaken near the water sources; investigating the presence and concentration of heavy metals in domestic water sources of parts of Busia district; and to investigate the likely health effects brought about by the consumption of the polluted water with heavy metals to the population of Busia district.

Effects of some heavy metals to human health

Copper: Copper is one of the valuable resources and most used metals in the world (Zhang et al., 2021) and is an essential nutrient to humans as reported by Megan Ware RDN LD (2017). Copper in humans play a role in making red blood cells and maintains the nerve cells. It naturally occurs in soil, water, rocks and sediments and hence, human beings are exposed to it through eating food, drinking water and breathing air (ATSDR, 2004). It is used as an additive to surface water to control growth of algae (Wuana & Okieimen, 2011). Ingestion of copper in excess amounts can cause nausea, vomiting, diarrhea, damage to the liver and kidneys (Pizarro et al.,1999).

Arsenic: Humans are exposed to arsenic through breathing in contaminated air, consumption of contaminated food and drinking water. Arsenic in its organic form such as arsenite and arsenate compounds are known to be dangerous to human health (Jaishankar et al., 2014). Arsenic is used in paints, dyes, soap and is contained in some drugs. Water can get contaminated with arsenic through improper disposal of household and industrial wastes as well as natural geological processes (Ryan et al., 2011). Drinking contaminated water as reported by Chowdhury et al.

(2000) is one of the major causes of arsenic toxicity in more than 30 countries in the world. Exposure of humans to arsenic increases the risk of cancer, is associated with skin damage, and leads to problems with the circulatory system (Saha et al., 1999). Long term exposure of arsenic leads to formation of skin lesions, internal cancers, neurological problems, pulmonary disease, peripheral vascular disease, hypertension and cardiovascular disease and diabetes mellitus (WHO, 2003).

Mercury: Mercury is one of the metals with no known biological function in the body and it is very toxic and exceedingly bio-accumulative (Chen et al., 2012). Mercury exists in the form of metallic mercury, inorganic salts and organic compounds with each, possessing different toxicity rating (Azeh Engwa et al., 2019). Mercury is used in artisanal and small-scale gold mining during the extraction of gold and it is mainly through this method that it contaminates the earth (Mantey et al., 2020). It is also used in skin lightening soaps and creams, wood preservatives and fungicides (Chen et al., 2012). Mercury is widely present in surface water sources such as rivers, streams and lakes. Microorganisms in mercury contaminated water transform it into methyl mercury which undergoes bio-accumulation causing disturbance in the microorganism. Humans are exposed to methyl mercury through consumption of contaminated aquatic organisms such as fish (Trasande et al., 2005). Mercury exposure targets the central nervous system and can lead to the damage of brain, kidneys and developing foetus in pregnant women (Alina et al., 2012; Park & Zheng, 2012). Methyl mercury is highly carcinogenic and also can lead to severe headaches, nervousness, fatigue, memory loss and loss of strength in the legs of human beings who use mercury-based products (Park & Zheng, 2012).

Lead: Lead performs no known essential function in the human body and has been known to cause extensive environmental contamination and health problems worldwide (Jaishankar et al., 2014). Lead is used in the manufacture of storage batteries, cable covers, ammunition, pigments and caulking (Wuana & Okieimen, 2011). Lead is exposed to the environment from lead-based paints, gasoline, cosmetics, toys, household dust, and industrial emissions (Gerhardsson et al., 2002). Human exposure to lead is through drinking of contaminated water that is transported through pipes that contain lead (Brochin et al., 2008). Exposure of lead to humans can cause loss of appetite, headache, hypertension, abdominal pain, renal dysfunction, fatigue, sleeplessness, arthritis, hallucinations and vertigo, mental retardation, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage and may even cause death (Martin & Griswold, 2009; NSC, 2009; Taylor et al., 2012).

It can therefore be observed that consumption of water contaminated with heavy metals may result into several ailments including stomach disorders, nausea, memory loss, damage to the brain, cardiovascular diseases and chronic illnesses among others, among human beings. Residents in Busia district obtain water for domestic use from several water sources including protected springs, shallow wells, bore holes and streams, where activities like mining, animal farming and irrigation take place. During these activities, there is a big likelihood of the release of the heavy metal into the environment which may eventually find their way into the water sources. Hence a study aimed at assessing the presence of heavy metals in the domestic water sources aimed at making informed decisions about the quality of water consumed by the residents in Busia district was very essential. The study aimed at achieving the following specific objectives. To determine the economic activities carried out near the water sources in Busia district; to investigate the concentrations of selected heavy metals in the water sources found in Busia district; and to investigate the likely health effects to people of Busia district, brought about by the consumption of water polluted by heavy metals.

Materials and methods

Study Area

The current study was undertaken in Sikuda and Western division found in Busia district, Uganda. Busia district is about 202Km East of Kampala, the capital city of Uganda and it is located between 33°05′E 00°10′N and 34°01′E 00°35′N (NEMA, 2004). The district lies within the Archaean greenstone belt that extends from eastern Tanzania through western Kenya. Its geology is composed of the Nyanzian-Kavirondian volcano-sedimentary formations and the rock types which include ironstones, phyllites, greywackes and carbonate altered mafic metavolcanic rocks (Mbonimpa et al., 2007). The district experiences two rainy seasons, one extending from March to May and a longer one from August to November, receiving a mean annual rainfall of 1,514 mm (Busia District Report, 2009). The sampling points were surface and ground domestic water sources as shown in Fig. 1. The surface water sampled were ponds and streams; while the groundwater sampled were protected springs, shallow wells and boreholes. The sampling points were within 20 metres from an area where some anthropogenic activities that had potential to cause water pollution and the water being used for domestic purposes, were taking place.

