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Assessment of water quality of the Nyando River (Muhoroni-Kenya) using the water quality index (WQI) method

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Abstract

The quality of a river water is described by the levels of physico-chemical and microbiological parameters. The aim of the present work was to determine the water quality of NyandoRiver water from four sampling stations (Muhoroni, Homalime, Kipchui and Wasao) in Muhoroni sub-catchment area and calculate the water quality index (WQI). Physicochemical and microbiological parameters were determined in water samples following standard protocols. The findings were compared with the allowable limits as stipulated by the World Health Organization (WHO) and Kenya Standard (KS) for drinking water. The calculated Water Quality Indices (WQI) ranged from 51.88 to 101.13 lying between "poor water quality" and "unsuitable for drinking". It is determined that TVC, Fe and Mn represent the most effective water quality parameters for calculation of WQI in Nyando River.

Keywords: Water quality index, Nyando River, drinking water.

Introduction

Water is an important chemical compound necessary for life[1].Therefore, drinking water quality is as important for public health as raw water is to aquatic life. The physico-chemical and biological parameters all define the quality of water and determine the suitability for the intended uses such as drinking, agriculture, recreation among others[2]. As such, deliberate and systematic water quality protection programs are crucial for both humans and aquatic life. The quality of water is determined by both natural processes and human induced activities. For instance, effects associated with climate change, land use and location on water quality parameters have been reported in literature[3]. Subramani and co-workers[4] demonstrated the role of lithological units on water quality. One of the criteria for classification of quality of a water resource is the use of water quality index (WQI) first formulated by Horton[5] and Brown et al.[6]. Water quality index (WQI) is a single number descriptor of the quality of the water established by summarizing the influence of several parameters of water analysis results into simple but comprehensive terms for both environmental assessment and management purposes[7,8]. It is a mathematical tool for classification of water quality and an index for suitability of surface waters for various uses. Water quality indices appear in varying forms and have been used extensively to express water quality especially of surface waters[1,9-11]. Muhoroni is a town situated in Kisumu County in the western part of Kenya and is traversed by Nyando River that eventually empties water into Lake Victoria. Noteworthy, a sizeable portion of the Muhoroni population has no access to municipally treated water for domestic utilization. Nyando River is the principal source of water for domestic use for the surrounding community. The underlying problem is that the quality of the river water is not empirically ascertained. The aim of this work was to assess the quality status of water from Nyando River in Muhoroni sub-catchment area based on physical, chemical and microbiological parameters relative to the World Health Organization (WHO) and Kenya standards (KS) for drinking water, and eventually establish the water quality index (WQI) and evaluate the impact of each parameter on the water quality index (WQI).

Materials and methods

Sampling stations and design: The study was conducted in Muhoroni area (altitude of 1475 m above the sea level) on geographical coordinates, 0°90'0" South and 35°12'0" East, explicitly in the regions bounded by Nyando River (Muhoroni, Homalime, Kipchui and Wasao). The town is located 50 kilometres east of Kisumu, the county capital and has an urban and a total population of about 13,664 and 31,148 (7 km radius), as at 2009, respectively (2009 census). The above enumerated sampling stations were selected for they represent the major raw water drawing points for domestic use by the most population in Muhoroni area and are potential points of punctual and diffuse pollutant loading into the river as noted from previous surveillance. The sampling points also included a downstream end of the sub-catchment area. A completely randomized design (CRD) was used for this study. Since the sampling points were within the same geographical area, the effects of lithology and river typology on water chemistry were assumed to be minimal relative to anthropogenic activities.

