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Full Length Research Paper

Risk assessment of cyanobacteria-toxins for small drinking water treatment plants with lake water intakes

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Recent increases in the frequency and severity of toxic algae blooms in freshwater lakes has been a major concern for small communities that rely on them for drinking water supply. A hazard quotient approach to risk characterization is employed to analyze the effectiveness of five conventional treatment methods for removal of cyanotoxins. The application of the method for risk assessment and mitigation is demonstrated for five case studies, including Lake Champlain (Quebec), Coal Lake (Alberta), Butte Lake (Alberta), Kubbani Lake (Nigeria) and Bomo Lake (Nigeria).

Key words: Cyanotoxins, human health, hazard quotient, lake water intake, water quality.

INTRODUCTION

Agricultural non-point source pollution combined with global warming have caused major algal blooms in our freshwater rivers and lakes (Asnaashari et al., 2015; Stang et al., 2016; Gazendam et al., 2016). Cyanobacteria are photosynthetic prokaryotes that thrive well in various kinds of habitats ranging from freshwater and marine environments to hot springs and deserts (Duy et al., 2000; Ballot et al., 2003, 2010; Baxa et al., 2010; Bogialli et al., 2013; Chia et al., 2009, Chia and Kwaghe, 2015). They are popularly referred to as blue-green algae but their physiological, morphological and metabolic structures clearly identify them as bacteria. The photosynthetic origin of cyanobacteria is similar to that of algae but the pigments are located in the thylakoids, which is in the cytoplasm (Chorus et al., 2000; Codd et al., 2005; Drabkova and Marsalek, 2007; Echenique et al., 2014; Ostermaier and Kurmayer, 2010; Sayyad et al., 2015).

One of the basic "metabolic processes of cyanobacteria" is the fixation of di-nitrogen in aerobic conditions using nitogenase, an enzyme that converts di-nitrogen to ammonium. This process enhances a bloom of cyanobacteria in surface waters (Ernst et al., 2006; Fastner et al., 2007; Fawell et al., 1999; Fischer et al., 2000; Graham et al., 2010; Gilroy et al., 2000; Harvey et al., 2015). Cyanobacteria have many properties which result in their relative success and predominance during the blooming season. The following factors are responsible for cyanobacteria blooms in aquatic habitat: aquatic temperatures above 25°C, low light intensity in water, and low nitrogen-to-phosphorous ratios (Hans and Timothy, 2013; Heisler et al., 2008; Hrudey et al., 1999; Griffiths and Saker, 2003; Kaushik and Balasubramanian, 2013; Paerl et al., 2011; Tencalla and Dietrich, 1997).

Presently, there about 3000 known species of

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cyanobacteria but not all produce toxins. Due to the increasing numbers of cases of cyanobacteria blooms, the occurrence of several harmful cyano-toxins in water supplies has also increased. There is growing concern about the potential for negative health effects on humans due to these toxins (Keijola et al., 1989; Baker et al., 2015; Makarewicz and Lewis, 2015; Merel et al., 2012; Mohamed et al., 2015).

Notwithstanding the recent scientific and technical advances in drinking water treatment plants around the globe, the concentrations of cyanobacterial-toxins have been reported to increase in treated drinking relative to raw water source for small water treatment plants. These toxins enter water supplies after lysis of cyano-bacterial cells, as induced by water collection and treatment activities resulting in subsequent release of toxins in finished treated waters. The toxins released by blue-green algae cannot be removed by conventional treatment methods (Merel et al., 2010; Newcombe and Nicholson, 2002; Nicholson et al., 2003; Szlag et al., 2015; Westrick et al., 2010; Zamyadi et al., 2012).

Drinking water treatment processes may cause breakthrough of toxins into treated drinking water as demonstrated by Zamyadi et al. (2012) in a full-scale water treatment plant system. The passage of toxins, toxic cells and cell debris through filtration systems inhibited chlorination that resulted in the breakthrough of microcystins, resulting in exceedance of Canadian and WHO water quality standards for treated drinking water. Long-term consumption of water contaminated by cyanobacteria and algae is known to cause liver failure, cardiac arrhythmia, dysfunction of the nervous system and skin tumors (Ontario Health Unit, 2014; Farrer et al., 2015).

The objective of this study is to evaluate the use of conventional treatment options and riverbank filtration for managing cyano-toxins, to assess the vulnerability of existing municipal drinking water facilities using surface water sources.

STUDY AREAS

The application of the hazard index is demonstrated for five case studies, including Lake Champlain (Quebec), Coal Lake (Alberta), Butte Lake (Alberta), Kubbani Lake (Nigeria) and Bomo Lake (Nigeria).

