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Determination of Residual Chlorine in Uasin Gishu's Country Water Supply

Kiprop CK*, Abuto E, Fredrick O and Kaneza Y

University of Eastern Africa, Kenya

***Corresponding author:** Conceslas Kibet Kiprop, University of Eastern Africa, P.O. BOX 5187-30100, Eldoret, Kenya, Tel: +254728640613; Email: SKIPCO0941@ueab.ac.ke

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Abstract

The knowledge of residual chlorine (RC) is important at final check to the quality of water supplied to consumers. World Health Organization (WHO) recommends a standard at 0.2 - 0.3 mg/L of RC allowable. According to the Centers for Disease Control and Prevention (2020), RC is important for it shows that a significant amount chlorine was initially added to the water to inactivate bacteria and also that the water is safe from recontamination. Given the current discussion on the global effects of chlorine to health, it would be of great importance to determine the levels of RC on the water that is consumed by households in Uasin Gishu County. This research work was set to evaluate the concentration of RC within the water supply of Uasin Gishu County in Kenya. Ten points were chosen at strategic points where tap drinking water were to be sampled for tests between the month of January and March 2021. The samples were tested using a comparator which showed exactly how much chlorine (in mg/L) is in the water if present.

Several factors may affect the amount of residual chlorine in water which include pH, temperature and chlorine decay. These factors greatly dictates the results depending on the time and conditions in which the sample is kept before the testing. This shows why water tests differently at different distance points from the treatment plant. The results were tabulated in excel spreadsheets while graphs and charts were used to show comparison of residual chlorine at different sampling points.

Keywords: Residual Chlorine; Clean Water

Introduction

Chlorine is a naturally occurring element with many uses, from purifying water to disinfecting and bleaching. In small quantities, exposure to chlorine gas or liquid can be poisonous. Chlorine as a gas has a pale green color with a smelly odor. Inhaling the gas can cause difficulty in breathing. Chlorine ion is abundant in nature and can be found in large amounts in salts. Residual chorine can also be referred to free chlorine and according WHO, its presence in drinking water indicates that a sufficient amount of chlorine was added initially to the water to inactivate the bacteria and some viruses that cause diarrheal disease; and, the water is protected from recontamination during storage. The presence of residual chlorine in drinking water is correlated with the absence of most disease-causing organisms, and thus is a measure of the potability of water. When chlorine is added to water, it destroys the membrane of microorganisms and kills them. The process only works, however, if the chlorine comes into direct contact with the organisms. If the water contains silt, the bacteria that reside within it may not be reached by the chlorine. Chlorine disinfects water but does not purify it: there are some contaminants that cannot be removed. Chlorine takes time to kill organisms. At temperatures of 18ºC and above, the chlorine should be in contact with the water for at least 30 minutes. If the water is colder, then the contact time must be increased.

Statement of the Problem

Because of the importance of testing RC on water, many researchers have dug all around the world and found out according to Lausch [1], the inexpensive method of water disinfection has now been found to increase the chances of breast, rectal and bladder cancers. According to Jenkinson & Kane [2], drinking, bathing or swimming in chlorinated water may increase the risk of bladder cancer. Villanueva, et al. [3], gave findings that suggest that chlorine is harmful when inhaled or absorbed through the skin, as well as when they are ingested.

Objectives

The main aim for this paper is to determine the amount of residual chlorine in water.

Literature Review

History of Chlorinated Water

"The addition of chlorine in drinking water began in the 1800s and became the standard in water treatment in 1904" [4]. Since 1849, when Dr. John Snow first suggested that disease could be transmitted through drinking water, many methods have been used to ensure clean and safe drinking water. Chlorination was first proposed in 1910 as a method for purifying water for soldiers who were in the field. A consistent, "safe" supply of drinking water in the developed world is a major public health sanitation success [5]. Millions of people still die from contaminated water in developing countries. Chlorine dissolves in water to form hypochlorous acid (HOCl) that partially breaks down again to form the hypochlorite ion (OCl-). Hypochlorous acid and the hypochlorite ion are toxic to potentially harmful microorganisms and disinfect drinking water.

