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Impact of Drought on Ground Water Quality in Langata Sub-County, Kenya

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Abstract A quality decline trend is suspected to be ensuing in the water originating from boreholes in Langata sub-County; a region located to the south of Nairobi, the capital city of Kenya in East Africa. Despite the existence of this worrisome suspicion, no investigation has been conducted to assuage the fears of the exposed population. This situation however contradicts the great augmenting role of borehole water delivered by vendors to consumers as a coping strategy against the pervasive drought induced water shortage challenge afflicting households in Langata. Hence, a question arose as to whether the identified past drought events have had any chance of influencing the ongoing declining trend of the area's ground water quality. The purpose of this study was therefore to assess the impact of historical drought events on the ground water quality in Langata Sub County. The profile of drought indices was superimposed over the area's time series geochemical water quality indices' profile. Further, the computed area's groundwater potability grade was used to estimate the probability of water quality deterioration due to drought impact, returning a value of 43.65%. It was found that indeed, ground water quality in the area is on a declining mode. Since water is an elixir of life; the finding from this study is expected to trigger an establishment of a water quality surveillance initiative as a safeguard to public health.

Keywords: *drought, water, quality, decline, surveillance*

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1. Introduction

Water is an elixir of all life forms on Earth [1]. Now-a-days; groundwater is a significant source of water for human consumption [2]. It is supplying nearly half of all drinking water in the world [3]. Scholars like those in [4] have argued that, groundwater is a reliable source of fresh water for mankind's water needs. Its slow response to meteorological conditions makes it a big buffer against climate variability including drought according [5,6]. It is estimated that 35% of the earth's surface does experience some form of drought in any given year [6]. This puts into doubt whether groundwater will meet the increasing water demand [7] given the emerging depletion threats from a reduced recharge rate in the face of an increasing demand [8].

Already, in the African continent, almost 44% of the people lacks access to safe water due to the region's susceptibility to rainfall variability [9]. Exacerbating this lack of safe water access is the threat from climate change which is suspected to be fueling groundwater quality decline [10,11,12,13]. Dietary exposure of contaminants through drinking water is a potential source of nearly 75% of the world's waterborne diseases [14]. In an effort to put in measures to protect groundwater quality; a lot of research work has gone in to investigate the sources of groundwater contaminants with an aim to ensuring the adherence to the World Health Organization's safe drinking water guidelines [15,16,17].

In the mid 1980s, worker in [17] pointed out that pesticide was a potential contaminant of ground water, a claim later affirmed by [19] who added that insecticide residues were also found in soil and fruits thereby affecting farmers' health. In the early 1990s, scholar in [20] added their voice, this time blaming pesticides infiltration into groundwater thereby causing adverse health effects on the exposed people. Weighing in on this point, workers in [21] further emphasized the danger people faced from exposure to pesticides in drinking water. Following this, the American Conference of Governmental Industrial Hygienists, a group of industrial hygienists and other occupational health safety professionals dedicated to promoting health and safety, on their part, recommended threshold limit values for chemical substances and physical agents [22]. That is why the workers in [23] recently recommended for the application of nanofiltration for removal of pesticides, nitrate and hardness from ground water to meet drinking water standards as per guidelines in [24]. Further, a decade ago, scholars in [25] noted that, the deterioration of water quality within the supply chain infrastructure including corrosion of pipes was on the rise. According to workers in [26] the galvanized steel pipes are plated with zinc, which usually has 1% of Cadnium, an element found also in the soldering of pipe-fittings. For this reason, an appropriate storage coupled with sustained quality surveillance is crucially important [27].

Other scholars like those in [28] proposed for the removal of pharmaceuticals during drinking water treatment processes using advanced technologies such as ozonation, granular activated carbon and membrane filtration techniques. This is in line with the toxicological evaluation of hazard, dose-response, exposure assessment for risk characterization for tolerable daily intake of chemicals [16]. Already, the World Health Organization has isolated more than 134 chemical substances on its watch list which every country's water standards must abide to maintain their safe limits of acceptable daily intake [15]. The forcing from the combination of anthropogenic global warming and urban heat island effects in cities has equally been associated with the catalysis of groundwater quality decline through biogeological reactions in the observation by [29]. In addition, the over pumping of subsurface aquifers also has been found to be contributing to groundwater quality distortion according to workers in [30]. This assertion was affirmed in the 1999-2004 study on water-quality assessment of the High Plains aquifer, the America's Ogallala aquifer that underlies eight different states, stretching across America's High Plains from South Dakota down to Northern Texas [31]. In the coastal cities, the study by scholars in [32] established that groundwater is very susceptibility to degradation due to salination which requires that it must be subjected to desalination procedures before use.

The same desalination procedures were also recommended for the removal of radioactive contaminants in groundwater like Uranium by workers in [33,34,35] in line with the advice from International Agency for the Research on Cancer [36]. The World Health Organization's guidelines on Uranium sets the safe concentration level for human intake as 15 µg/L. Several studies on the effect of Uranium on human health have been done which have revealed its disease causing nature. Excess Uranium intake is associated with leukemia [37], stomach cancer [38], urinary cancer [39], cancer of urinary organs [40], kidney toxicity [33] and bone toxicity [34]. In fact, the presence of Uranium in groundwater is of a significant concern in a number of countries including; USA, Canada, Germany, Norway, Greece and Finland where its high chemical toxicity and lethal effects on human skeleton and kidney have been identified [33,34,41].

In the oil and gas industry, scholars have also identified shale gas development as posing a potential negative impact on groundwater quality [42]. The fracking technology impact on groundwater quality was first raised by [43] who documented a felt seismicity associated with the shale gas hydraulic fracturing in Europe. Just recently, workers in [44] affirmed the same concern through the finding from the study on the baseline groundwater monitoring for shale gas extraction in Wysin, Northern Poland. The study established that there is a potential contaminant flow into groundwater aquifers from fracking activities, posing a real danger to groundwater users. In developing countries, pit latrines have been found to pose a real challenge to groundwater quality according to study results by workers in [45,46]. From the foregoing, it can be deduced that groundwater quality is under threat from multiple sources including from climate change impacts. Seemingly, it appears that to date, little has been documented on the measurable influence of drought episodes on groundwater quality. Before attempting to address this gap, this study first presents the background information on the need to control groundwater quality.

2. Groundwater Quality Control

Scientific records show that groundwater is the largest distributed store of freshwater but one which continues to expose consumers to varying doses of heavy metal toxicity [47]. Notwithstanding the toxicity challenge, it fascinately plays a critical role in sustaining and enabling human adaptation to climate change [2]. One of the contributing factors to its quality problem is the continuing subsurface thermal regime changes attributable to the global warming. Unfortunately, this fact is yet to be fully understood by researchers as asserted by [48]. Consequently therefore, a region like East Africa with high climate variability records could be exposing her people to groundwater quality danger [49]. The danger notwithstanding, groundwater is a credible source of emergency freshwater everywhere [50].