Lake Champlain's Missisquoi Bay (Quebec)

The population is about 330,000. The Missisquoi River is 130 km long and a tributary of Lake Champlain. The Missisquoi River cuts across Vermont in the United States and southern Quebec in Canada located between Latitude 45° and 0' E and longitude 72° and 35' due west. The Missisquoi River catchment area covers the Green

mountains along the US-Canada border (Lake Champlain and Eastern townships in Quebec before emptying into Lake Champlain's Missisquoi Bay at Richford (Zamyadi et al., 2012).

Coal Lake, City of Wetaskiwin (Alberta)

The population is about 12,525. Wetaskiwin is a city in the Province of Alberta Canada (coordinates 52°N and 113°W). Wetaskiwin is located 70 km south of Edmonton; it sits on what was "formerly a coast of the large sea that covered much of Alberta, millions of years ago". Wetaskiwin sits at an elevation of 760 m. Coal Lake, a reservoir developed on the Battle River, is on the east side of the City (Zurawell, 2002).

Butte Lake, Town of Picture Butte (Alberta)

The population is about 1650. Picture Butte is a city in southern Alberta (coordinates 49° 52' N and 112° 46' W). Picture Butte has a landmass of 2.9 km^2 and sits at an elevation of 900 m, 27 km north of the City of Lethbridge. Old-man River and Picture Butte Lake is the sources of drinking water for this town (Zurawell, 2002).

Kubanni Lake (Nigeria)

The population of this community is about 560,000. The coordinates of this water body are 11° 08'N and 07° 43'E. It has two major tributaries: Kampagi River and Kubanni River. Kubanni Lake is the major source of water to Ahmadu Bello University community and its environs. Surrounding the Kubanni Lake catchment is agricultural land; the farmers in this location utilize agricultural practices that are not environmentally sustainable for the lake (Chia and Kwaghe, 2015).

Bomo Lake (Nigeria)

The population is about 300,000. This lake is 6 km north west of ABU Zaria; it is located 11° 12'N and 07° 38'E and about 671 m above sea level (Chia et al., 2009).

MATERIALS AND METHODS

Due to variations in the species, concentrations and locations of cyanotoxins, appropriate analytical methods are required in order to understand the abundance and occurrence and the potential toxicity of cyanobacterial populations, and to effectively assess the risk of cyanotoxins to humans in drinking water supplies (Kutovaya and Watson, 2014).

Data for small drinking water treatment plants in Eastern Township Quebec, Wetaskiwin Alberta, Picture Butte Alberta, Kubanni and Bomo Lake in Zaira Nigeria are adapted from different

Table 1. Concentrations of cyanotoxins in raw and treated water.

Location	Raw water (µg/L)	Treated water (µg/L)	References
Eastern Township (Quebec)	118.7	2.47	Zamyadi et al. (2012)
Wetaskiwin (Alberta)	14.8	0.155	Zurawell (2002)
Picture Butte (Alberta)	0.105	0.077	Zurawell (2002)
Kubanni (Nigeria)	3.8	2.8	Chia and Kwaghe (2015)
Bomo (Nigeria)	2.4	1.8	Chia et al. (2009)

Table 2. Reference daily doses.

Food	Cyano-toxin	References
Reference daily dose for an adult	0.0001 mg/L	Ohio EPA, 2013
Reference daily dose for a baby	1.43×10^{-5} mg/L	Ohio EPA, 2013

Table 3. Hazard quotient summary for an adult and a baby consuming raw water.

Location	Raw water source	Hazard quotient for an adult	Hazard quotient for a baby
Eastern Township	Missisquoi River	33.9	197
Wetaskiwin	Coal Lake	4.2	24.5
Picture Butte	Butte Lake	0.03	0.18
Kubanni	Kubanni Lake	2.17	6.3
Bomo	Bomo Reservoir	1.3	3.9

literature before, and after conventional treatment. Data are collected and monitored on a weekly basis for spring and summer seasons for the raw water samples from these plants; the changing characteristic of the toxins in the raw water and treated drinking water are the major foci for the drinking water data collected.

Table 1 lists the concentrations of cyanotoxins in raw and treated water for the selected study regions. The data in Table 1 are in agreement with the removal efficiencies of Cyanotoxins using the conventional treatment range from 25 to 99%. Apart from Picture Butte in Table 1, the concentrations of cyanotoxins in the raw water for all other locations are above the Canadian guidelines for microcystins in drinking water. Further, the concentrations of cyanotoxins in the treated waters, with the exception of Wetaskiwin and Picture Butte, remained above WHO and Canadian guideline.