Water sampling and preparation: Sampling was done in triplicate samples 5 cm from the surface and at the centre of the main flow from the four sampling stations using 500mL sterilized glass bottles. In order to certify the sampling tools and containers were free from contamination, bottles meant for microbiological samples were cleaned and disinfected with 90% ethanol while for heavy metals, the sampling vessels were cleaned using 10% v/v nitric acid and rinsed severally with deionized water. As for odor, pH, EC (electrical conductivity), SM (suspended matter), TDS (total dissolved solids), turbidity, fluoride, sulphate, chloride and nitrate, the glass containers were cleaned then rinsed in de-ionized water. All the bottles were accurately coded then kept in cooler boxes equipped with ice packs and transported to CSI International Ltd. Laboratories in Nairobi, Kenya for preparation and analysis.

Instrumental analysis: The water samples were analyzed for microbiological parameters, nitrates, sulphates, chloride and metal contents according to the protocols described by the American Public Health Association[12]. Precisely eight metals (Ca, Na, Zn, Mg, Pb, Cu and Mn) were detected and quantified using Atomic Absorption Spectrophotometer (model AA320N, China). pH, EC, TDS, turbidity and fluoride levels were determined using their appropriate meters while odour (obnoxious smell) and SM (suspended matter) were assessed by organoleptic threshold odor number (TON) and gravimetric techniques, respectively. The microbiological parameters were Total Viable Counts (TVC), E. Coli (*Escherichia Coli*), Total coliforms and Salmonella.

Calculating Water Quality Index (WQI): WQI is described as a rating indicating the aggregate impact of various water quality parameters[13]. Each parameter was first ascribed a weight value (w) on a scale ranging from 1 to 5 depending on their perceived impacts on health. The lowest weight (1) represented parameters with the feeblest influence on water quality while the highest weight (5) was designated to parameters possessing adverse immunological toxicity and whose occurrence above the allowable limits prohibit the use of the water for drinking purposes[14].

NO_3, Fe, Cu, Mn and TVC were ascribed the highest weight (5) associated with their reported significance in water quality assessment; a low weight of 2 was designated Mg and Na due to their relatively insignificant effect in assessing water quality. The relative weight (W) was computed following the relation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where W_i is relative weight, w_i is weight of the i^{th} parameter while n is the number of parameters. Next, a quality rating (Q_i) for the i^{th} parameter was obtained by the observed value in the samples divided by its set limit value stipulated by the WHO[15] expressed as percent:

$$Q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

Where Q_i is the quality rating, C_i is the value of the i^{th} parameter in the sampled water, and S_i is the drinking water standard limit for the i^{th} parameter. To obtain the WQI, sub-index value of i^{th} parameter (SI_i) was calculated using the equations below:

$$SI_i = W_i \times Q_i \quad (3)$$

$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

The calculated WQI values were categorized into five classes described in Table-1.

Table-1: Water Quality Index (WQI) scale.

WQI Range	Description
0 – 25	Excellent water quality
26 – 50	Good water quality
51 – 75	Poor water quality
76 – 100	Very poor water quality
>100	Unsuitable for drinking

Furthermore, in order to identify the water quality parameter possessing the strongest impact on WQI values, the effective weight (*Ew*) for every analyzed parameter was computed by dividing its sub-index value (SI_i) by net WQI value as previously defined and the result multiplied by 100 according to the equation below:

$$Ew_i = \frac{SI_i}{WQI} \times 100 \quad (5)$$

The relative weights compared with effective weights were an indicator of the influence of each parameter used in determination of WQI.

Results and discussion

The statistical results of this study based on various physicochemical and microbiological parameters of the water samples from Muhoroni, Homalime, Kipchui and Wasao compared to the WHO and Kenya Standards for drinking water are summarized in Table-2.

Table-2: Mean levels (mean±SD) of physical, chemical and microbiological parameters.