Because of this, surveillance on groundwater quality has become a mandatory undertaking [51] particularly in Africa where reliance on groundwater is growing [52] even though the full knowledge on its quality regime still remains a challenge [53], a point recently affirmed by [54] for the Kenya's case. Actually, groundwater quality management is becoming a complex matter for three reasons; one, the transient nature of standards of drinking water, two, the increasing pollution threats and lastly, the rising water shortage challenges in communities. It is these complexities that drinking water treatment processes are always on regular reviews to help remove pesticides, hardness, nitrates and natural organic matter. In addition, a continuous monitoring and surveillance measures are also always put in place to track water quality to ward off accidental ingress of contaminants after water is treated [55]. For the groundwater, the contaminants originate from geological conditions, industrial activities, and agricultural processes.

The contaminants contain; microorganisms, inorganic matter, organic matter and radionocludes. It is sometimes insinuated that, the inorganic matter holds a greater portion in the contamination problem compared to the organic chemicals according to [24]. Some inorganic chemicals are in mineral form of heavy metals. When heavy metals accumulate in human organs and nervous systems they cause impairment in their normal functions. The culprit heavy metals include; Lead (Pb), Arsenic (As), Magnesium (Mg), Nickel (Ni), Copper (Cu) and Zinc (Zn) all of which are continuing to pose serious health issues on mankind if ingested beyond the tolerable daily limit. Their presence is measured using approved methods [56] by applying Flame Atomic Absorption Spectrometry (FAAS) as discussed in [57].

The standards include; Manganese [58], Copper [59], Iron [60], Zinc [61], Cadnium [62], Chromium [63], Lead [64], Arsenic [65] and Mercury [66]. These heavy metals have varying implications on human health when ingested beyond daily tolerable limit. For example, Cadnium (Cd) and Chromium (Cr) over exposure is implicated with the cardiovascular diseases, kidney related problems, neurocognitive diseases and cancer according to some past epidemiological findings in Peninsular Malaysia by workers in [67]. Further, Cadnium (Cd) which ordinarily occurs naturally in rocks and soils is known to enter water when there is contact with soft groundwater. It can also be introduced by paints, pigments, plastic stabilizers, mining and smelting operations and industrial operations such as electroplating and fossil fuels, fertilizers and sewerage sludge disposal [26].

On the other hand, Lead (Pb) is associated with causing delay in the physical and mental growth in infants. Mercury (Hg) intake has been attributed to poisoning with skin pathology, cancer, damage to both kidney and liver [68]. Additionally, Mercury compounds are classified by International Agency for Research on Cancer (IARC) as being in group 3 carcinogens [36,69]. In addition, poisoning by Arsenic (As) found in groundwater, fish and sea foods is a global problem [70]. For example, in Bangladesh, chronic Arsenic poisoning has become a major public health problem where its concentration in water is above the WHO provisional guideline value for drinking water of 10 mg/L [71]. Chronic Arsenic exposure may lead to irreversible damage to several vital organs; moreover Arsenic is established as carcinogen [72]. Cessation of exposure to Arsenic and providing Arsenic safe water are currently the mainstays of management of arsenicosis patients [73].

The purpose of analysis methods applied to water resources is to identify potential problems before they give rise to serious adverse health effects [17]. These methods include the analysis of different parameters such as pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), and heavy metals [56,57]. These parameters can affect the drinking water quality, if their values are in higher concentrations than the safe limits set by the World Health Organization (WHO) and other in-country regulatory frameworks [24]. Therefore, the investigation of the drinking water quality by researchers and governmental departments has been performed regularly throughout the world [74,75,76]. The big question is, why do all these tests? The tests are done because drinking water should have a composition favorable to human health and be devoid of harmful substances especially the control of the level of concentration of the important basic inorganic elements that include ;Calcium, Magnesium, Sodium, Potassium and Bicarbonate ions.

These inorganic elements are considered as being the main components in a typical natural freshwater as they form over 90% of the dissolved substances. Freshwater quality and the content of inorganic components depend on the type of substratum. The quality of groundwater may pose a threat to consumers' health, mainly because of high nitrate concentrations [77]. Nitrates may cause methaemoglobinemia in infants and little children and diseases of alimentary tract and hypertension in adults [78]. Long exposure to high nitrate concentrations may be carcinogenic [79]. Drinking water is an important source of Calcium and Magnesium in diet [80]. Both Calcium and Magnesium participate in many physiological processes in human organism at subcellular, cellular and tissue level [81].

Their deficit leads to hypocalcemia and hypomagnesemia [78]. Chronic hypocalcemia may result in osteoporosis [82]. Moreover, hypocalcemia increases the risk of cerebral stroke and leads to an increase of blood pressure [83]. Magnesium deficit in human body contributes to diseases of blood circulation system, disturbs heartbeat rhythm, causes vertigo and muscle spasms. High Magnesium intake may reduce the occurrence of colorectal cancer in women [80]. Systematic uptake of higher amounts of Phosphates in drinking water may result in unfavorable effects on bone metabolism and disturbed Calcium-Phosphate equilibrium [84]. But generally; there is need for risk awareness and communication about heavy metal contamination in groundwater [85].

In the physical tests, turbidity measurement is listed first. It indicates the cloudiness of water due to the presence of particles. Remotely, it is a proxy indicator of the content of disease causing organisms in water which may originate from soil runoff. The standard maximum level by WHO is 5 Nephelometric Turbidity Units (NTU). Another important physical feature of water is the electrical conductivity or the specific conductance measuring the water's ionic content. Electrical conductivity is simply the ability of water to convey an electric current. The presences of dissolved solids (the inorganic) like; Calcium, Chloride and Magnesium in a water sample carry the electric current through the water. The maximum allowable level of conductivity by WHO is 1000 µS/cm (1000 microsiemens/centimeter). Conductivity does not have a direct impact on the human health but the measured value can be used to; estimate the existence of minerals such as Potassium, Calcium and Sodium and estimate the amount of chemical reagents to be used in water treatment.

It is said that high conductivity may lower the aesthetic value of water by raising the level of mineral taste .In the agricultural sector as well as in the industrial set ups; high conductivity may cause corrosion of equipment such as boilers. This may also affect home appliances such as water heater systems and faucets. Another important physical water parameter is the P^H .Measurement of water P^H is an indicator of acidity or alkalinity. Water sample is considered as acidic if the P^H value is below 7.0 and when above this, then the water sample is alkalinic. Acidic water can lead to corrosion of metal pipes and plumbing systems. On the other hand, alkaline water is an indicator of presence of disinfectants. The drinking water should have a P^H value ranging between 6.5 to 8.5 as per World Health Organization's guidelines. In Africa, studies of metal pollution are scarce [86], yet there are growing evidences that problems of heavy metals are posing increasing risks to the residents in the continent [87]. In South Africa, a study by workers in [88] on groundwater toxicity established its unsuitability for drinking purposes.