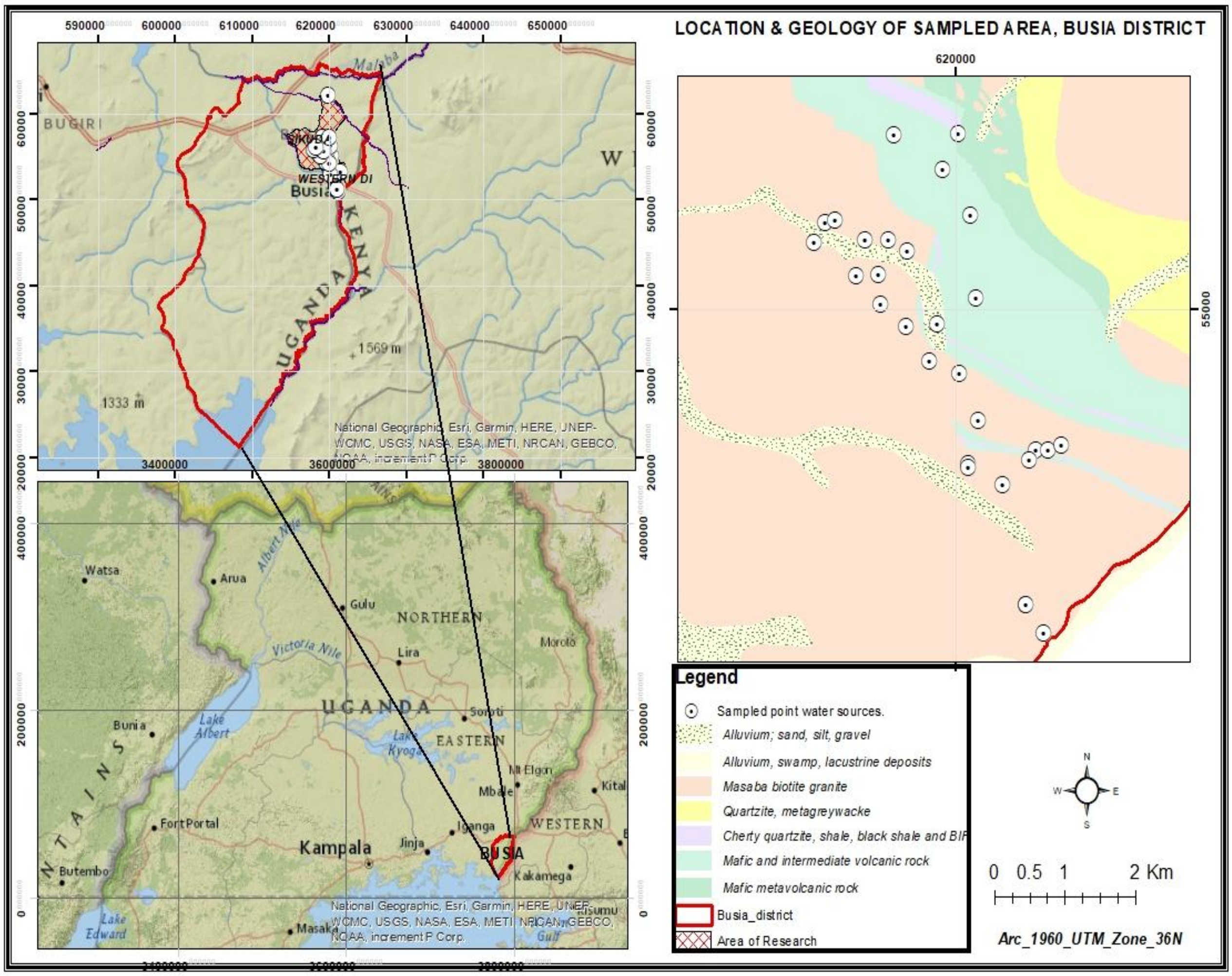

Fig. 1: Location for the study area **(Geology of the area after SMMRP, DGSM, 2014)**

Data Collection

The socio-economic data of the respondents from the study area were collected using a semi-structured questionnaire. Data were randomly collected from a total of eighty-eight respondents who resided near or around the water sources and were expected to be using the water for domestic purposes. The data were collected to help understand the respondent's knowledge, experience and understanding of the topic on anthropogenic activities that might have led to heavy metal accumulation and the likely diseases caused as a result of consumption of water that is viewed to have been polluted with heavy metals. The reliability statistics for the items found in the questionnaire were determined and the Cronbach's alpha, α = 0.826 was obtained. The Cronbach's alpha calculated exceeded α = 0.70 which indicated that there was good internal-consistency reliability of the research instrument (Amin, 2005).

Water sample collection

Twenty-nine-point water sources as shown in Fig. 1 were sampled in duplicate for both dry and wet seasons. Sterilized plastic bottles of 250 ml were used for the collection and storage of the water samples that were used for chemical analysis. A Syringe and 0.45-micron filter paper were used to collect and filter water samples respectively. The water samples were filtered to remove suspended solids before storage. 1.0 ml of conc. Nitric acid was then used to acidify the samples in the field in order to prevent sorption.