Harmful Effects of Chlorinated Water

Chlorine helps protect water from picking up diseases and microbes as it travels the pipes to our homes. But once that water arrives at our tap, there's really no reason that the chlorine needs to stay for it causes more harm than the projected good.

Dealing with faded laundry problem

Aside from being smelly Mohsen, et al. [6] noted that chlorinated water can cause a few other problems around the house like with laundry. Residual chlorine in water however little it can be, reacts to form a weak hypochlorite (active component in bleach) therefore making the water to be a slightly bleaching agent. When used to continually clothes, it will have the effect of bleaching on clothes leading to faded laundry.

Effect on shower water

When used for bathing, there will be no refreshing effect after the bath for it makes the skin dry, irritates the eyes and also makes hair brittle. It is even worse when used in hot water showers because chlorine is then released its vapor form and this exposes the lungs to poisoning and irritation which is fatal [7].

By - Products

Residual chlorine in water also introduces other health problems due to the formation of by products which include Trihalomethanes (THM). Osoro [8] indicates that THM's are a group of four chemicals that are formed along with other disinfection by products when chlorine used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water [9]. THM includes chloroform, bromodichloromethane, dibromochloromethane, and bromoform and extensive study shows that THM are carcinogenic.

By Product Formation

Chlorine reacts in solutions of organic compounds by one or more of three basic mechanisms [10] namely, addition, during which chlorine atoms are added to a compound; oxidation; and substitution, during which chlorine atoms are substituted for some other atom that is present in the organic reactant. All three of these reactions involve hypochlorous acid as an electrophile.

Only addition and substitution reactions produce chlorinated organic compounds. Oxidation reactions account for most of the "chlorine demand" of natural waters and waste treatment effluents [11], but the end products are not chlorinated organic compounds. That is not to say that those products cannot be harmful [4]. Have mentioned that epoxides can be produced from carbon-chlorinated compounds at pH values that are common in water treatment plants (e.g., pH 9.5-10.5) where softening is practiced. To illustrate, they describe the reaction between ethylene (C_2H_4) and hypochlorous acid, which yields ethylene chlorohydrin ($ClCH_2CH_2OH$) as an intermediate. This hydrolyzes to form the epoxide, ethylene oxide (C_2H_4O)[12]. Mentioned one such reaction, in which a mixture of chlorohydrin resulted from the reaction of oleic acid [CH_3 $(CH_2)_7CH{=}CH$ $(CH_2)_7COOH$] with hypochlorous acid. Presumably, these would be converted to epoxides if the pH were to be increased. Carlson and Caple also showed how a ubiquitous natural compound, *a*-terpineol [$CH_3C_6H_4C(CH_3)_2OH$], could form epoxides when reacted with hypochlorous acid. These reactions illustrate how chlorination may result in the development of non-chlorinated products, e.g., the epoxides, which may pose health risks. In instances such as those just discussed, a chlorinated intermediate, which itself should be evaluated toxicologically, is involved. The table below illustrates how prevalent and harmful to our health THMs are.

Trihalomethane	Prevalence	Health Effects
Chloroform ($CHCl_3$)	High	Carcinogenic
Bromodichloromethane ($CHBrCl_2$)	Moderate	Carcinogenic, Genotoxic
Dibromochloromethane ($CHBr_2Cl$)	Moderate	Carcinogenic, Genotoxic
Bromoform ($CHBr_3$)	Moderate	Carcinogenic, Genotoxic

Table 1: Characteristics of Common Trihalomethanes [13].

Water- Using Appliances

Another problem with chlorine is that it is really good at breaking down the rubber seals used in most appliances. Rubber gaskets in some of the appliances can wear down a lot faster when our water isn't chlorine-free. Everything from a dishwasher, to a water heater, the machine in the laundry room, and even the heating element in most instant showers can be affected by chlorinated tap water.

Methodology

Experimental Design

This study was conducted between January 2021 and April 2021 in areas surrounding Uasin Gishu County, Kenya. Tap water which is used for drinking by the local communities in Eldoret town and its environs was investigated for the presence and specific amount of residual chlorine. Tap water was collected into 500mL plastic bottles. The 500mL bottles were obtained from UEAB chemistry lab, washed and air dried. Each water sample was tested for Residual Chlorine and the physical properties (pH, Color, and Temperature).