In Kenya, workers in [89] reported on heavy metal toxicity exposure among the inhabitants around the Kenyan side of Lake Victoria shoreline, which was a parallel finding as that done recently by scholars in [90] for the Uganda side. But the biggest contamination challenge for Lake Victoria water is from Nitrogen inflow from the upstream environments. The Nitrogen enrichment of Lake Victoria stems mainly from sewage effluents and river discharges carrying residual farm inputs according to workers in [91]. This has caused groundwater Nitrate contamination in the larger Kisumu city and its environs like Kano Plains [92] which fortifies the earlier findings by [93] on heavy metals toxicity problem. Even in Kakamega County, a northern neighboring city to Kisumu has the same problem with its groundwater quality as per a study by scholars in [94]. In Kiambu County of central Kenya region, workers in [95] reported a seasonal variation in physicochemical and microbiological groundwater quality which was similarly reported by [96] for Tharaka Nithi County in the Eastern Kenya region. In 2016, a study was conducted in Ongata Rongai town in Kajiado County which is located to the south of Nairobi City County. It observed that groundwater quality is largely affected by the proximity to sanitation facilities [97] which is similar to the findings from the Republic of Malawi as was reported by workers in [45].

In Nairobi City County itself, workers in [98] while using spectroscopic technique, established that Nairobi River System's waters are polluted with a matrix of toxic metals. It should be noted that it is the same river system that plays the groundwater recharging role thereby indicating the proximal potential the toxicity challenge may confer to the receiving aquifer. In 2007, a study by [99] had also reported heavy metal pollution around Dandora Municipal solid waste dump site which is located to the north of Nairobi's city centre. This again explains the finding by [100] which reported that African leafy vegetables grown in the urban and peri-urban zones of Nairobi city have high presence of heavy metals. On the ground water context, a study by [101] using laboratory testing method had established that Langata sub County region's groundwater was too alkaline having recorded the highest P^H value of 8.75 relative to the other regions of Nairobi.

This added to the earlier finding using same method by [102] which had flagged the issue of Flouride over-concentration in Nairobi city's groundwater. From the foregoing, it is noticeable that the augmenting role of groundwater resource is plagued by contaminants' exposure problem inevitably calling for the establishment of a quality control early warning initiative framework. Accordingly and as a first step, this study aims to develop an understanding of the influence of drought events action on groundwater quality decline within Langata sub County. This will be reinforced by the calculation of the probability of the effect on areas' groundwater quality grade by drought events. This proposed method has an advantage over the laboratory based approaches used in the previous studies because it is simply a desktop based activity. The rest of the remaining sections of this paper are; Section 3 presents materials and methods, Section 4 outlines the results and discussions while section 5 is the conclusion.

3. Materials and Method

3.1. Study Area

Langata sub County is found in the south of Nairobi city center, located approximately at 1o 22'0" S, 36o44' 0" E. Its topography height range is between 1,600m to 1,850 m above mean sea level. It covers an area of about 196.8 km² in area, with a tolerable temperate tropical climate throughout the year see location map in Figure 1 below. In terms of population growth, the record shows that in a span of 50 years, the population of Nairobi city grew 12- fold, from around 293,000 inhabitants in 1960 to about 3.4 million in 2010 as reported by [103,104]. Between 1948 and 1999 workers in [105] also reported that the city population grew by 12.2%.

Equally, in terms of urbanization, the city was 3.84 square kilometers in 1910 compared to its current area of 696 square kilometers according to [106] as cited by [107]. For the study area, record in [108] shows that Langata sub County had 174,314 or 5.7% of the 3,078,180 city's residents spread in 52,656 households. This rapid population growth and a steep urbanization rate for Nairobi city is described by [109] as being typical of a sub-Saharan Africa (SSA) urban centre characteristic. Geologically, Nairobi city area lies immediately east of the Kenyan rift valley. As such, volcanic, mainly lava flows dominate the geology of this area. These are of the Cenozoic age, overlying a basement of folded schists and gneisses of the Mozambique belt [110].

In terms of water supply, Nairobi City County imports 80% of its bulk water supply from Ndakaini and Sasumua dams located more than 50km away, see Figure 1. There are a number of challenges on the water supply system. Firstly, the current bulk system is not reliable due to drought impacts and siltation of reservoirs arising from deforestation in the upstream catchments. Further, there is a considerable inefficiency in the distribution system causing nearly 50% unaccounted water associated mostly with pipe leakages and illegal connections. As a result, the city is under severe water rationing [111]. To cope, residents have turned to groundwater being supplied by both publicly and privately operated boreholes. On a larger scale, the government has also responded by drawing a robust long term water master plan for the city which is hinged on the Integrated Urban Water Management (IUWM) system up to year 2035 time horizon [112]. These ambitious plans are faced with additional challenges like; climate variability and uncertainty in the projected water supply and demands. This means, sources like the informal water market must also be included in the water plan. But their sources of water must be within the safety guidelines.

Records show that Nairobi boreholes abstract their water from unconfined, confined and perched aquifers with variable chemical quality. This means the water has varying geochemistry due to localized geochemical processes and possible faulting compartmentalization. This raises questions on the quality of ground water for human consumption. A number of groundwater quality investigation studies have been done in different parts of the city most of which have established a high fluoride concentration beyond WHO recommended guidelines which proposes r mixing of groundwater with surface water in a ration of 1:1 to improve its potability. With the increasing water demand, the demand for groundwater is increasing in Nairobi. This demand must be met with a good safety plan in the form of water quality monitoring and control according to [102].

3.2. Material

For drought risk quantification, the monthly rainfall data for the period 1957 to 2013 (57 years) was sourced from Wilson Airport; Kenya Meteorological Service station number: 9136130. This was backed up with the discussion on 2016 drought by [113] that extended the data period from 2013 to 2016.Additionally, on groundwater quality index computation and grading, the borehole drilling data was sourced from Water Resources Authority (WaRA) offices in Nairobi's industrial area. The borehole commissioning data for Langata sub County region for years 1982 to 2017 was issued which had a total of 137 borehole files. On analysis using the perspective of hydrogeochemical parameters, 98 files missed on one or more of the eight inorganic parameters; Potassium K^+, Sodium Na^+, Calcium Na^+, Iron Fe^{2+},Flouride F^-, Chloride Cl^-, Sulphite SO_4^{-2} and Electrical Conductivity Ec (µS/cm).This left 39 sample files for analysis.