Water Sample analysis

Analysis for the presence and concentration of As, Cu, Pb and Hg was carried out using Inductively Coupled Plasma Optical Emission Spectrometry (ICP – OES). The analyses took place from the directorate of geological survey and minerals laboratory, Entebbe.

Data analysis

The demographic data collected was entered into SPSS version 20.0 for further management while the water sample data were entered into a Microsoft excel to show the distribution of the contaminants. The results were discussed and compared with the World Health Organization (WHO) and Uganda / East African Community (EAC) limits for portable water quality. Student's T-test and ANOVA were used to compare the element means difference between the water samples collected in dry and wet seasons.

Results

Socio-Economic Activities of the Respondents

The respondents obtained water for domestic use from a number of sources which included boreholes (42%), shallow wells (26%), taps (18%), protected springs (12%) and streams (2%). The economic activities carried out by the respondents near or around the water sources included artisanal mining (40%), crop farming and animal rearing (19%) and small-scale businesses (17%) among others as shown in Table 1.

Table 1: Economic activities carried out in the study area

Economic Activity	Frequency (n=85)	Percentage
Small-Scale business	14	16.47
Artisanal Mining	34	40.00
Animal Rearing and Crop Farming	16	18.82
Other (peasant)	21	24.70
Total		100

Source: Questionnaire Survey, 2022

Gold mining was the most predominant activity undertaken by the artisanal miners in the study area. Information gathered from interviews indicated that the miners used mercury in the process of extracting gold. The excavated ore and mercury in tailings have a potential of being washed downstream leading to pollution of the water sources.

Animal rearing and crop growing formed the second largest economic activity undertaken in the study area. Crops which are grown in the study area include maize, beans, sweat potatoes, cassava, bananas, and yams. Animals reared included cattle and goats. Organic and inorganic fertilizers, pesticides, insecticides were all used to improve on the soil fertility and control diseases. The organic fertilizers used in the study area included chicken and animal wastes. The excessive use of the mentioned products during agricultural activities in the study area are likely to have leached in the water environment causing pollution. In the small-scale businesses, commodities sold included plastics, foodstuffs, clothes and mobile phones accessories. The activities contributed to the release of municipal wastes which are some of the contributors to the pollution of water sources.

Physico-Chemical Parameters of Water Samples

Water samples were collected from both surface water sources including ponds and rivers; and ground water sources including shallow wells, bore holes and protected springs during the dry and wet seasons. The physico-chemical parameters analyzed included pH and total dissolved solids (TDS).

The average pH of ground water samples from shallow wells, boreholes and protected springs was 5.9 ± 0.36 during the wet season while the average pH of 6.05±0.36 was obtained during the dry season. The average pH of the surface water samples from ponds and rivers during the dry season was 6.5 ± 0.23, while the mean values for the pH of water samples during the wet season was 6.8 ± 0.35. All the pH values obtained during the experiments were within the EAC 2018 recommended ranges of 5.5 – 9.5. However, the pH of the water samples collected from the ground water sources during the dry and wet seasons were below the range recommended by WHO which is 6.5 - 8.5. Such waters are likely to be of health concern since the waters tending to be acidic in nature may cause corrosion of the mains and pipes that distribute water to the households.

The TDS measured in all the water samples from the study area were between 151.5 ± 93.7 mg/l and 192 ± 107.8 mg/l which were generally considered to be good as per the WHO acceptable guidelines of <600 mg/l and EAC acceptable requirement of <1500 mg/l for natural portable water (Table 2).

Table 2: Physico-chemical parameters of domestic water sources

Parameter	pH		TDS/ mg/l	
	Mean ± SD		Mean ± SD	
Water source	Dry	Wet	Dry	Wet
Surface water, (n = 6)	6.5 ± 0.23	6.8 ± 0.35	151.5 ± 93.7	192 ± 107.8

Groundwater, (n = 6)	6.05±0.36	5.9 ± 0.36	125.15 ± 87.2	163.6 ± 96.94
WHO Limit (2017)	6.5-8.5		<600	
EAC Limit (2018)	5.5-9.5		<1500	

Source: Primary data (2022)

Heavy Metal Concentration in Water Sources

Underground water sources represented by boreholes, shallow wells and protected springs were the most widely used (80%) water sources for domestic purposes by the respondents. The rest of the respondents (20%) used surface waters for domestic consumption.

The analytical results about the surface water of Sikuda and Western division revealed higher concentrations of As, 0.0173 ± 0.000mg/l and 0.0185 ± 0.0004 mg/l during the dry and wet seasons respectively (Table 3). The values obtained were higher than the WHO (2017) and EAC (2018) recommended provisional limit (0.01 mg/l) for portable water. The surface water samples registered some traces of Cu and Pd during dry and wet seasons, although, their concentrations were below the WHO (2017) and EAC (2019) recommended provisional limit (0.01 mg/l) for drinking water. The heavy metal concentrations (mg/l) in surface water samples during dry and wet seasons from the study area decreased in the order of As > Cu > Pb. The concentration of Hg was below detection limit in all water samples during dry and wet seasons. Pond water exhibited more concentrations of As, Cu, and Pb than the stream water. This was probably because water in the ponds is static while the water in the streams is flowing tending to become dilute as water flows.