Risk assessment of cyanotoxins

A hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. Risk assessment using the intake rate, hazard quotient and hazard indices using the equations presented below, are described to determine the risk associated with drinking water contaminated with cyano-bacterial toxins.

$$\text{Intake rate} \left(\frac{\text{mg}}{\text{kg}-\text{day}} \right) = \frac{Cw \times IF \times EF \times ED}{BW \times AT} \tag{1}$$

Where: CW = concentration in water (mg/l); IF= intake frequency (L/day); EF = exposure frequency (days); ED = exposure duration (years); BW = body weight (kg); AT = average time (days).

$$\text{Hazard quotient} = \frac{\text{Intake Rate}}{\text{Reference Dose}} \tag{2}$$

Where: HQ = hazard quotient.

The intake rate and hazard quotients for consuming raw water, water after conventional treatment in the two geographical locations are calculated using Equations 1 and 2 using the data presented in Table 2. The calculation conditions below are used in deriving Tables 3 and 4.

Key assumptions

1. Body weight for adult, 70 kg.
2. Body weight for a baby, 10 kg.
3. Water ingestion rate for an adult is 2 L/day for Canada and 4 L/day for the hot climate in Nigeria.
4. Water ingestion rate for a ten-month-old baby is 0.24 L/day.
5. Unintentional ingestion is 1.5 L/day for Canada and Nigeria.
6. Exposure frequency is 182 days for an adult and a baby in Canada
7. Exposure frequency is 365 days for an adult and a baby in Nigeria
8. The reference dose for an adult is 0.0001 $\frac{\text{mg}}{\text{L}}$ per day for both water (Ohio State Environmental Protection Agency, 2013).
9. Reference dose for a baby is ($\frac{10\text{kg}}{70\text{ kg}} \times 0.0001$) = $1.43 \times 10^{-5} \frac{\text{mg}}{\text{L}}$ per day.
10. The cyanobacteria toxins in the assumed intake are derived only from water.

Table 4. Hazard quotient summary for an adult and a baby consuming treated water.

Location	Raw water source	Water treatment technology	Hazard quotient for an adult	Hazard quotient for a baby
Eastern Township	Missisquoi River	Conventional Treatment (Coagulation, Powdered activated carbon, post clarification and chlorination)	1.6	4.1
Wetaskiwin	Coal Lake	Conventional Treatment (pre-oxidation, clarification and chlorination)	0.04	0.26
Picture Butte	Butte Lake	Conventional treatment, membrane filtration and chlorination	2.5×10^{-8}	0.02
Kubanni	Kubanni Lake	Riverbank filtration, sedimentation and chlorination	2.5	4.6
Bomo	Bomo Reservoir	Sand filtration, pre-oxidation and chlorination	1.86	2.9

11. Conventional drinking water treatment plant removal efficiency for cyanobacteria toxins was between 25% for small drinking water treatment plants in Nigeria (Mouchet and Bonnélye, 1998).

RESULTS

Table 3 summarizes the hazard quotient (the ratio of the potential exposure to a substance and the level at which no adverse effects are expected) of raw water and cow milk for an adult and a baby drinking raw water. From the hazard quotient values presented in Table 3, the results indicate that the Butte Lake is the only safe drinking water in terms of microcystins.

Table 4 presents a summary that relates the hazard index of treated drinking water for an adult and a baby to the water treatment technology used drinking water treatment plants; from the hazard quotient values presented in Table 4, the results indicate that a combination of conventional treatment and membrane filtration which is used in Picture Butte is an efficient technique for removing cyanotoxins.

Table 1 was used together with Equations 1, 2, and 3 to calculate the non-carcinogenic risk for a person that weighs 70 kg and drinks 2 L (Canada) and 4 L (Nigeria) of water daily. The individual drank directly from the contaminated lake. Furthermore, the same approach is performed for a baby that weighs 10 kg and drinks 0.24 L of water per day.

A hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. The hazard quotients for an adult and a baby consuming raw water are summarized in Table 3. The hazard quotient for an adult consuming raw water in four communities (study areas in Canada and Nigeria) except Picture Butte exceeded unity. This was similar to the hazard quotient for a baby consuming raw untreated water for all the communities under study with the exception of Picture Butte.