Sample Collection

Water samples were collected from Eldoret and its environs, to test for residual chlorine. Water samples were collected into 500mL plastic bottles from Kapsoya Estate (Ainabkoi Sub County), Outspan Shopping Center (Kapseret Sub County), Jua Kali Shopping Center (Turbo Sub County), Kapkures Shopping Center (Soy Sub County), Kimumu Shopping center (Moiben Sub County), and Annex (Kesses Subcounty), hence a total of 6 samples. These samples were collected directly from the tap into the plastic bottles after allowing the water to flow out for one minute; the bottle was filled to the brim, closed and labeled, then it was refrigerated at 4°C before analysis started 12 hours later (Figure 1).

Figure 1: Water sample collection.

Measurement of Colour

Colour was measured using visual comparison with deionized water. According to Rahmanian, et al. [14] it can be achieved by obtaining a standard of distilled water and visually compared to the sample and results recorded as either normal or not.

Temperature and pH

Temperature and pH will be measured using a Hanna Pen Type pH and Temperature meter. It was first calibrated using 4.0, 7.0 and 10.2 pH buffers. The use of this equipment was to give out results with a ±0.1 error (Figure 2).

Figure 2: Temperature and pH measurements using Hanna Pen Type pH and Temperature meter.

Testing Residual Chlorine

Testing Methods: The method used for testing Residual Chlorine in water employs a chemical known as DPD (N-N Diethylparaphenylenedyamine). Previous methods involved the use of OT (Orthotolidine) and starch- potassium iodide. OT is now known to cause cancer and so it is not recommended. There are many types of equipment for measuring chlorine using the DPD reagent. For this study we used Lovibond® Comparator 2000+ No 14 20 00 which tested residual chlorine when DPD 1 was used and pH when Phenol Red tablets were used. Below is an image of the Lovibond® Comparator 2000+ No 14 20 00 (Figure 3).

Figure 3: Chlorine Comparator.

It is important to measure the pH of the water before measuring the Chlorine levels because chlorine works best at pH values between 6.5 and 8.5. If the pH is higher than 8.5, aluminium sulphate is added to the water, if the pH is lower than 6.5 then lime is added to the acidic water.

Using the Chlorine Comparator: The chlorine comparator was rinsed three times with the sample water to be tested then it was filled with the water sample to be tested to the 10 mL mark. A DPD 1 tablet was then added to the cuvette on the left side of the comparator. Readings were recorded comparing the colour of the water against 13.5mm CELL, Number 3/40A 234010 Chlorine disk colour disk (Figure 4).

If the comparator has a cell marked "Phenol Red" or "pH" then one Phenol Red tablet is added to that cell. (It does not apply for this comparator and so one test is done at a time using specific colour disks). The lid was replaced on the comparator cuvette and counterchecked that it holds well. The comparator was then shaken until all the tablets had dissolved then it is held up to allow plenty of light to enter the cells observing the water cells. If chlorine is present in the water depending on the samples, the dissolved DPD tablet gives a pink colour to the water. The colour was then matched to a disk of colours provided to read the amount of chlorine in the water sample from the scale. If the comparator has a pH cell, the colour is also compared to the colour disk provided or the permanently fixed colour scale on the comparator and readings recorded from the scale. When the test was complete, the lid was removed off the comparator cuvettes and the water poured into organic waste container and not in the water supplies or other water sources. The comparator was then washed with clean water and stored in a place where it cannot be damaged.

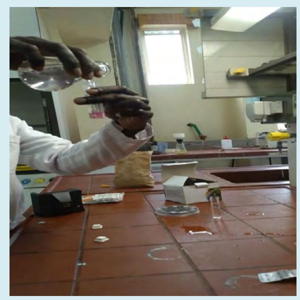


Figure 4: A scientist injecting a water sample to a cuvette with DPD 1 tablet.