Table 3: Concentration of heavy metals in surface water collected during the dry and wet season

Water Source	Stream (n=6)		Pond (n=6)		WHO Limit (2017)	EAC Limit (2018)
Element	Mean ± SD		Mean ± SD			
	Dry	Wet	Dry	Wet		

As	0.0184 ± 0.0094	0.0164 ± 0.0002	0.0185 ± 0.0004	0.0160 ± 0.0005	0.01	0.01
Cu	0.0094 ± 0.0008	0.0131 ± 0.0051	0.0109 ± 0.0018	0.0090 ± 0.0047	2	1
Pb	<0.0017	0.0046 ± 0.0064	<0.0017	<0.0017	0.01	0.01
Hg	<0.001	<0.001	<0.001	<0.001	0.006	0.001

Source: Primary data (2022)

A single factor ANOVA test was performed to determine whether the mean concentrations of the heavy metals in different water sources (streams and ponds) were different during the dry season. The results revealed that there was a significant difference in the mean concentrations of heavy metals in the surface water sources during the dry season ($P<0.05$) as shown in Table 4.

Table 4: ANOVA test on mean concentration of heavy metals in surface water during the dry season from the study area.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000405	3	0.000135	477.6224	0.000045	6.591382
Within Groups	1.13E-06	4	2.83E-07			
Total	0.000406	7				

Source: Primary data

Focusing on the results obtained from the Tables 3 and 4, it can be concluded that the concentrations of heavy metals during the wet season, may also show some significant difference among the different water sources. This means that the effects that manifest as a result of consuming water from the streams may not be the same as those when pond water is consumed.

The groundwater sources including protected spring, shallow wells and boreholes also registered a higher concentration of As during both dry and wet seasons as compared to the recommended provisional limit (0.01 mg/l) by the WHO and EAC (2018). Borehole's water exhibited a higher concentration of As compared to protected springs and then lastly in the shallow wells. However, the concentrations of the As in surface water sources were more than the concentrations of As in ground water sources during both seasons. Further still, there were traces of Cu, Pb, and Hg in the water samples, though at lower concentrations than those in surface waters as observed in Table 4. Similar to the surface water samples, the concentrations of heavy metals in the ground water samples during dry and wet seasons from the study area decreased in the order of As > Cu > Pb, while Hg was below the detection limit in all water the samples.

Table 5: Concentrations (mg/l) of heavy metals in groundwater sources from the study area

Water Source	Protected Spring (n=6)		Shallow Wells (n=6)		Borehole (n=6)		WHO Limit (2014)	EAC Limit (2018)
Element	Mean±SD		Mean±SD		Mean±SD			
	Dry	Wet	Dry	Wet	Dry	Wet		
As	0.0174 ± 0.0007	0.0154 ± 0.0009	0.0171 ± 0.0009	0.0164 ± 0.0011	0.0185 ± 0.0009	0.015± 0.0009	0.01	0.01
Cu	0.0087 ± 0.0018	0.0065± 0.0025	0.0089 ± 0.0027	0.0063 ± 0.0023	0.0107 ± 0.0022	0.006± 0.0033	2	1
Pb	<0.0017	0.0013 ± 0.0036	<0.0017	<0.0017	<0.0017	0.000± 0.0009	0.01	0.01
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.001

Source: Primary Data (2022)

Additionally, ANOVA test was performed to determine whether there was a significant difference in the concentrations of the heavy metals in different ground water sources during the wet season. The results are as shown in Table 6.

Table 6: ANOVA test on concentrations of heavy metals in different ground water sources during the wet season.

Source of	SS	df	MS	F	P-value	F

Variation						crit
Between Groups	0.000214	3	7.15E-05	238.237	0.004183	19.16429
Within Groups	6E-07	2	3E-07			
Total	0.000215	5				

Source: Primary data (2022)

The results revealed that there was a significant difference in the concentrations of heavy metals obtained from ground water sources during the wet seasons ($P<0.05$) from the study area. This means that different ground water sources, that is, protected springs, shallow wells, and boreholes have varying amounts of heavy metals and they can produce different effects to people who consume the different types of water. Observing from the results obtained in Table 5, similar outcomes would be obtained if ANOVA test was determined on the water samples collected during the dry season. Despite the likely outcomes, a calculated t-test to determine whether there was a significant difference between the mean concentration of heavy metals in the water samples collected during the dry and wet seasons, the results are as shown in Table 7.

Table 7: T-test on concentrations of heavy metals in water samples collected during the dry and wet seasons from the study area.

	Dry	Wet
Mean	0.00917	0.00725
Variance	3.45695E-06	9.52474E-06
Observations	20	20
Pearson Correlation	0.539050202	
Hypothesized Mean Difference	0	
df	19	
t Stat	3.293894786	
P(T<=t) one-tail	0.001908743	
t Critical one-tail	1.729132812	
P(T<=t) two-tail	0.003817487	
t Critical two-tail	2.093024054	

Source: Primary data (2022)

The results revealed that there was a significant difference between the concentrations of heavy metals in the water samples collected during the dry and wet seasons ($P<0.05$) from the study area. This means that during the wet seasons, there is a likelihood of the dilution of the heavy metals contributing to their smaller concentrations.