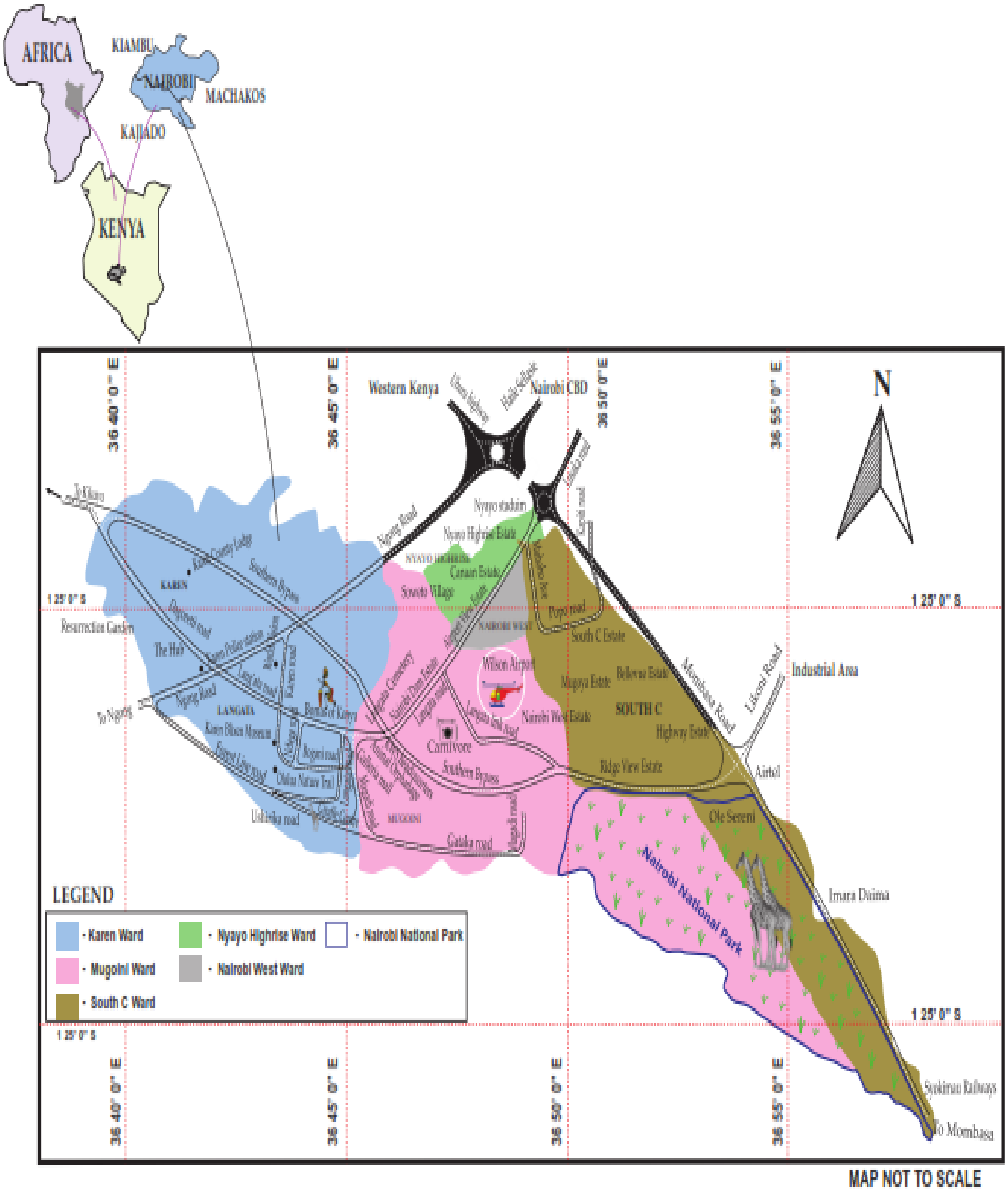

Figure 1. Study area map

3.3. Method

The Standard Precipitation Index formula usually expressed as; $SPI = \frac{X_i - \overline{X}}{\sigma}$ was used to characterize drought in Langata. A detailed procedure is explained in the paper by [114]. In this formula X_i is the annual rainfall of the i-th year and $\overline{X}$ is the mean annual rainfall over the full period, while ɗ is the standard deviation. The SPI values range between -2.5 and 2.5 with 0 being the turning point between wetness and dryness. This study is interested only on dryness and so any SPI value below 0 is counted as a dry year. On groundwater potability estimation, the study deployed the guide by [115]. The full procedure of how the above 8 selected inorganic chemical parameters from 39 boreholes making 312 samples for analysis is explained in the paper by [116] From the results of groundwater potability evaluation and drought characterization Table 1 below was prepared. Using the approach explained in the handbook by [117] in pages 133 and the Z-Normal Distribution Table as presented in pages 147-148, the water quality index of the 39 boreholes used in the quality analysis were taken as the variables to be analyzed.

Table 1. Drought and water quality indices values

	Year	S/N	WQI	SPI	Dry Year Mean WQI	Wet Year WQI
1	1983	465	11.4	0.4		11.4
2	1985	484	23.25	-1.75	23.25	
3	1992	584	33.42	-0.8	36.62	
4	1992	445	39.82	-0.8		
5	2003	622	29.45	0.25	29.45	
6	2004	511	33.88	-0.1	37.64	
7	2004	530	41.4	-0.1		
8	2005	651	32.79	-0.6	40.03	
9	2005	636	27.2	-0.6		
10	2005	463	35.11	-0.6		
11	2005	706	65.04	-0.6		
12	2006	832	98.6	1.1	48.91	
13	2006	540	23.51	1.1		
14	2006	612	24.63	1.1		
15	2007	757	54.81	-0.7	64.32	
16	2007	575	73.83	-0.7		
17	2008	231	77.16	-0.3	77.16	
18	2009	16	32.16	-0.88	45.06	
19	2009	510	57.96	-0.88		
20	2010	132	40.76	-0.1	40.61	
21	2010	492	31.04	-0.1		
22	2010	1412	50.04	-0.1		
23	2011	240	80.6	0.4		56.45
24	2011	243	65.59	0.4		
25	2011	278	26.16	0.4		
26	2011	633	60.75	0.4		
27	2011	853	67.63	0.4		
28	2011	1102	37.97	0.4		
29	2012	237	91.8	1.55		72.65
30	2012	272	53.51	1.55		
31	2014	338	68.29	2.03		55.39
32	2014	373	23.23	2.03		
33	2014	394	56.69	2.03		
34	2014	396	30.17	2.03		
35	2014	401	55.3	2.03		
36	2014	416	98.68	2.03		
37	2015	665	105.99	1.8		78.54
38	2015	676	51.08	1.8		
39	2016	1383	163.38	-1	163.38	
Average WQI			**53.18153846**		**55.13**	
Standard Deviation of WQI			**29.92458754**			

The evaluated overall groundwater quality for Langata according to workers in [116] is grade "C" which falls in the grading band 40-60 with an actual score of 53.18.It should be noted that grade "A" band is 0-20; with grade "B" falling in the band 20-40 and any score beyond 100 is unsuitable for drinking. In grade "C", the upper limit of the score is 60.Therefore, to calculate the probability of exceedance of grade "C" whose maximum value score is 60, the following pieces of information are worked out in MS Excel as presented in Table 1 here: the mean of the dry spell borehole water quality index and the standard deviation. For a normally distributed data, the probability of exceeding a standard value set is;

$$P(X > X_S) = P(Z > Z_\alpha) = \alpha$$

Where Z_α is computed from $\frac{X_S - \mu}{\sigma}$. It is the Z_α which is read out from Z-Table to give the probability of exceedance in percentage.