Results and Discussion

Results

The results to the water quality with respect to residual chlorine (RC), are tabulated below in Table 2 where a wide range of between 0.1 to 1.0 mg/L were obtained in comparison to WHO recommendation of between 0.2 to 0.5 mg/L.

	8th Feb,2021			15th Feb,2021			22nd Feb,2021			1st Mar, 2021		
WS(ID)	**pH**	**Temp**	**RC**	**pH**	**Temp**	**RC**	**pH**	**Temp**	**RC**	**pH**	**Temp**	**RC**
KS	6.8±0.1	23.5±0.1	0.1	6.7±0.1	22.1±0.1	0.6	7.2±0.1	21.4±0.1	0.4	7.4±0.1	22.8±0.1	0.3
OP	6.9±0.1	22.9±0.1	0.8	6.0±0.1	22.1±0.1	0.2	7.1±0.1	23.1±0.1	0.2	6.8±0.1	21.4±0.1	0.5
An	7.2±0.1	21.9±0.1	0.6	6.9±0.1	20.0±0.1	0.6	8.4±0.1	21.8±0.1	>1.0	7.2±0.1	22.5±0.1	0.1
JK	6.6±0.1	22.4±0.1	1	7.0±0.1	23.5±0.1	0.2	7.8±0.1	22.4±0.1	0.3	8.3±0.1	22.1±0.1	<0.1
KM	7.9±0.1	22.2±0.1	0.1	7.8±0.1	23.4±0.1	0.3	6.9±0.1	23.3±0.1	0.3	7.4±0.1	23.1±0.1	<0.1
KK	7.7±0.1	23.0±0.1	0.9	6.1±0.1	23.0±0.1	0.2	7.2±0.1	20.4±0.1	0.4	6.5±0.1	21.4±0.1	0.3

Table 2: Results for pH, RC and Temperature.

Using the data on Table 2 above, we can calculate the mean values as tabulated in Table 3.

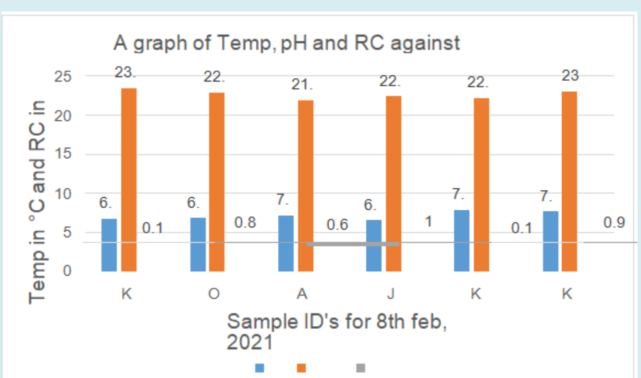
	8th Feb,2021			15th Feb,2021			22nd Feb,2021			1st Mar, 2021		
WS(ID)	**pH**	**Temp**	**RC**	**pH**	**Temp**	**RC**	**pH**	**Temp**	**RC**	**pH**	**Temp**	**RC**
KS	6.8	23.5	0.1	6.7	22.1	0.6	7.2	21.4	0.4	7.4	22.8	0.3
OP	6.9	22.9	0.8	6	22.1	0.2	7.1	23.1	0.2	6.8	21.4	0.5
An	7.2	21.9	0.6	6.9	20	0.6	8.4	21.8	1	7.2	22.5	0.1
JK	6.6	22.4	1	7	23.5	0.2	7.8	22.4	0.3	8.3	22.1	0.1
KM	7.9	22.2	0.1	7.8	23.4	0.3	6.9	23.3	0.3	7.4	23.1	0.1
KK	7.7	23	0.9	6.1	23	0.2	7.2	20.4	0.4	6.5	21.4	0.3
mean	7.18	22.65	0.58	6.75	22.35	0.35	7.43	22.07	0.43	7.27	22.22	0.23

Table 3: Mean Results of pH, RC and Temperature.

The following Table 4 shows the names of the abbreviated samples and other abbreviated terms in the results and discussion section.