Health effects due to consumption of water polluted with heavy metals

The survey was carried out from the study area to determine the diseases that were likely to have been caused as a result of consuming water from the contaminated water sources. The common diseases that were reported by the respondents included diarrhea (44%), abdominal pain (28%), kidney failure (3%), cancer (4%) and spontaneous abortion at (1%). Other disease reported included typhoid (5%), and cholera (1%) as shown in Table 8. Related to the diseases contracted by the respondents as a result of consuming the contaminated water, one of the health Officers reported that;

"There is an increase of cancer cases among the population in this district and the likely cause of this outbreak is attributed to the consumption of the water that has been polluted with mercury".

Table 8: Health problems reported by the respondents as a result of consuming polluted water

Common diseases	Frequency (n=88)	Percentage
Diarrhea	39	44
Abdominal pain	25	28
Typhoid	4	5
Cholera	1	1
Spontaneous abortion	1	1
Cancer	3	4
Others	7	8
None	8	9

Source: Questionnaire survey (2022)

In conclusion, people living in Busia district obtain water for domestic uses from protected springs, shallow wells, boreholes, streams and ponds that are contaminated with heavy metals which include arsenic, copper and lead. These contaminants are likely to have originated from the use of fertilizers, pesticides during agricultural production and artisanal mining. The health problems reported by the residents as a result of consuming the contaminated water are cancer, diarrhea and abdominal pains among others.

Discussion

Increase in population and the need for food security has led to the use of fertilizer and pesticides to increase agricultural production. UBOS and MAIF (2015), reported that a total of 53,180 MT of fertilizer including Urea, NPK, DAP, MOP, TSP were used on production of sugarcane and banana in Uganda. Application of organic fertilizer in agriculture for a long time as noted by Rashmi et al. (2020) in Western Europe led to the contamination of water bodies. A study by Walekhwa et al. (2022) cites agricultural practices as a factor affecting the quality of water in Kibuku district, eastern Uganda. In this study, agricultural activities were noted to have been a source of heavy metal pollution to water sources.

Mining activities are known to escalate heavy metal accumulation in water sources worldwide. Obasi & Akudinobi (2020) reported that water sources around active mine sites in Nigeria were polluted with heavy metals such as Pb, Hg and As. As is also reported to be in high concentrations in the water sources of Kampala (Bamuwamye et al., 2017). A study by Barasa et al. (2016) showed that water obtained from the tributaries of Okame river was contaminated with mercury. Although mercury in all samples collected and analyzed in this study showed low concentrations of mercury, there is a likelihood that the trace mercury originated from the mines. In addition, the little concentrations of Hg could have been because minimal mining activities were taking place at the time of the study (Mantey et al. 2020).

In this study, concentrations of As were above the recommended WHO and EAC standard limits of 0.01 mg/l. The concentration of As in the study area was possibly because of weathering process of rocks in Busia district since the geology is composed of carbonate altered mafic metavolcanic rocks and sulfide bearing rocks (Mbonimpa et al. 2007). These rocks cause arsenic to be released to drinking water under oxidizing environment (Dinwiddie & Liu, 2018). In addition, Busia is a gold mining district where gold is mined from sulfide bearing quartz veins. The sulfides in tailings can be oxidized and leached into surface and groundwater sources resulting to elevated levels of As and other heavy metals concentrations.

In this study, all samples in dry season recorded Pb concentrations below detection limit and only one sample from borehole, protected spring and stream recorded presence of Pb in wet season. Pb as reported by Bamuwamye et al. (2017) was reported to be contained in some ground water sources of Kampala, capital city of Uganda. The presence of Pb in wet season in this study could have been due to the run off from use of fertilizer in gardens that found their way into surface and groundwater.

Cu concentrations in the study area were in low concentrations and below the WHO and EAC prescribed limits in both dry and wet seasons. The results are in agreement with the study conducted by Bamuwamye et al. (2017) who found out that surface and groundwater sources in Kampala contained some Cu concentrations which were within the acceptable limits. Muwanga and Barifaijo (2006) study is also in agreement with the current study where they stated that most of the heavy metals in water samples from Busia are below maximum permissible limits of WHO.

The reported diseases which people suffered as a result of consuming contaminated water are diarrhea, kidney failure, anemia, kidney failure and liver damage. In relation to the study findings, (Kapaj et al. (2006) reported that exposure of As at low concentrations (even as low as <0.01mg/l) can cause harmful effects to humans including decreased birth weights, increase in fetal loss and premature delivery. During the study carried out in West Bengal, India, Guha Mazumder & Dasgupta, (2011), found out that diarrhea, abdominal pain and anemia were some of the symptoms and signs reported by patients exposed to As, that was as a result of consuming polluted water.

Conclusion

Mining, agriculture and small-scale businesses are among the economic activities that the people of Sikuda and Western division, Busia district depend on for their livelihoods. The different concentration levels of As, Pb, Cu and Hg in the water sources of Sikuda and Western division, Busia district were likely to have emanated from the uncontrolled and different economic activities carried out in the region. The concentrations of As in all water point samples collected in both dry and wet seasons were above the WHO and EAC permissible limits possibly because of the mining activities and weathering processes of rocks. The concentrations of the As in water samples are believed to be the sources of various ailments members of the local community are experiencing.