4. Results and Discussions

From the probability of exceedance formula as above presented the, X_S is 60 and reading from Table 1 above for the dry year mean, μ is 55.13 and the standard deviation σ is 29.92. Therefore, Z_α is 0.16 as read out from Z-Table giving the probability of exceedance in this case as 0.4365 from the Z-Normal Distribution Table. This probability value therefore when expressed as a percentage by multiplying by 100 means that the drought events in Langata have up to 43.65% chance of lowering the ground water quality by exceeding the grade "C" limit of 60.Using values in Table 1 above, the profile of water quality and drought index values were plotted in Excel as presented in Figure 2 below. The blue line is the water quality profile line for the data period and the red line is the rainfall performance profile from the SPI values in Table 1. For the rainfall, values below zero SPI value are drought events. It can be deduced from Figure 2 that as the drought frequency increases so does the ground water quality continues to deteriorate showing a quality decline mode.

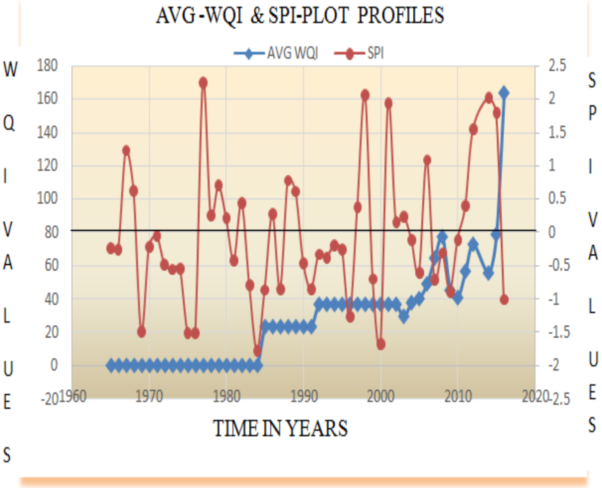

Figure 2. Profile of drought events and ground water quality in Langata

5. Conclusion and Recommendation

The objective of this study was to establish if the drought events in Langata have had an effect on the deterioration of groundwater quality. In addition, it sought to estimate the probability of the effect on quality. Findings from the study reveal that, the past historical drought events have had a significant role in the decline of the groundwater quality based on the assessment of geochemistry parameters. In 1983, the borehole file with serial number (S/N 465) in Table 1 was having grade potability. But regrettably, in 2005, the groundwater quality in Langata reduced drastically with the 2016's record being the worst ever at grade F (163.38), see Table 1 above for borehole with the serial number (S/N 1383).Consequently with respect to the water from this particular borehole (S/N 1383), it becomes unsuitable for drinking purposes.However, this study suspects that the consumers may not be aware this anomaly. In terms of the probability of drought events' influence on the groundwater quality decline, the computation returned a value of 43.65%. This means that, the groundwater quality in the area is substantially susceptible to decline with every drought event. From the findings therefore, it is hereby recommends that, a groundwater quality control and monitoring scheme be started in Langata sub County to safeguard public life from exposure to any form of toxicity.

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References

[1] Balan I N, Shivakumar M, Madan Kumar P D (2012). An assessment of groundwater quality using water quality index in Chennai, Tamil Nadu, India. Chron Young Sci 2012; 3: 146-50.

[2] Taylor, R. G. et al. Dependence of groundwater resources on intense seasonal rainfall: evidence from East Africa. Nature Clim. (2012).

[3] WWAP, The United Nations World Water Development Report 3, Water in a Changing World, World Water Assessment Programme, Paris, UNESCO Publishing, p. 34, 2009.

[4] MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. É. Ó., and Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. Environmental Research Letters, 7(2), 024009.

[5] Calow, R. C., Robins, N. S., Macdonald, A. M., Macdonald, D. M. J., Gibbs, B. R., Orpen, W. R. G., … Appiah, S. O. (1997). Groundwater Management in Drought-prone Areas of Africa. International Journal of Water Resources Development, 13(2), 241-262.

[6] Calow, R. C., MacDonald, A. M., Nicol, A. L., & Robins, N. S. (2010). Ground Water Security and Drought in Africa: Linking Availability, Access, and Demand. Ground Water, 48(2), 246-256.

[7] Mosley, L.M., 2015. Drought impacts on the water quality of freshwater systems; review and integration. Earth-Science Reviews, 140, 203-214.

[8] Wada, Y. et al., (2010) Global depletion of groundwater resources. Geophys. Res. Lett. 37, L20402 (2010).

[9] Olago, D., Opere, A., and Barongo, J. (2009). Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift. Hydrological Sciences Journal, 54(4), 765-780.

[10] Zektser IS, Loaiciga HA (1993).Groundwater fluxes in the global hydrologic cycle: past, present and future. J Hydrol 144(1-4): 405-427.

[11] Green,T. R. , M. Taniguchi, H. Kooi , J. J. Gurdak, D. M. Allen, K. M. Hiscock, H. Treidel, and A. Aureli, Beneath the surface of global change: Impacts of climate change on groundwater, Journal of Hydrology, (2): 200-230, 2011.

[12] Kumar, C. (2012). Climate change and its impact on groundwater resources. International Journal of Engineering Science, 1, 43-60.

[13] Hasan, S., Adham, A., Islam, M. T. and Islam, D. (2016). Effect of climate change on groundwater quality for irrigation purpose in a limestone enriched area. International Review of Civil Engineering, Vol. 7, N. 1.

[14] Aktar et al., (2018). Dietary Exposure of Contaminants through Drinking Water and Associated Health Risk Assessment. Polish Journal of Environmental Studies 27(2)

[15] Van Leeuwen, F. X.. (2000). Safe drinking water: the toxicologist's approach. Food and Chemical Toxicology, 38, S51-S58.

[16] Greim, H. (2000). Scientific justification of setting limits. Food and Chemical Toxicology, 38, S107-S110.

[17] Dissmeyer, G. E. (2000). *Drinking water from Forests and Grasslands*, South Research Station, USDA Forest Service, Ashville, NC, USA, 2000.

[18] Aharonson,N. ., S. Z. Cohen, N. Drescher, T. J. Gish, S. Gorbach, P. C. Kearney, S. Otto, T. R. Roberts, J. W. Vonk. "Potential contamination of ground water by pesticides", Pure Appl. Chem. 59, 1419-1446 (1987).

[19] Del Prado-Lu, J. L. (2014). Insecticide Residues in Soil, Water, and Eggplant Fruits and Farmers' Health Effects Due to Exposure to Pesticides. Environmental Health and Preventive Medicine, 20(1), 53-62.

[20] Maroni M. and Fait A. (1993). Health effects in man from long-term exposure to pesticides. A review of the 1975-1991 literature. Toxicology 78, (1-3): 1-180.

[21] Younes, M., and Galal-Gorchev, H. (2000). Pesticides in drinking water-A case study. Food and Chemical Toxicology, 38, S87-S90.

[22] ACGIH (1998) Threshold Limit Values for Chemical Substances and Physical Agents. American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

[23] Van der Bruggen B., Everaert K., Wilms D., Vandecasteele C.: Application of nanofiltration for removal of pesticides, nitrate and hardness from ground water: rejection properties and economic evaluation. J Membrane Sci 2001; 193(2): 239-248.