The hazard quotients for an adult and a baby consuming treated drinking water is presented in Table 4; for an adult in Eastern Township, Kubanni and Bomo consuming treated drinking water the hazard quotient is greater than one, while for an adult in Wetaskiwin and Picture Butte consuming treated drinking water, the hazard quotient is less than one. Similarly, the hazard quotient result for a baby consuming treated drinking water in Eastern Township, Kubanni and Bomo exceeds 1, while for a baby consuming treated water in Alberta (Wetaskiwin and Picture Butte), the hazard quotient is less than one.

DISCUSSION

The presences of cyanotoxins in treated drinking water supply from small water treatment plants reaffirms the need to assess the risk of cyanotoxins from these small water treatment plants. In this study, the hazard quotients for an adult and a baby were calculated for a single exposure of treated water for the five treatment plants. The summary calculations are shown in Table 3. The results indicate that a combination of conventional treatment and membrane filtration used in Picture Butte (Table 4) is an efficient technique for removing cyanotoxins. The other Canadian water treatment plants that use combination of coagulation, activated carbon, oxidation, clarification and chlorination have shown a high percentage of removal of cyanotoxins (greater than 97%). This highlights the importance of adopting a more efficient water treatment technologies in affected areas to minimize the risk to a human receptor. On the other hand, in Nigeria, a simple sand filtration or riverbank filtration combined with only chlorination was found to be ineffective in reducing the cyanotoxins concentration to a safe and tolerable level. The efficiency of cyanotoxins removal for both treatment systems in Nigeria were found to around 25%. The people living in these two communities are exposed to elevated concentration of toxin in their drinking water supply.

The results in the different communities included in this study show clearly that hazard quotient for babies are much higher than that for adults. Excluding Picture Butte community, the increased risk for babies compared to adults is between 1.6 and 4.1 to all other four communities. Moreover, all the results above were

calculated based on a single exposure (drinking water). Therefore, it is expected that the risk index, which is defined as the sum of hazard quotients due to different exposures, is also alarming. Other exposures that were not considered in this study are food crops irrigated with cyanotoxins-contaminated water, inhalation of water aerosols, and other water sports like swimming and surfing (Queensland Health, 2001).

Conclusions

The assessment of the cyanotoxin removal capacity for small water treatment plants shows that the concentrations of cyanobacterial toxins in treated drinking water in Quebec and northern Nigeria are of concern; the hazard quotient derived from a combination of treated or untreated water from drinking water treatment plants in Quebec and northern Nigeria exceeded unity which indicates the need for appropriate remedial action to be taken or an alternative water supply developed. Also, the intake rate exceeded the recommended World Health Organization intake guideline of 1 µg/L.

Applicable strategies to eliminate cyanobacteria blooms would be appropriate to adopt for water treatment facilities in Eastern Township (Quebec) and northern Nigeria in order to protect consumer's health. A more sustainable strategy that consists of reducing the introduction of nutrients in surface waters is ideal for a long-term solution. Advanced water treatment techniques such as membrane filtration should be adopted since they have been proven to be very effective in treating all kinds of organic contaminants. Small drinking water treatment plants can be upgraded to include membrane filtration and ozonation. This will help to achieve high removal efficiency.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Irrigation water quality of River Kulfo and its implication in irrigated agriculture, South West Ethiopia

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Irrigation is a common agricultural practice for farmers in the periphery of flowing rivers in Ethiopia. In the south west Ethiopia, fruits and vegetables are majorly produced under irrigation where the mode of irrigation is by pumping water from flowing rivers. Irrigated agriculture has only been linked to the availability of water in physical terms, while the quality of water is significantly important for sustainable agricultural production. A study was conducted to assess the water quality parameter of the Kulfo River in South West part of Ethiopia. Accordingly, the concentration of calcium cation (21 g/L) is the highest concentrated followed by sodium (8.3 g/L), magnesium (5 g/L) and potassium (1.8 g/L) is the least concentrated in the Kulfo River. The concentration level of the chloride ion has significantly (25 mg/L) increased from what it was reported (3 to 12 mg/L) in 2004. More importantly, both the electrical conductivity and the sodium adsorption ration are relatively low, implicating the water is non saline and can safely be used for irrigation.

Key words: Electrical conductivity, irrigation water, pumping, sodium absorption ratio, river.

INTRODUCTION

Irrigation practices have played an important role in increasing agricultural production and productivity so as to meet the ever increasing food, fibre, etc. demands of the growing population. Water resources like rivers and streams are serving as source of irrigation water, while crossing different territories. Irrigated agriculture, however, has only been linked to the availability of water in physical terms while the quality of water is significantly important for sustainable agricultural production. However, the latter has often been neglected, until the situation when most of irrigated agriculture is heavily dependent on lower water quality and less desirable sources elsewhere in the world (FAO, 1985; Islam et al., 2004). Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available (Islam et al., 2004; Causapé et al., 2004; Rao and Devadas, 2005; Raju, 2006; Singh et al., 2008; Dhirendra et al., 2009; Megersa et al., 2009).