Recommendations

The concentrations of As in drinking water from the study area were above the regulatory limits of WHO and EAC. This calls for stakeholder awareness by Ministry of Health Officials to the people who use the water for domestic purposes to avoid consuming it and use other alternative sources like piped water. Also, there should be periodic monitoring on the levels of heavy metals in the water sources which are commonly used by household consumption to avoid the escalation of diseases among the populace.

The Government should facilitate in conducting thorough geochemical survey to determine the up-to-date elemental composition of the rocks in the area so as to facilitate making informed decisions on the alternative source of water for domestic use.

References

Abedin, M. J., Cotter-Howells, J., & Meharg, A. A. (2002). Arsenic uptake and accumulation in rice (Oryza sativa L.) irrigated with contaminated water. *Plant and Soil*, *240*(2). https://doi.org/10.1023/A:1015792723288

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water (Switzerland)*, *13*(19). https://doi.org/10.3390/w13192660

Alina, M., Azrina, A., Mohd Yunus, A. S., Mohd Zakiuddin, S., Mohd Izuan Effendi, H., & Muhammad Rizal, R. (2012). Heavy metals (mercury, arsenic, cadmium, plumbum) in selected marine fish and shellfish along the straits of malacca. *International Food Research Journal*, *19*(1), 135–140.

Ambika Asati1, Mohnish Pichhode2, & and Kumar Nikhil3. (2016). Effect of Heavy Metals on Plants: An Overview. *International Journal of Application or Innovation in Engineering & Management*, *5*(3).

Amin, M. E. (2005). Social Science Research: Conception, Methodology and Analysis. Makerere University Press, Kampala, Uganda.

Azeh Engwa, G., Udoka Ferdinand, P., Nweke Nwalo, F., & N. Unachukwu, M. (2019). Mechanism and Health Effects of Heavy Metal Toxicity in Humans. In *Poisoning in the Modern World - New Tricks for an Old Dog?* https://doi.org/10.5772/intechopen.82511

Baig, M. A., Qamar, S., Ali, A. A., Ahmad, J., & Qureshi, M. I. (2020). Heavy metal toxicity and tolerance in crop plants. In *Contaminants in Agriculture: Sources, Impacts and Management*. https://doi.org/10.1007/978-3-030-41552-5_9

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. In *Frontiers in Pharmacology* (Vol. 12). https://doi.org/10.3389/fphar.2021.643972

Bamuwamye, M., Ogwok, P., Tumuhairwe, V., Eragu, R., Nakisozi, H., & Ogwang, P. E. (2017). Human Health Risk Assessment of Heavy Metals in Kampala (Uganda) Drinking Water. *Journal of Food Research*, *6*(4), 6. https://doi.org/10.5539/jfr.v6n4p6

Barasa, B., Kakembo, V., & Karl, T. (2016). Characterization of artisanal gold mining activities in the tropics and their impact on sediment loading and stream flow in the Okame River catchment, Eastern Uganda. *Environmental Earth Sciences*, *75*(14). https://doi.org/10.1007/s12665-016-5876-y

Barrachina, A. C., Carbonell, F. B., & Beneyto, J. M. (1995). Arsenic uptake, distribution, and accumulation in tomato plants: Effect of arsenite on plant growth and yield. *Journal of Plant Nutrition*, *18*(6). https://doi.org/10.1080/01904169509364975

Brochin, R., Leone, S., Phillips, D., Shepard, N., Zisa, D., & & Allan Angerio. (2008). *The Cellular Effect of Lead Poisoning and Its Clinical Picture*. *5*(2), 1–19.

Cavin, O. (2017). *Distribution of Heavy Metals in Water and Sediments of Lower River Nzoia*. *6*(4), 537–546.

Chen, C.-W., Chen, C.-F., & Dong, C.-D. (2012). Distribution and Accumulation of Mercury in Sediments of Kaohsiung River Mouth, Taiwan. *APCBEE Procedia*, *1*. https://doi.org/10.1016/j.apcbee.2012.03.025

Chibuike, G. U., & Obiora, S. C. (2014). Heavy metal polluted soils: Effect on plants and bioremediation methods. *Applied and Environmental Soil Science*, *2014*. https://doi.org/10.1155/2014/752708

Chowdhury, U. K., Biswas, B. K., Chowdhury, T. R., Samanta, G., Mandal, B. K., Basu, G. C., Chanda, C. R., Lodh, D., Saha, K. C., Mukherjee, S. K., Roy, S., Kabir, S., Quamruzzaman, Q., & Chakraborti, D. (2000). Groundwater arsenic contamination in Bangladesh and West Bengal, India. *Environmental Health Perspectives*, *108*(5). https://doi.org/10.1289/ehp.00108393

Coelho, L. M., Rezende, H. C., Coelho, L. M., de Sousa, P. A. R., Melo, D. F. O., & Coelho, N. M. M. (2015). Bioremediation of Polluted Waters Using Microorganisms. *Advances in Bioremediation of Wastewater and Polluted Soil*, 1–22. https://doi.org/10.5772/60770

Dinwiddie, E., & Liu, X. M. (2018). Examining the Geologic Link of Arsenic Contamination in Groundwater in Orange County, North Carolina. *Frontiers in Earth Science*, *6*. https://doi.org/10.3389/feart.2018.00111