[24] World Health Organization (WHO, 2011). *Guidelines for Drinking-Water Quality*, WHO Press, Geneva, Switzerland, 4th edition, 2011.

[25] Elala D, Labhasetwar P, Tyrrel SF. Deterioration in water quality from supply chain to household and appropriate storage in the context of intermittent water supplies. Water Sci Technol: Water Supply. 2011; 11(4): 400-8.

[26] El-Harouny, M., S. El-Dakroory, S. Attalla, N. Hasan, and R. Hegazy, "Chemical quality of tap water versus bottled water: evaluation of some heavy metals and elements content of drinking water in Dakhlia Governorate-Egypt," *The Internet Journal of Nutrition and Wellness*, vol. 9, no. 2, 2009.

[27] Lloyd, B. and Helmer, R. (1991). Surveillance of drinking water quality in rural areas. Longman, New York.

[28] Ternes, T. A., Meisenheimer, M., McDowell, D., Sacher, F., Brauch, H.-J., Haist-Gulde, B., … Zulei-Seibert, N. (2002). Removal of Pharmaceuticals during Drinking Water Treatment. Environmental Science & Technology, 36(17), 3855-3863.

[29] Taniguchi M, Burnett WC, Ness GD (2008) Integrated research on subsurface environments in Asian urban areas. Sci Total Environ 404(2-3): 377-392.

[30] Lambrakis N, Kallergis G (2001) Reaction of subsurface coastal aquifers to climate and land use changes in Greece: modelling of groundwater refreshening patterns under natural recharge conditions. J Hydrol 245(1-4):19-31.

[31] McMahon PB, Dennehy KF, Bruce BW, Gurdak JJ, Qi SL (2007) Water-quality assessment of the High Plains aquifer, 1999-2004. U.S. Geological Survey. Professional Paper 1749, 136 pp., Reston, Virginia.

[32] Morris, B.L., A.R.L. Lawrence, P.J. Chilton, P. Adams, R.C. Calow, and B.A. Klinck. 2003. Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management. Early Warning and Assessment Report Series, RS. 03-3. Nairobi, Kenya: United Nations Environment Programme.

[33] Katsoyiannis, I. A. and A. I. Zouboulis, (2013). Removal of uranium from contaminated drinking water: a mini review of available treatment methods," *Desalination and Water Treatment*, vol. 51, no. 13-15, pp. 2915-2925, 2013.

[34] Tuzen, M. and M. Soylak, (2006). Evaluation of metal levels of drinking waters from the Tokat-black sea region of Turkey," *Polish Journal of Environmental Studies*, vol. 15, no. 6, pp. 915-919, 2006.

[35] Campbell, N. R., and Ingram, J. C. (2014). Characterization of 234U/238U Activity Ratios and Potential Inorganic Uranium Complexation Species in Unregulated Water Sources in the Southwest Region of the Navajo Reservation. Water Reclamation and Sustainability, 77-94.

[36] IARC (International Agency for the Research on Cancer)(1993). Beryllium, Cadmium, Mercury, and Exposures in the Glass Manufacturing Industry, vol. 58 of IARC Monographs on the Evaluation of Carcinogenic Risk to Humans, IARC, Lyon, France, 1993.

[37] Auvinen, A.; Kurttio, P.; Pekkanen, J.; Pukkala, E.; Ilus, T.; Salonen, L. (2002).Uranium and other natural radionuclides in drinking water and risk of leukemia: a case-cohort study in Finland. Cancer Causes Control 2002, 13 (9), 825-9.

[38] Auvinen, A.; Salonen, L.; Pekkanen, J.; Pukkala, E.; Ilus, T.; Kurttio, P. (2005).Radon and other natural radionuclides in drinking water and risk of stomach cancer: a case-cohort study in Finland. Int. J. Cancer 2005, 114 (1), 109-13

[39] Kurttio, P.; Harmoinen, A.; Saha, H.; Salonen, L.; Karpas, Z.; Komulainen, H.; Auvinen, A.(2006). Kidney toxicity of ingested uranium from drinking water. Am. J. Kidney Dis. 2006, 47 (6), 972-82.

[40] Kurttio, P.; Komulainen, H.; Leino, A.; Salonen, L.; Auvinen, A.; Saha, H.(2005) Bone as a possible target of chemical toxicity of natural uranium in drinking water. Environ. Health Perspect. 2005, 113 (1), 68-72.

[41] Prat, O., Vercouter, T., Ansoborlo, E., Fichet, P., Perret, P., Kurttio, P., & Salonen, L. (2009). Uranium Speciation in Drinking Water from Drilled Wells in Southern Finland and Its Potential Links to Health Effects. Environmental Science & Technology, 43(10), 3941-3946.

[42] Lefebvre R (2017). Mechanisms leading to potential impacts of shale gas development on groundwater quality. Wiley Interdiscip Rev Water 4:e1188.

[43] Clarke, H., Eisner, L., Styles, P., and Turner, P. (2014). Felt seismicity associated with shale gas hydraulic fracturing: The first documented example in Europe. Geophysical Research Letters, 41(23), 8308-8314.

[44] Montcoudiol, N., Banks, D., Isherwood, C., Gunning, A., & Burnside, N. (2019). Baseline groundwater monitoring for shale gas extraction: definition of baseline conditions and recommendations from a real site (Wysin, Northern Poland). Acta Geophysica, 67(1), 365-384.

[45] Back, J.O., Rivett, M.O., Hinz, L.B., Mackay, N., Wanangwa, G.J., Phiri, O.L., Songolo, C.E., Thomas, M.A.S., Kumwenda, S., Nhlema, M., Miller, A.V.M., Kalin, R.M., (2018). Risk assessment to groundwater of pit latrine rural sanitation policy in developing country settings. Science of the Total Environment. 613-614C, 592-610.

[46] Okotto-Okotto, J., Okotto, L., Price, H., Pedley, S., Wright, J., 2015. A longitudinal study of long-term change in contamination hazards and shallow well quality in two neighbourhoods of Kisumu, Kenya. Int. J. Environ. Res. Public Health 12(4), 4275-4291.

[47] Malassa et al.,(2014).Assessment of Groundwater Pollution with Heavy Metals in North West Bank/Palestine by ICP-MS.Journal of Environmental Protection, 2014, 5, 54-59.

[48] Aureli A,and Taniguchi M (2006). Groundwater assessment under the pressures of humanity and climate changes - GRAPHIC. United Nations Educational Scientific and Cultural Organization, Paris

[49] Schreck, C. J., and Semazzi, F. H. M. (2004). Variability of the recent climate of eastern Africa. International Journal of Climatology, 24(6), 681-701.

[50] Vrba, J. and Verhagen, B. T. Groundwater for Emergency Situations: A Methodological Guide (UNESCO IHP, 2011).

[51] Howard,G and Bartram,J.(2005).Effective surveillance in urban areas of developing countries. Journal of Water and Health. 03.1. 2005.