Salinity is a common problem facing farmers who irrigate in arid climates. This is because all irrigation waters contain soluble salts. Whether derived from springs, diverted from streams, or pumped from wells, the

waters contain appreciable quantities of chemical substances in solution, dissolved from the geological strata through and over which the waters have flowed. Waters with a high salt content may have moved from a saline water table. In areas with intensive agriculture, fertilization is a major cause of aquifer salinization. The composition of salts in water varies according to the source and properties of the constituent chemical compounds (Guy, unpublished).

These salts include substances such as gypsum (calcium sulphate, $CaSO_4.2H_2O$), table salt (sodium chloride NaCl) and baking soda (sodium bicarbonate $NaHCO_3$). When dissolved in water, salts separate into ions; e.g. sodium chloride breaks down into sodium and chloride ions. Thus, it is customary to refer to ions rather than salts under low quality water, the performance of irrigated agriculture is expected to be below normal, in addition to its environmental impact on soil system. The application of irrigation water to the soil introduces salts into the root zone. Plant roots take in water but absorb very little salt from the soil solution. Similarly, water evaporates from the soil surface but salts remain behind. Both processes result in the gradual accumulation of salts in the root zone, even with low salinity water. This situation may affect the plants in two ways: (a) by creating salinity hazards and water deficiency; and (b) causing toxicity and other problems (Singh et al., 2008; Sukhdev, 2012).

The build-up of salinity in the root zone increases the osmotic pressure of the soil solution and causes a reduction in both the rate of water absorption by the plants and the soil water availability. Thus, a continuous water deficiency may exist even though the field is heavily irrigated. Plant wilting symptoms may not become apparent, but growth and yield are depressed. Under such circumstances, it is not possible to maintain good crop growth and development conditions and obtain high yields. Instead, plant growth is delayed and there will be a considerable reduction in yield. Seed germination is also affected by the presence of salts. It is usually delayed and in some cases does not occur. The level of salinity build-up depends on both the concentration and the composition of salts in the water. Chloride is highly soluble and remains in the soil solution, while sulphate and bicarbonate combine with calcium and magnesium, where present, to form calcium sulphate and calcium carbonate, which are sparingly soluble compounds (Quddus and Zaman, 1996).

The use of such saline water with excessive salt content may also cause secondary salinization of cultivated soils, and bring a series of serious consequences to the agricultural environment and the ecosystem (Kumar et al., 2015). The use of saline irrigation directly affects the soil profile and the dissolved salts may cause changes in the salt balance of the soil system. Zhai et al. (2015) reported that the salt concertation in the soil profile under tomato production was increased by 47% for the use of saline water more than 5 dS/m.

The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering availability of nutrients (Ayers and Westcot, 1985). For instance, in the study conducted in China, it was confirmed that irrigation water more than 5 Ds/m significantly affect the fruit yield of tomato (Zhai et al., 2015). The associated effect of salt in irrigation is attributed to decreased turgor pressure, a lowered speed of cell expansion and damage to chloroplasts, thus reducing the growth rate and photosynthesis. These changes ultimately influence the dry matter accumulation and yield of crops. Ragab (2004) also substantiated that there was a progressive increase in the soil salinity as saline water is continuously used for irrigation. The source of water is the most important phenomenon, whether it is a canal or drainage water. Drainage water is usually affecting the soil system than the water from the canal, in terms of salinity. The complicated nature of the interaction of soils systems and water is governed by the process the exchange of chemical between the water and the soil (Asante et al., 2005).

The other most important problem of the effect of the poor quality water is toxicity of some ions in irrigation water. Many fruit trees and other cultivations are susceptible to injury from salt toxicity. Chloride, sodium and boron are absorbed by the roots and transported to the leaves where they accumulate. In harmful amounts, they result in leaf burn and leaf necrosis. Moreover, direct contact during sprinkling of water drops with a high chloride content may cause leaf burn in high evaporation conditions. To some extent, bicarbonate is also toxic. Other symptoms of toxicity include premature leaf drop, reduced growth and reduced yield. In most cases, plants do not show clear toxicity problems until it is too late to remedy the situation.