Fashola, M. O., Ngole-Jeme, V. M., & Babalola, O. O. (2016). Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. In *International Journal of Environmental Research and Public Health* (Vol. 13, Issue 11). https://doi.org/10.3390/ijerph13111047

Ferreira Da Silva, E., Zhang, C., Serrano Pinto, L., Patinha, C., & Reis, P. (2004). Hazard assessment on arsenic and lead in soils of Castromil gold mining area, Portugal. *Applied Geochemistry*, *19*(6). https://doi.org/10.1016/j.apgeochem.2003.10.010

Gerhardsson, L., Dahlin, L., Knebel, R., & Schütz, A. (2002). Blood lead concentration after a shotgun accident. *Environmental Health Perspectives*, *110*(1). https://doi.org/10.1289/ehp.02110115

Guha Mazumder, D., & Dasgupta, U. B. (2011). Chronic arsenic toxicity: Studies in West Bengal, India. In *Kaohsiung Journal of Medical Sciences* (Vol. 27, Issue 9). https://doi.org/10.1016/j.kjms.2011.05.003

Gworek, B., Dmuchowski, W., & Baczewska-Dąbrowska, A. H. (2020). Mercury in the terrestrial environment: a review. In *Environmental Sciences Europe* (Vol. 32, Issue 1). https://doi.org/10.1186/s12302-020-00401-x

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. In *Interdisciplinary Toxicology* (Vol. 7, Issue 2). https://doi.org/10.2478/intox-2014-0009

Kabata-Pendias, A., & Pendias, H. (2001). Trace elements in Solids and Plants. In *Trace Elements in Soils and Plants, Fourth Edition* (Vol. 2nd, Issue 2).

Kabata-Pendias, A., & Szteke, B. (2015). Trace Elements in Abiotic and Biotic Environments. In *Trace Elements in Abiotic and Biotic Environments*. https://doi.org/10.1201/b18198

Kapaj, S., Peterson, H., Liber, K., & Bhattacharya, P. (2006). Human health effects from chronic arsenic poisoning - A review. *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, *41*(10). https://doi.org/10.1080/10934520600873571

Lenntech. (2004). Lenntech Water Treatment and Air Purification. *Water Treatment*, *31*(0).

Mantey, J., Nyarko, K. B., Owusu-Nimo, F., Awua, K. A., Bempah, C. K., Amankwah, R. K., Akatu, W. E., & Appiah-Effah, E. (2020). Mercury contamination of soil and water media from different illegal artisanal small-scale gold mining operations (galamsey). In *Heliyon* (Vol. 6, Issue 6). https://doi.org/10.1016/j.heliyon.2020.e04312

Martin, S., & Griswold, W. (2009). Human Health Effects of Heavy Metals: Briefs for Citizens. *Environmental Science and Technology*, *15*.

Mbonimpa, A. B., Barifaijo, E., & Tiberindwa, J. V. (2007). The potential for gold mineralisation in the Greenstone belt of Busia district, south eastern Uganda. *African Journal of Science and Technology*, *8*(1), 116-134–134.

Megan Ware RDN LD. (2017). *Health benefits and risks of copper*. Medical News Today.

Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. Bin, Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., & Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University - Science*, *34*(3), 101865. https://doi.org/10.1016/j.jksus.2022.101865

Muwanga, A., & And Barifaijo, E. (2006). Impact of Industrial Activities on Heavy Metal Loading and Their Physico-Chemical Effects on Wetlands of Lake Victoria Basin (Uganda). *African Journal of Science and Technology (AJST) Science and Engineering Series*, *7*(1), 51–63.

Najeeb, U., Ahmad, W., Zia, M. H., Zaffar, M., & Zhou, W. (2017). Enhancing the lead phytostabilization in wetland plant Juncus effusus L. through somaclonal manipulation and EDTA enrichment. *Arabian Journal of Chemistry*, *10*(2014), S3310–S3317. https://doi.org/10.1016/j.arabjc.2014.01.009

Njuguna, E., & Rutebuka, A. (2003). *A ssessm ent o f land u se, vegetation and hum an perceptions on environm ent on environm ent: Buyuba -Busiri (N am w endw a*.

Nsubuga, F. N. W., Namutebi, E. N., & Nsubuga-Ssenfuma, M. (2014). Water Resources of Uganda: An Assessment and Review. *Journal of Water Resource and Protection*, *06*(14), 1297–1315. https://doi.org/10.4236/jwarp.2014.614120

Obasi, P. N., & Akudinobi, B. B. (2020). Potential health risk and levels of heavy metals in water resources of lead–zinc mining communities of Abakaliki, southeast Nigeria. *Applied Water Science*, *10*(7), 1–23. https://doi.org/10.1007/s13201-020-01233-z

Omara, T., Karungi, S., Kalukusu, R., Nakabuye, B. V., Kagoya, S., & Musau, B. (2019). Mercuric pollution of surface water, superficial sediments, Nile tilapia (Oreochromis nilotica Linnaeus 1758 [Cichlidae]) and yams (Dioscorea alata) in auriferous areas of Namukombe stream, Syanyonja, Busia, Uganda. *PeerJ*, *2019*(10). https://doi.org/10.7717/peerj.7919