	Parameter	Muhoroni	Sampling Points			
			Homalime	Kipchui	Wasao	Std. Limits
Chemical Parameters	Odour	ND	ND	Detected	ND	ND
	pH	7.07±0.15	8.02±0.15	7.05±0.13	7.15±0.07	6.5-8.5 U
	EC	604.00±2.65	272.00±4.00	394.00±2.08	252.00±1.73	*
	Turbidity	12.00±2.00	17.00±1.00	24.00±1.00	26.70±6.00	5 NTU
	TDS	302.00±0.58	136.00±2.00	197.00±1.15	126.00±2.00	1000 mg/L
	SM	6625.67±24.38	7568.33±27.02	12171.00±25.51	12421.67±15.63	NIL
	Ca	<0.001	<0.001	<0.001	<0.001	200 mg/L
	Na	64.51±0.60	159.50±0.89	70.64±1.06	69.11±0.96	200 mg/L
	Fe	0.31±0.01	0.18±0.08	0.68±0.04	0.36±0.06	0.3 mg/L
	Zn	0.07±0.03	0.04±0.01	0.09±0.04	0.08±0.02	5 mg/L
	Mg	0.25±0.31	0.02±0.01	0.06±0.02	0.05±0.02	100 mg/L
	Pb	<0.001	<0.001	<0.001	<0.001	0.01 mg/L
	Cu	0.14±0.08	0.22±0.02	0.02±0.01	0.01±0.004	1.0 mg/L
	Mn	0.07±0.03	0.30±0.04	0.08±0.04	0.06±0.02	0.5 mg/L
	F^-	1.34±0.10	0.02±0.01	1.34±0.12	1.45±0.08	1.5 mg/L
	SO_4^{2-}	11.97±2.05	19.70±0.70	29.63±1.26	90.10±1.85	400 mg/L
	Cl^-	5.15±0.93	15.30±0.83	9.32±0.94	9.87±2.59	250 mg/L
	NO_3^-	26.13±0.15	21.96±0.14	42.30±0.40	15.91±0.24	50 mg/L
Microbiological Parameters	TVC	297±5.77	183±28.87	600±20.00	141±1.15	100 cfu/mL
	Total Coliforms	12±2.52	77±2.89	177±25.17	13±2.89	NIL
	E. Coli	NIL	20±5.00	37±2.89	NIL	NIL
	Salmonella	NIL	NIL	Detected	NIL	NIL

* No standard limit quoted for this parameter

Odour, Turbidity and Suspended matter: Odour (obnoxious smell) is caused by algae, bacteria, anthropogenic activities namely, wastewater effluents and chemical spills[16] which ultimately contaminate both ground and surface waters. The results indicate that this quality parameter was detected in Kipchui while the rest of the sampling points were odour free, implying that Muhoroni, Homalime and Wasao were less polluted with the parameters that are responsible for odour, ultimately justifying the order of the levels of TVC in the samples as Kipchui>Muhoroni>Homalime>Wasao. Turbidity levels exceeded the stipulated allowable limits in all the sampling sites. Suspended matter is a water quality parameter whose standard limit is recommended to be nil in a typical drinking water. The study findings established very high levels of suspended matter in all the four raw water samples. This observation is expected since sampling was conducted during short rains. High suspended matter has been associated with rainy seasons[17].Very high turbidity values observed in the samples from all the four sites correlated well with the levels of suspended matter, that is, both parameters increased correspondingly from Muhoroni through Homalime and Kipchui to Wasao. APHA[18] also linked turbidity in water to suspended and colloidal matter. Such elevated values prohibit the usage of the water for drinking purpose. Tinker *et al.*[19] showed that gastrointestinal illnesses for a faecally polluted water source are attributed to turbidity. Pre-treatment of Nyando River water is therefore required for turbidity reduction before consumption to limit the associated health risks. The odour (obnoxious smell) detected in Kipchui validates the elevated levels of Total Viable Counts detected in the sample, since high correlation between the two parameters has also been reported[20].