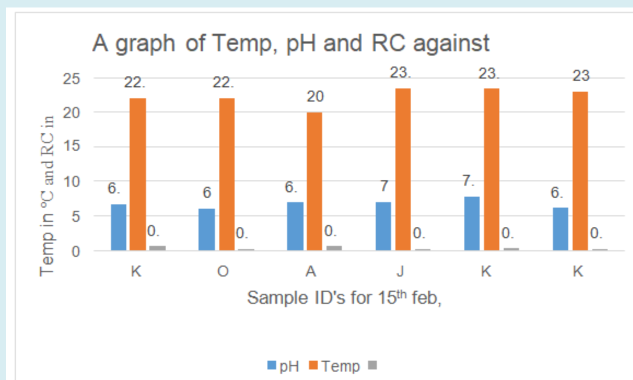
Abbreviation/Acronyms	Meaning
KS	Kapsoya
OP	Outspan
An	Annex
JK	Jua Kali
KM	Kimumu
KK	Kapkures
Temp	Temperature
RC	Residual Chlorine
UG	Uasin Gishu

Table 4: Abbreviation/Acronyms.



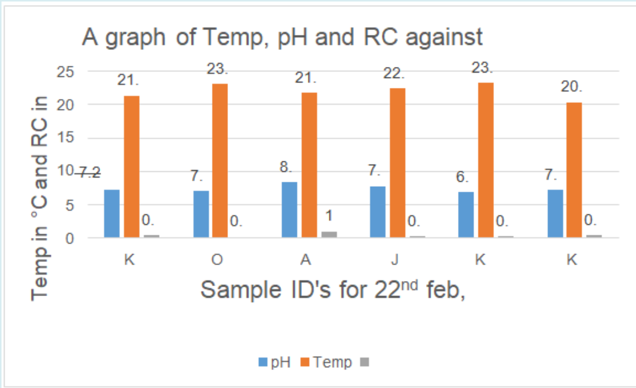
Graph 1: Bar graph representation for 8th Feb results.

The above Graph 1 shows the presence of residual chlorine in water from one single supply to different consumer points. The sample in KS and KM shows the lowest RC values while samples from KK have the highest RC values. In this specific day, 66.7% percent of Uasin Gishu's water supply had a higher than allowed RC contents in water. The pH ranges this day was from 6.6 to 7.9 whereas the water temperatures were between 21.9°C to 23.5°C.



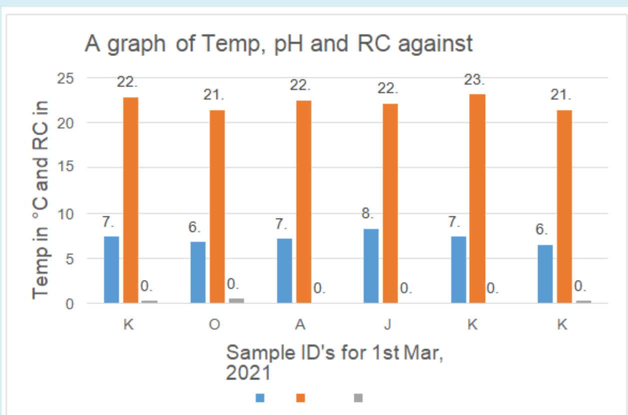
Graph 2: Bar graph representation for 15th Feb results.

This particular Graph 2 gives the RC contents on that specific day amounting to a total of 50% of Uasin Gishu's water supply having more than the allowed 0.2 to 0.3 mg/L of RC. The pH ranges this day were 6.0 - 7.8 whereas the temperature ranges from 20.0 to 25.5. The highest RC values were reported from an and KS samples while OP, JK and KK recording the least values of RC.



Graph 3: Bar graph representation for 22nd Feb results.