Park, J. D., & Zheng, W. (2012). Human exposure and health effects of inorganic and elemental mercury. *Journal of Preventive Medicine and Public Health*, *45*(6), 344–352. https://doi.org/10.3961/jpmph.2012.45.6.344

Patra, M., & Sharma, A. (2000). Mercury toxicity in plants. *Botanical Review*, *66*(3). https://doi.org/10.1007/BF02868923

Pietrini, F., Carnevale, M., Beni, C., Zacchini, M., Gallucci, F., & Santangelo, E. (2019). Effect of different copper levels on growth and morpho-physiological parameters in giant reed (Arundo donax L.) in semi-hydroponic mesocosm experiment. *Water (Switzerland)*, *11*(9). https://doi.org/10.3390/w11091837

Pizarro, F., Olivares, M., Uauy, R., Contreras, P., Rebelo, A., & Gidi, V. (1999). Acute gastrointestinal effects of graded levels of copper in drinking water. *Environmental Health Perspectives*, *107*(2). https://doi.org/10.1289/ehp.99107117

Rashmi, I., Roy, T., Kartika, K. S., Pal, R., Coumar, V., Kala, S., & Shinoji, K. C. (2020). Organic and inorganic fertilizer contaminants in agriculture: Impact on soil and water resources. In *Contaminants in Agriculture: Sources, Impacts and Management*. https://doi.org/10.1007/978-3-030-41552-5_1

Ryan, P. C., Kim, J., Wall, A. J., Moen, J. C., Corenthal, L. G., Chow, D. R., Sullivan, C. M., & Bright, K. S. (2011). Ultramafic-derived arsenic in a fractured bedrock aquifer. *Applied Geochemistry*, *26*(4). https://doi.org/10.1016/j.apgeochem.2011.01.004

Saha, J. C., Dikshit, A. K., Bandyopadhyay, M., & Saha, K. C. (1999). A review of arsenic poisoning and its effects on human health. *Critical Reviews in Environmental Science and Technology*, *29*(3). https://doi.org/10.1080/10643389991259227

Siddiqa, A., & Faisal, M. (2020). Heavy metals: Source, toxicity mechanisms, health effects, nanotoxicology and their bioremediation. In *Contaminants in Agriculture: Sources, Impacts and Management*. https://doi.org/10.1007/978-3-030-41552-5_6

Singh, R., Gautam, N., Mishra, A., & Gupta, R. (2011). Heavy metals and living systems: An overview. In *Indian Journal of Pharmacology* (Vol. 43, Issue 3). https://doi.org/10.4103/0253-7613.81505

Taylor, M. P., Winder, C., & Lanphear, B. P. (2012). Eliminating childhood lead toxicity in Australia: a call to lower the intervention level. In *The Medical journal of Australia* (Vol. 197, Issue 9). https://doi.org/10.5694/mja12.11159

Tomašek, I., Mouri, H., Dille, A., Bennett, G., Bhattacharya, P., Brion, N., Elskens, M., Fontijn, K., Gao, Y., Gevera, P. K., Ijumulana, J., Kisaka, M., Leermakers, M., Shemsanga, C., Walraevens, K., Wragg, J., & Kervyn, M. (2022). Naturally occurring potentially toxic elements in groundwater from the volcanic landscape around Mount Meru, Arusha, Tanzania and their potential health hazard. *Science of the Total Environment*, *807*. https://doi.org/10.1016/j.scitotenv.2021.150487

Trasande, L., Landrigan, P. J., & Schechter, C. (2005). Public health and economic consequences of methyl mercury toxicity to the developing brain. *Environmental Health Perspectives*, *113*(5). https://doi.org/10.1289/ehp.7743

UBOS. (2017). Area Specific Profiles Bugiri District. *Report on National Population and Housing Census 2014 Area Specific Profiles*, *April*, 1–75.

UBOS and MAIF. (2015). *Fertilizer consumption and fertilizer use by crop in uganda*. 1–29.

Walekhwa, A. W., Ntaro, M., Kawungezi, P., Nimusiima, E., Achangwa, C., Musoke, D., & Mulogo, E. M. (2022). Water quality of improved water sources and associated factors in Kibuku District, Eastern Uganda. *Sustainable Water Resources Management*, *8*(2), 1–13. https://doi.org/10.1007/s40899-022-00604-5

WHO. (2003). Arsenic, Drinking-water and Health Risk Substitution in Arsenic Mitigation: a

Discussion Paper (report prepared for the Arsenic Policy Support Unit, Local Government Division, Government of Bangladesh World Health Organization). *World Health*.

WHO. (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva. *World Health Organization*, *4*(Licence: CC BY-NC-SA 3.0 IGO.).

Wu, Y., Liang, Q., & Tang, Q. (2011). Effect of Pb on growth, accumulation and quality component of tea plant. In *Procedia Engineering* (Vol. 18, pp. 214–219). https://doi.org/10.1016/j.proeng.2011.11.034

Wuana, R. A., & Okieimen, F. E. (2011). Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *ISRN Ecology*, *2011*, 1–20. https://doi.org/10.5402/2011/402647

Zhang, H., Nguyen, H., Vu, D. A., Bui, X. N., & Pradhan, B. (2021). Forecasting monthly copper price: A comparative study of various machine learning-based methods. *Resources Policy*, *73*. https://doi.org/10.1016/j.resourpol.2021.102189

Data availability:

The data presented in the manuscript is available on request.