pH, EC, TDS, Metals and Anions: pH is an essential parameter in a water resource that often influences the dynamics of the other water quality parameters especially when it changes from acidic to basic conditions or vice versa. pH in all the sampling stations fell within the allowable limits. The pH levels remained relatively constant with an exception of Homalime in which a basic pH was noted. EC and TDS levels were in the order Muhoroni>Kipchui>Homalime>Wasao. The TDS were within the allowable limits provided for by the Kenya Standard (KS) and the World Health Organization[15] standards for drinking water. Compared against Egereonu[21], the results suggest that the water samples are free from laxative or constipation effects, a condition caused by TDS levels beyond 500 mg/L. The examined anions (F, Cl, NO_3 and SO_4) afforded values that were also within the standard limits. The order of the anions was NO_3>SO_4>Cl >F. Consumption of water containing fluoride levels exceeding 1.5 mg/L is a potential cause for various disorders such as mottling of teeth[22], methaemoglobinaemia in infants below the age of 6 months[23] for excess NO_3^-, and an objectionable taste in water is caused by high concentrations (> 400 mg/L) of SO_4^{2-} [24]. As for the metals, Ca and Pb were below the instrumental detection limit. Fe was above the set 0.3 mg/L limit except at Homalime station. The variation of the metal concentrations across the sites is due to anthropogenic activities and partly due to dynamics in water-rock interactions.

Microbiological parameters: Microbiological parameters are but not limited to bacteria and Protozoa. These are microscopic organisms that can survive in many different environments. Several species of bacteria and protozoa have the potential of causing infection, disease, or illness in other living things[25,26]. Illnesses caused by bacteria and protozoa are often spread through drinking water, therefore testing drinking water for the presence of live bacteria and protozoa is indispensable to confirm it is fully disinfected[26].

Total Viable Counts (TVC) levels in all the sampling points surpassed the KS and WHO limits. This clearly testifies of poor quality of these raw water samples since TVC is the best rapid indicator of the microbiological contamination level of any water source[27]. Total coliforms were detected in all the sampling points, *E. coli* in Homalime and Kipchui samples while salmollema was in Kipchui samples. It is worth noting that the levels of total coliforms, *E. coli* and salmonella chiefly depend on total viable counts (TVC) quantification as reported by Dulo[28] and Tenge *et al.*[29]. The reported link is corroborated by the findings in the present study.

Water Quality Index (WQI): In the present work, usability of Nyando River water for drinking purposes was investigated following the WQI method. Fourteen water quality parameters were used for determination of WQI using the aforementioned World Health Organization limits.

To compute WQI values for each of the sampling stations, the weight values were assigned to individual water quality parameters as aforementioned depending on their perceived significance in the quality of water intended for drinking (Table-3). Nitrates, Fe, Mn, Cu and Zn were ascribed a weight of 5 each. The selected metals assigned a weight value of 5 have adverse effects on human health when they exceed the allowable limits[30]. In terms of nutrients, high NO_3levels has been associated with methemoglobinemia, gastric carcinomas, disturbance of central nervous system and diabetes among others[14]. Turbidity, SO_4, TDS and TVC were allocated weight 4; pH, Flouride and Chlorine were ascribed a weight of 3. Mg and Na were ascribed the lowest weight of 2 for they bear least significance in water quality. The weights assigned to the parameters under study are consistent with those reported in literature[31]. The relative weights (W_i) were also calculated following Equation (1) and the corresponding values are listed in Table-3. Water quality index values were computed following Equations. (2), (3) and (4) and the water quality for all the sampling stations classified (Table-4).

The calculated WQI values ranged between 51.88 and 101.131 depicting the fact that the water quality of Nyando river lies between “poor water quality” and “unsuitable for drinking” evidently due to effluents and run offs from the agricultural activities within the river banks. The water quality at Homalime, Wasao and Muhoroni was classified as poor quality while that at Kipchui was classified as unsuitable for drinking.