Chloride and sodium ions are both present in the solution. Thus, it is difficult to determine whether the damage caused is due to one or to the other. Chloride ions in high concentrations are known to be harmful to citrus and many woody and leafy field crops. A chloride content exceeding 10 meq/litter may cause severe problems to crops. The effect of sodium toxicity is not very clear. However, it has been found that it may cause some direct or indirect damages to many plants. Boron is an essential element to the plants. However, where present in excessive amounts, it is extremely toxic, even at relatively very low concentrations of 0.6 mg/litter. Toxicity occurs with the uptake of boron from the soil solution. The boron tends to accumulate in the leaves until it becomes toxic to the leaf tissue and results in the death of the plant. In arid regions, boron is considered the most harmful element in irrigation water (Guy, unpublished).

In assessing, the quality of irrigation water, one has to identify the relative concentration of the cations, ions and compounds that have a direct effect on plant physiology,
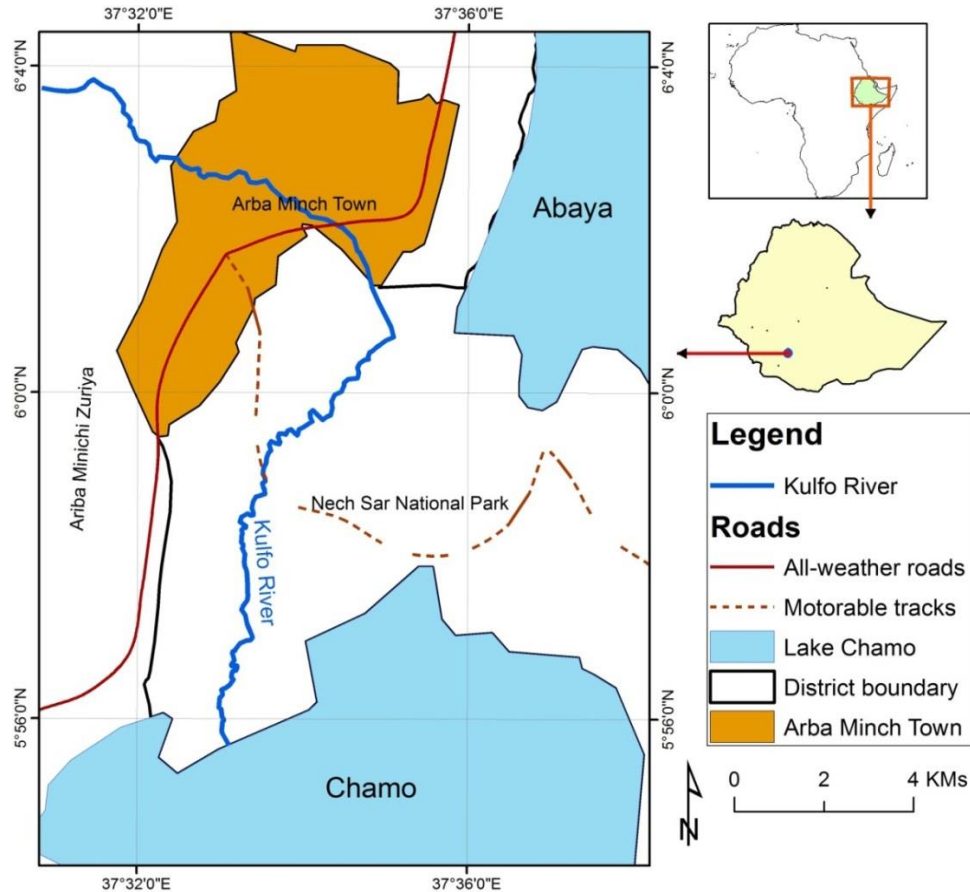
Figure 1. Location map of the study area.

growth and also the soil system. More importantly, the acceptable limits of the concentrations should be known. There are a number of laboratory techniques to measure the quality of water for each of the parameters. For instance, the suitability of water for irrigation is usually assessed by measuring the total dissolved salts (TDS) and or the electrical conductivity where a close relationship exists between the two measurements. But the latter is easier and TDS is easily inferred from the electrical conductivity. The acidity or alkalinity of water is assessed by pH reading where the hydrogen ion concentration of water is directly measured in the water solution.

Given that water is available for irrigation practice, proper assessment and analysis of the quality of water is congruently importance. Information on the quality of water will support to develop strategies for appropriate irrigation practices that will reduce the impact of the undesirable chemicals on proposed crop yields and also the soil profile. In Ethiopia, particularly, at Kuflo River where this study has been conducted, data on water quality of rivers is scarcer, and the purpose of this study was therefore to make the information available so that it can assist future irrigation water management options.