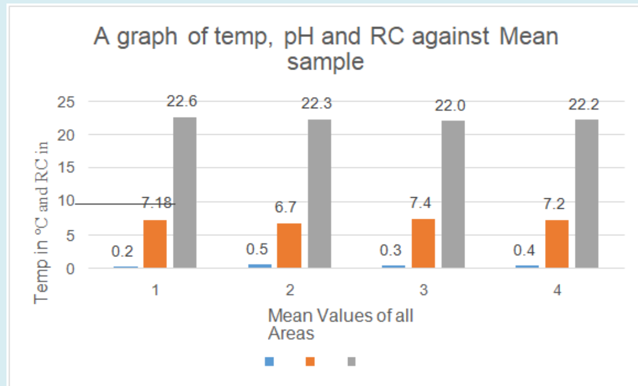
Graph 3 above shows the results recorded on the 22nd Feb, 2021. The highest RC levels were recorded by samples obtained from an while the lowest were recorded from OP samples. Generally, 50% of the day's water supply had more RC than the allowed range of 0.2-0.3mg/L. The temperature range was from 20.4 -23.3°C and pH ranges were from 6.9-8.4.



Graph 4: Bar graph representation for 1st March results.

Graph 4 gives a summary of 1st March, 2021 results where the highest RC values were recorded from OP while samples from an, JK and KM recorded the lowest. In this day, only 16.6% of the supply's water had RC values that are above the allowed values of 0.2-0.3mg/L but 50% had a lower value than the allowed. The temperature ranges were 21.4-23.1°C while those of pH ranged from 6.5 to 8.3.

The water consumed by Uasin Gishu's population within a month may indicate that during every month water with a higher than allowed RC values are consumed. The ranges for pH are from o 7.43 while that of temperature range from 22.07°C to 22.65°C.



Graph 5: Means of water pH, Temperature and RC values in a month.

Discussion

The difference in RC values in water could be attributed to the distance from the treatment plant to the consumer, this is so because the RC will be used up in disinfecting the dirt, germs and other microorganisms causing disease. The distance also has an effect on chlorine decay in water whereby the higher the distance, the longer the time the water will travel through a system thus increasing decay. RC will decay at different rates depending on the temperature of water and the pH. The distance from the source (treatment) to the consumer point (sample collection) has a factor time and the time at which the sample was collected to the time of testing. All these factors if increased, increases the decay and in turn decreased the amount of RC [15]. During chlorination water reacts with chlorine to form a pH dependent equilibrium mixture of chlorine, Hypochlorous acid and Hydrochloric acid. This is shown below.

$$Cl_2\,(g) + H_2O\,(l) \leftrightarrow HOCl\,(aq) + HCl\,(aq)$$

The hypochlorous acid then partly dissociates depending on the pH to form hypochlorite ions and hydrogen as illustrated below.

$$HClO\,(aq) \rightarrow H^{+}\,(aq) + ClO^{-}\,(aq)$$

The ClO^{-} which is dependent on pH is responsible for disinfection of germs and dirt in water. This means that this method of treatment is satisfactory. However, the RC will react with natural decaying matter to form by products that are harmful. "Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (i.e., decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts for which regulations have been established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate, and chlorite [8]. This by products are actively responsible for causing a number of disorders including but not limited to bladder cancer. Chlorination of water is effective as it kills almost all microorganisms that could cause disease. According to WHO [16], some organisms might require a higher concentration of chlorine. This means that even the perfectly treated water might not be safe as assumed. Studies done by many organizations links the RC in water, however small it is, to the ever increasing cancer pandemic. The RC if used in instant showers will vaporize to form gaseous, elemental chlorine which is inhaled. This gas is highly poisonous and a continuous exposure to it is deadly Botlagunta, et al. and Mohsen, et al. [6,17].

Conclusion and Recommendations

Conclusion

The water in Uasin Gishu County has RC that is higher than the allowed amount, this means that the amount of harmful by products will be high and hence higher chances of contacting several cancer disease over the continued use of this water. Bottom line, the ‘safe’ water of Uasin Gishu is not that safe. Therefore, Uasin Gishu’s water treatment and supply is not consistent in the duty to treat water effectively. Distance from the treatment plant to the consumer point also greatly affects the amount of RC. The distance will increase Chlorine decay and therefore reducing RC.

Recommendation

I would recommend that Uasin Gishu treatment plants to fit working filters at the consumer points possibly using Metal Organic Frameworks filter. The filters will help in the adsorption of the RC to avoid formation of by-products. For further study, the subject “Organo-Metallic Frameworks” would be recommended in order to cut down the cost of water filters in the future.

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