[52] Adelana, S.M.A., and A.M. MacDonald, eds. (2008). Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology, Volume 13. Leiden, The Netherlands: CRC Press/Balkema.

[53] Foster, S.S.D. 1984. African groundwater development: The challenges for hydrogeological science. In Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium, July 1984), ed. D.E. Walling, S.S.D. Foster, and P. Wurzel, 3-12. IAHS Publication 144. Wallingford, UK: IAHS.

[54] Olago, D.O. (2019). Constraints and solutions for groundwater development, supply and governance in urban areas in Kenya. Hydrogeol J 27, 1031-1050 (2019).

[55] Ab Razak, N. H., Praveena, S. M., Aris, A. Z., and Hashim, Z. (2015). Drinking water studies: A review on heavy metal, application of biomarker and health risk assessment (a special focus in Malaysia). Journal of Epidemiology and Global Health, 5(4), 297-310.

[56] APHA. (1995). American Public Health Association, Standard Methods: For the Examination of Water and Wastewater, APHA, AWWA, WEF/1995, APHA Publication, 1995.

[57] Sawyer,C. N. , P. L. McCarty, and C. F. Parkin,(1994). *Chemistry for Environmental Engineering*, McGraw-Hill, 1994.

[58] ASTM International, *ASTM D858-12, Standard Test Methods for Manganese in Water*, ASTM International, West Conshohocken, Pa, USA, 2012.

[59] ASTM D1688-12, *Standard Test Methods for Copper in Water*, ASTM International, West Conshohocken, Pa, USA, 2012.

[60] ASTM International, *ASTM D1068-10, Standard Test Methods for Iron in Water*, ASTM International, West Conshohocken, Pa, USA, 2010.

[61] ASTM D1691-12, *Standard Test Methods for Zinc in Water*, ASTM International, West Conshohocken, Pa, USA, 2012.

[62] ASTM International, *ASTM D3557-12, Standard Test Methods for Cadmium in Water*, ASTM International, West Conshohocken, Pa, USA, 2012.

[63] ASTM D1687-12, *Standard Test Methods for Chromium in Water*, ASTM International, West Conshohocken, Pa, USA, 2012.

[64] ASTM International, *ASTM D3559-08, Standard Test Methods for Lead in Water*, ASTM International, West Conshohocken, Pa, USA, 2008.

[65] ASTM D2972-08, *Standard Test Methods for Arsenic in Water*, ASTM International, West Conshohocken, Pa, USA, 2008.

[66] ASTM International, "Standard test method for total mercury in water," *ASTM* D3223-12, ASTM International, West Conshohocken, Pa, USA, 2012.

[67] Azrina, A., H. E. Khoo, M. A. Idris, I. Amin, and M. R. Razman, "Major inorganic elements in tap water samples in Peninsular Malaysia," *Malaysian Journal of Nutrition*, vol. 17, no. 2, pp. 271-276, 2011.

[68] Fawell,J. K. (1993). The impact of inorganic chemicals on water quality and health. *Annali dell'Istituto Superiore di Sanita*, vol. 29, no. 2, pp. 293-303, 1993.

[69] Jia, W., C. Li, K. Qin, and L. Liu, (2010). Testing and analysis of drinking water quality in the rural area of High-tech District in Tai'an City. *Journal of Agricultural Science*, vol. 2, no. 3, pp. 155-157, 2010.

[70] Mandal, B.K. and Suzuki, K.T. (2002). Arsenic round the world: a review. Talanta 58 (2002) 201-235.

[71] Ng JC and Moore MR. (2005). Arsenic in drinking water: a natural killer in Bangladesh and beyond. Med J Aus 2005; 183: 562-63.

[72] Chen Y and Ahsan H.(2004). Cancer burden from arsenic in drinking water in Bangladesh. Am J Public Health. 2004; 94: 741-744.

[73] Khan, M.H and Ahmad, S.A (2015).Field detection method of arsenic in urine. Journal of preventive and social medicine. JOPSOM 2015; 34 (2): 10-16.

[74] Heydari, M. M. and H. N. Bidgoli (2012).Chemical analysis of drinking water of Kashan District, Central Iran.*World Applied Sciences Journal*, vol. 16, no. 6, pp. 799-805, 2012.

[75] Kavcar, P., A. Sofuoglu, and S. C. Sofuoglu. (2009). A health risk assessment for exposure to trace metals via drinking water ingestion pathway. *International Journal of Hygiene and Environmental Health*, vol. 212, no. 2, pp. 216-227, 2009.

[76] Cidu, R.,F. Frau, and P. Tore (2011). Drinking water quality: comparing inorganic components in bottled water and Italian tap water," *Journal of Food Composition and Analysis*, vol. 24, no. 2, pp. 184-193, 2011.

[77] Jaszczyński J., Sapek A., Chrzanowski S.(2006). Chemical indices of drinking water from wells in farms situated in the buffer zone of the Biebrza National Park. Woda Środ Obsz Wiej. 2006; 62(18): 129-142.

[78] Fewtrell L. (2004). Drinking-water nitrate, methemoglobinemia, and global burden of disease: a discussion. Environ Health Persp 2004; 112(14): 1371-1374.

[79] Jamaludin N., Sham S.M., Ismail S.N.S. (2013). Health risk assessment of nitrate exposure in well water of residents in intensive agriculture area. Am J Appl Sci. 2013; 10(5): 442-448.

[80] Larsson S.C., Bergkvist L., Wolk A.(2005).Magnesium intake in relation to risk of colorectal cancer in women. JAMA. 2005; 293(1): 86-89.

[81] Grzebisz W. (2011). Magnesium - food and human health. J Elementol 2011; 16(2): 299-323.

[82] Wojtyła-Buciora, P. and Marcinkowski, J. T. (2010). Estimation of health risk resulting from excessive chemical parameters in drinking water. Probl. Hig. Epidemiol. 91 (1), 137-142.

[83] Morr S., Cuartas E., Alwattar B., Lane J.M. (2006). How much calcium is in your drinking water? A survey of calcium concentrations in bottled and tap water and their significance for medical treatment and drug administration. HSSJ. 2006; 2: 130-135.

[84] Kemi V.E., Kärkkäinen M.U.M., Lamberg-Allardt Ch.J.E. (2006). High phosphorus intakes acutely and negatively affect Ca and bone metabolism in a dose-dependent manner in healthy young females. Brit J Nutr 2006; 96, 545-552.

[85] Akoto, O., Teku, J.A. and Gasinu, D. (2019).Chemical characteristics and health hazards of heavy metals in shallow groundwater: case study Anloga community, Volta Region, Ghana. Appl Water Sci 9, 36 (2019).

[86] Banza, C.L.N., Nawrot, T.S., Haufroid, V., Decree, S., De Putter, T., Smolders, E., Kabyla, B.I., Luboya, O.N., Ilunga, A.N., Mutombo, A.M., Nemery, B., (2009). High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo. Environ. Res. 109, 745-752.

[87] Nriagu, J.O., 1992. Toxic metal pollution in Africa. Sci. Total Environ. 121, 1-37.