The effective weight of individual water quality parameter was computed following Equation (5) and the values are presented in Table-5 with their corresponding relative weights. As it can be seen, TVC, Mn and Fe had the highest average effective weights with 30.11, 17.45 and 16.55%, respectively. This implies that these 3 parameters represent the most critical parameters in determination of WQI of Nyando River. Noteworthy, the relative weight of TVC (8.16%) is lower than that of the trace metals yet it presented the highest effective weight. than the Mg parameter (4.08%). TDS, Na, Mg, Cl, F had considerably low relative weight also consistently revealed low effective weight. Here, Mg and Cl had the least relative weight of 0.01 and 0.33 %, respectively. It is intriguing to note that though the trace metals (Zn and Cu) and the nutrients (SO_4 and NO_3) have been assigned high relative weights due to their associated health effects, they had low effective weights attributed to the low concentrations detected.

The results suggest that the water samples are polluted with a major contribution from microbiological parameters (TVC) whose main means of entry into natural waters are from air, soil, sewage, organic wastes, dead plants and animals[32-34]. Tinker *et al.*[19] confirmed that gastrointestinal illness was more pronounced in unfiltered raw River water as opposed to a filtered one, a disclosure emphasizing the necessity of treatment of such microbiologically contaminated waters.

Table-3: Relative weight of selected parameters.

Parameters	Standard limits	weight w_i	relative weight W_i
pH	9.5	3	0.0556
Turbidity	25	4	0.0741
TDS	1500	4	0.0741
Na	200	2	0.0370
Fe	0.3	5	0.0926
Zn	5	5	0.0926
Mg	100	2	0.0370
Cu	1.0	5	0.0926
Mn	0.1	5	0.0926
F^-	1.5	3	0.0556
SO_4^{2-}	400	4	0.0741
Cl^-	250	3	0.0556
NO_3^-	45	5	0.0926
TVC	100	4	0.0741
		Σw_i=54.0	ΣW_i=1.0

Table-4: Water Quality Index (WQI) scale.

WQI Range	Description	W_iQ_i	Water Sample
0 – 25	Excellent water quality		
26 – 50	Good water quality		
51 – 75	Poor water quality	67.6506 51.8800	Homalime Wasao
		60.5362	Muhoroni
76 – 100	Very poor water quality		
>100	Unsuitable for drinking	101.1310	Kipchui

Table-5: Relative weight of selected parameters.

Parameters	weight w_i	Relative weight W_i	Mean Effective weight %
pH	3	5.56	6.47
Turbidity	4	7.41	8.89
TDS	4	7.41	1.40
Na	2	3.70	2.52
Fe	5	9.26	16.55
Zn	5	9.26	0.19
Mg	2	3.70	0.01
Cu	5	9.26	1.38
Mn	5	9.26	17.45
F^-	3	5.56	5.89
SO_4^{2-}	4	7.41	1.17
Cl^-	3	5.56	0.33
NO_3^-	5	9.26	7.62
TVC	4	7.41	30.11
	Σw_i=54.0		

Conclusion

The study results demonstrated that a good number of the analyzed water quality parameters met the standard limit requirements in various sampling points. However, some of the parameters attained values that surpassed the permissible levels as stipulated in the world health organization (WHO) and Kenya Standards (KS), among them were Fe in Muhoroni, Kipchui and Wasao; Turbidity, Suspended Matter, Total Viable Counts and Total Coliforms in all the sampling points; *E. Coli* in Homalime and Kipchui; and odour in Kipchui. Water Quality Index (WQI) determination gave ratings of 67.65, 60.53, 51.88 and 101.13 for Homalime, Muhoroni, Wasao and Kipchui, respectively, which were classified as “poor water quality” and “unsuitable for drinking”. This observation was ascribed to microbiological parameter TVC, Fe and Zn as indicated by their high effective weights relative to other water quality parameters. The deteriorated water quality is effectively attributed to anthropogenic activities as opposed to lithological sources. Necessary Nyando river water protection steps are critically needed before domestic consumption to safeguard the users from contracting water pollution-related illnesses.

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