MATERIALS AND METHODS

The study site is located Arba Minch Zuriya district in the Gamo Gofa zone of the Southern Nations and Nationalities Peoples' Regional State of Ethiopia. Situated in the Great Rift Valley region, the district is located about 505 km south west of Addis Ababa, the capital of the country. The district has a total of 29 kebeles (the smallest administration unit in the country). Agro ecologically 4 kebeles are highlands, 15 kebeles at mid altitude and the rest 10 are found in the low land zone. The district has a total area of 168,172 hectares and the total population is 74,879 in Arba Minch city (the capital of the Zone and the district) and 164,529 in Arba Minch Zuriya district. The altitude of the district ranges from 1200 - 3300 masl with a rainfall amount of 800 to 1200 mm per annum. The temperature also ranges from 16 - 37°C. There are two cropping seasons, namely, Belg (short rainy season from March to May), Meher (main rainy season of June to September). The district is also surrounded by the two Rift Valley lakes namely Chamo and Abaya that have a great economic as well as ecological value to the area (FDRE-PCC, 2008).

The district has about 8 major rivers of which River Kulfo is being used by farmers and private investors to grow different crops. The smallholder farmers and the private investors grow crops like banana, mango, papaya, maize, cotton, sweet potato, etc. (Zenebe et al., 2015) (Figure 1).

The upper catchment of the Kuflo River where samples were taken is presented in Figure 2.   The widely accepted threshold values for classifying the suitability of water for irrigation (FAO,

Figure 2. The upper catchment of where water samples was taken

Table 1. Quality parameters and procedures and equipment.

Quality parameters	Equipment
pH	pH meter reading
Electrical conductivity	EC meter reading
Chloride	Argentometric titration with silver nitrate method
Nitrate	DR_2800 spectrophotometric
Calcium	EDTA titrimetric method
Soluble reactive phosphorous (SRP	Spectrophotometry
Potassium	
Turbidity	The nephelometric turbidimeteric
Total dissolved salts	Weighing
Total Hardness as $CaCO_3^{-2}$	

1989) were used. The analysis for the physio-chemical parameters of the samples was carried out using the standard laboratory procedures. Electrical conductivity (ECw) and pH (H_2O) were determined using electrical conductivity meter provided with automatic temperature compensation and potentiometrically with pH-meter equipped with single probe combined glass-calomed electrode (Greenbergs et al., 1992) respectively. Soluble Na+ and K+ were determined by flame-photometer after proper calibration with combined Na-K standard solutions (RTI, 1991), while soluble Ca^{+2} and Mg^{+2}, were analyzed directly by atomic absorption spectrophotometer (APHA, 1998). Chloride (C^{1-}) and HCO_3 ions were measured by the argentometric method, by titrating against silver nitrate standard solution with potassium chromate indicator with a procedure from (Greenbergs et al., 1992). The turbid metrical procedures were solid residues weighed after evaporation for measuring TDS (Chopra and Kanwar, 1980). Similarly, sulfate (SO_4^{2-}) was analyzed turbidmetrically as described by Rezwanul et al. (2007) and nitrate content (NO^{3-}) was determined with spectrophotometric (AOAC, 1990).

The water quality parameters tested and the procedures and equipment used is described in Table 1.

RESULTS AND DISCUSSION

The concentration of important cations of the irrigation water is presented as in Table 1. Calcium cation (21 g/L) had the highest concentrated followed by sodium (8.3 g/L), magnesium (5) and potassium (1.8) has the least concentrated in the Kuflo River. The relatively higher concentration of the calcium cations can be linked with the existence of the calcium bicarbonate in the river (Ababu and Bern, 2014) which might have originated from basaltic formation of parent rock in the region. The relatively high concentration of calcium cation may limit the hazardous effect of sodium which latter causes the dispersion of the soil aggregates and eventually creating problem water and movement in the soil systems (Mathess, 1982). The low level of potassium concentration in the water may implicate minimum wash away of the fertilizers from the soil into the water from the

Table 2. Concentration of cations in the river.

Cations	Concentration (mg/L)
Sodium (Na^{+1})	8.3
Potassium (K^{+1})	1.8
Calcium(Ca^{+2})	21
Magnesium (Mg^{+2})	5

Table 3. Anion concentration in the river.

Anions	Concentration (mg/L)
Sulfate as SO_4^{-2}	14
Nitrate as NO_3^{-1}	34
Nitrite as NO_2-1	0.38
Boron	0.01
Phosphate as PO_4^{+3}	0.24
Carbonate as $CaCO_3^{-2}$	0
Bicarbonate as $CaHCO_3^{-1}$	145
Chloride as Cl^{-1}	25

Table 4. Irrigation water quality parameters.