[88] Elumalai, V., Brindha, K., and Lakshmanan, E. (2017). Human Exposure Risk Assessment Due to Heavy Metals in Groundwater by Pollution Index and Multivariate Statistical Methods: A Case Study from South Africa. Water, 9(4), 234.

[89] Oyoo-Okoth, E., Admiraal, W., Osano, O., Ngure, V., Kraak, M. H. S., and Omutange, E. S. (2010). Monitoring exposure to heavy metals among children in Lake Victoria, Kenya: Environmental and fish matrix. Ecotoxicology and Environmental Safety, 73(7), 1797-1803.

[90] Bakyayita, G. K., Norrström, A. C., and Kulabako, R. N. (2019). Assessment of Levels, Speciation, and Toxicity of Trace Metal Contaminants in Selected Shallow Groundwater Sources, Surface Runoff, Wastewater, and Surface Water from Designated Streams in Lake Victoria Basin, Uganda. Journal of Environmental and Public Health, 2019, 1-18.

[91] Nyilitya et al., (2016). Tracking sources of excess nitrate discharge in Lake Victoria, Kenya for improved Nitrogen use efficiency in the catchment. International Nitrogen Initiative Conference, "Solutions to improve nitrogen use efficiency for the world". Melbourne, Australia Volume: http://www.ini2016.com/pdf-papers/INI2016_Nyilitya_Benjamin.pdf.

[92] Nyilitya, B., Mureithi, S., and Boeckx, P. (2020). Tracking Sources and Fate of Groundwater Nitrate in Kisumu City and Kano Plains, Kenya. Water, 12(2), 401.

[93] Mireji, P.O.; Keating, J.; Hassanali, A.; Mbogo, C.M.; Nyambaka, H.; Kahindi, S.; Beier, J.C.(2008). Heavy metals in mosquito larval habitats in urban Kisumu and Malindi, Kenya, and their impact. Ecotoxicol. Environ. Saf. 70, 147-153.

[94] Christine, A.A., Kibet, J.K., Kiprop, A.K. et al. (2018). The assessment of bore-hole water quality of Kakamega County, Kenya. Appl Water Sci 8, 47 (2018).

[95] Olonga, R. O., E. Nduda, and M. Makokha. (2015). Seasonal Variations of Physico-Chemical and Microbiological Characteristics of Groundwater Quality in Ruiru, Kiambu County, Kenya. International Journal of Scientific and Research Publications 5 (12): 411-423.

[96] Mbura, K.S. (2018). Assessment of selected physico-chemical parameters of ground water in Tharaka Nithi County, Kenya. Masters degree thesis. Kenyatta University, Kenya.

[97] Hinga Mbugua. (2016). The effect of septic tanks sewage disposal system distances on borehole water quality in Ongata Rongai, Kajiado County, Kenya. Masters Degree Thesis, University of Nairobi.

[98] Chebet et al., (2018). The Speciation of Selected Trace Metals in Nairobi River Water, Kenya.Eurasian Journal of Analytical Chemistry, 2018, 13(4), em24.

[99] United Nations Environment Program, UNEP (2007). Environmental Pollution and Impacts on Public Health: Implications of the Dandora Municipal Dumping Site in Nairobi, Kenya. 2007.

[100] Mutune, A.N.; Makobe, M.A.; Abukutsa-Onyango, M.O.O. Heavy metal content of selected African leafy vegetables planted in urban and peri-urban Nairobi, Kenya. Afr. J. Environ. Sci. Technol. 2014, 8, 66-74.

[101] Muraguri, P.M. (2013). Assessment of Groundwater Quality in Nairobi County, Kenya. Thesis, Jomo Kenyatta University of Agriculture and Technology.

[102] Coetsiers et al., (2008). Hydrochemistry and source of high fluoride in groundwater of the Nairobi area, Kenya. Hydrological Sciences-Journal-des Sciences Hydrologiques, 53(6) December 2008.

[103] Jacobsen, Michael, Michael Webster, and Kalanithy Vairavamoorthy, eds. 2012. The Future of Water inAfrican Cities: Why Waste Water? Directions in Development. Washington, DC: World Bank. License: Creative Commons Attribution CC BY 3.0.

[104] Beguy, D., Elung'ata, P., Mberu, B., Oduor, C., Wamukoya, M., Nganyi, B., & Ezeh, A. (2015). Health and Demographic Surveillance System Profile: The Nairobi Urban Health and Demographic Surveillance.

[105] Owuor, S.O and Mbatia, T. (2008). Post independence development of Nairobi city, Kenya. Paper presented at Workshop on African capital Cities Dakar, 22-23 September 2008.

[106] Morgan, W.T.W. (ed.) (1967), Nairobi city and region. Nairobi: Oxford University Press.

[107] Gutkind, P. C. W. (1968). Nairobi: City and Region. Edited by W. T. W. Morgan. Nairobi: Oxford University Press, 1967. Pp. ix, 154, ill., map. 42s. 6d. Africa, 38(03), 353-354.

[108] Central Bureau of Statistics (2009). Population and Housing Statistics. Population Projections by Province. Nairobi Central Bureau of Statistics. Retrieved from www.cbs.go.ke.

[109] UN-HABITAT. The State of African Cities 2008 - A Framework for Addressing Urban Challenges in Africa. Nairobi: UNHABITAT, 2008.

[110] Onyancha, C. and Getenga, Z. (2013). Geochemistry of Groundwater in the Volcanic Rocks of Nairobi City. Global Journal of Science Frontier Research Environment & Earth Science Volume 13 Issue 3 Version 1.0 Year 2013.

[111] Ledant, Martin (2013). Water in Nairobi: Unveiling inequalities and its causes», Les Cahiers d'Outre-Mer, 263 | 2013, 335-348.

[112] Eckart, J., K. Ghebremichael, K. Khatri, S. Tsegaye, and K. Vairavamoorthy. 2012. "Integrated Urban Water Management for Nairobi." Report prepared for the World Bank by Patel School of Global Sustainability, University of South Florida, Tampa.

[113] Ochungo et al., (2018). Water Supply Security in a Drought Exposed Nairobi: Adopting a Blockchain Provenance Tracking for Informal Alternatives. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 7, Issue 10, October 2018, pp 10475-10483.

[114] Uhe, P., Philip, S., Kew, S., Shah, K., Kimutai, J., Mwangi, E., … Otto, F. (2017). Attributing drivers of the 2016 Kenyan drought. International Journal of Climatology, 38, e554-e568.

[115] Shah, K. A., and Joshi, G. S. (2015). Evaluation of water quality index for River Sabarmati, Gujarat, India. Applied Water Science, 7(3), 1349-1358.

[116] Ochungo et al., (2019). Water Quality Index for Assessment of Potability of Groundwater Resource in Langata Sub County,

Nairobi-Kenya. American Journal of Water Resources. 2019, 7(2), 62-75.

[117] Moser, J.H., and K.R. Huibregtse. (1976). Handbook for sampling and sample preservation of water and wastewater. USEPA 600/4-76-049.