Parameter	Unit	Values
Total dissolved salts	mg/L	87
Turbidity	NTU	68
Sodium abortion ratio (SAR)	meq/L	0.593
Electrical conductivity (EC)	µS/cm	99
pH	Unit	8.1
Total alkalinity	mg/L	145
Na %	%	35.5

upstream farming areas. However, this could be relatively higher in the downstream areas where compounds may settle (Table 2).

Similarly, the ion concentrations of the important anions for the quality of water are presented in Table 3. The bicarbonate ion is highly concentrated followed by the chlorides and nitrates. The abundant presence of the bicarbonate is again associated with the basaltic formation of the parent material in the vicinity areas of the river, Kulfo. The relatively high nitrates in the form of NO_3 could be associated with high use of nitrogen fertilizers and agrochemicals in the upstream areas. Furthermore, the relative high concentration of nitrates in this form might have been linked to the repeated irrigation practices in the area.

The concentration level of the chloride ion has significantly (25 mg/L) increased from what it was reported (3 to 12 mg/L) in 2004 by Ababu and Bern (2004). The chloride ion can be taken up by plant roots and accumulate in the leaves. The progressive increase of the chloride ion is a warning that there could be some sorts of pollution to the water due to human activity, though the current range is no hazardous. Excessive accumulation of chloride my cause burning of the leaf tops or margins, bronzing and permanent yellowing. Most importantly, fruit trees are sensitive while there are moderate, crops, like vegetables. In general, intents of the nature of the concentration of ions and anions, the water is still safe for irrigating for most of the crops.

The most important water quality parameters are presented in Table 3. Accordingly, both the electrical conductivity and the sodium adsorption ration are

relatively low and it implicates that the water is non saline and can safely be used for irrigation. The electrical conductivity of water is an important quality parameter that categorizes the nature of water for irrigation use. Irrigation water with more than 0.7 dS/m and TDS greater than 450 mg/l are labelled as saline water and caution need to be taken in using the water. The high electrical conductivity of water affects the water availability to plants once it enters the soil profile and eventually reduces the growth and yield of crops. For instance, under repeated irrigation, salinity levels of a saline water with greater than 3 dS/m would reduce the total yield of lemon and keeping the salinity of irrigation water is critical for areas that are irrigated continuously (Blaine et al., 2006).

In the due courses of climate change that causes more evaporative demand and repeated irrigation practices, the development of soil salinity is expected. Due to the complicated interaction of the soil system and water bodies, the rise in the salt concentration of water is axiomatic. Kulfo River is located in the semi-arid areas of Ethiopia, the contribution of climate change and interest in the expansion of irrigation would impact the chemical composition of the water. Hence, proper use of irrigation water demands protection of the river from polluting substances from the upper catchment that may be engaged in irrigated agriculture (Table 4).

As expected, the alkalinity (145 mg/l) of the water is relatively high and corresponds to the high concentration of the bicarbonates in the water. The turbidity of water is high and might have resulted from anthropogenic activities in the vicinity of the river. Among which, construction and agricultural production trend might have disturbed land surfaces, potentially contributing to soil particles as well as nutrients to aquatic systems. Landscape fertilization and chemicals for weed control activities tend to be leached into the river.

Conclusions

Irrigation is a common practice for farmers in the periphery of flowing rivers in Ethiopia. In the south west Ethiopia, fruits and vegetables are majorly produced

under irrigation where the mode of irrigation is by pumping water from flowing rivers. Irrigated agriculture has only been linked to the availability of water in physical terms while the quality of water is significantly important for sustainable agricultural production. A study was conducted to assess the water quality parameter of the Kuflo River in South West part of Ethiopia. Accordingly, the analysis of the results showed that calcium cations is the highest concentration followed by sodium, magnesium and potassium is the least concentrated in the Kuflo River. The relatively higher concentration of the calcium cations can be linked to the existence of the calcium bicarbonate in the river which might have originated from basaltic formation of parent rock in the region. Similarly, the bicarbonate ion is the highset concentrated followed by the chlorides, and nitrates. The abundant presence of the bicarbonate is again associated with the basaltic formation of the parent in the vicinity areas of the river, Kuflo. The relatively high nitrates in the form NO_3 could be associated with high use of nitrogen fertilizers and agrochemicals in the upstream areas. Furthermore, the relative high concentration of nitrates in this form might have been linked to the repeated irrigation practice in the area. More importantly, both electrical conductivity and sodium adsorption ration are relatively low and it implicates that water is non-saline and can safely be used for irrigation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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