EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 3 (4): September 2022

This article is licensed under a Creative Commons license, Attribution 4.0 International (CC BY NC SA 4.0)

The use of water quality index and water pollution index in assessing the water quality and suitability of the river Molo water basin, Kenya

*[1]KIPSANG N K., [1]*KIBET J K., [1]ADONGO J O.*

[1]Faculty of Science, Department of Chemistry, Egerton University, P.O Box 536 -20115, Egerton, Kenya

***Corresponding Author**: jkibet@egerton.ac.ke

Abstract

Water quality assessment has become a very essential scientific procedure for qualifying water for drinking and general purpose use, and better public health policy on clean water supply. Various tools have been employed to determine the status of water systems for drinking, industrial and general use. For the purpose of this study, water quality index (WQI) and the recently developed water pollution index (WPI) have been adopted to evaluate the water of the Molo water basin. The world health organization (WHO) has defined limits of these parameters beyond which the quality of water is considered unsuitable for a specific use. The study was carried out in December, 2021 during the dry season. In this contribution, pH, conductivity, TDS, salinity, major cations and anions, and selected heavy metals were explored. Of the major cations Na reported the highest concentration at 1800 mg/L whereas in the anion category, the Cl gave the highest concentration at 110 mg/L. The highest pH, TDS and salinity were 8.5, 146.33, and 282.67, respectively. The data obtained were used to determine the water quality index (WQI) and water pollution index (WPI) of the Molo water basin based on the world health organization (WHO) standards. The average WQI obtained was 57.47 indicating that the water is slightly polluted. Also the average WPI obtained was 0.77 indicating that the water from the water basin is not of good quality. Sediment morphology and composition was also determined using energy dispersive X-ray spectroscopy (EDS). The findings showed the presence of heavy metal pollutants of concern which include lead, manganese and copper. Therefore, with respect to WQI, WPI and sediment morphology, the water basin is significantly polluted. There is need therefore for the government and health authorities to formulate policies aimed at regulating pollution activities which may endanger the Molo water basin.

Keywords: *Pollution; Sediment; Water pollution index; Water quality index*

Received:	25/05/22
Accepted:	10/09/22
Published:	29/09/22

Cite as: *Kipsang et al., (2022)* The use of water quality index and water pollution index in assessing the water quality and suitability of the river Molo water basin, Kenya. *East African Journal of Science, Technology and Innovation 3(4).*

Introduction

The inevitable advancement in industrialization, mechanized agriculture, and accidental waste discharge coupled with natural disasters has become a serious health concern towards safe drinking water. It is against this backdrop that intense research on water quality has been mounted by various researchers and public health authorities. Water is an important resource for human life essentially because it is used in agriculture, industry, and for domestic purposes. From a domestic standpoint, water is mainly used for cooking, drinking, cleaning, personal hygiene and watering gardens (Kadibadiba *et al.*, 2018; Walker, 2019). Water for domestic use in Africa is particularly sourced from rivers, springs, wells, Lakes, boreholes, dams, rain water, piped water and pans, and is direct source of essential and non-essential nutrients (Njora and YILMAZ, 2021; Onyango *et al.*, 2018).

In order to evaluate the extent of water pollution, two important characteristics are examined – water quantity and water quality. Water quantity is basically defined as the sufficiency to serve the intended purpose whereas water quality is defined as the suitability of water to serve an intended purpose without any negative health impacts over the lifetime of its use (Adimalla and Qian, 2019; Gunda *et al.,* 2019). Fresh water pollutants include pathogens, organic matter, minerals, pesticides, pharmaceuticals and plastics with industries, agriculture, domestic effluent, soil erosion and rock weathering, volcanic activities and forest fire accidents being the main sources (Bashir *et al.,* 2020). River water system physical and chemical characteristics are determined by climatic, geomorphological and geochemical conditions of the drainage basin with river currents and turbulence being a major factor for water to achieve continuous mixing and flow histories (Chakraborty, 2021).

The assessment using water quality index and water pollution index, in some cases used together with hazard quotient and hazard index to determine the health risk of water varies depending on the source, location and time (Pacheco Castro *et al.,* 2018; Xu *et al.,* 2019). They both are measured by factors such as the concentration of dissolved oxygen (DO), bacteria levels, the amount of salt (salinity), amount of suspended material (turbidity), the concentration of microscopic algae, concentration of pesticides and heavy metals present in the water system (Devi *et al.,* 2017; Ewaid *et al.,* 2020). In Kenya, water quality index has been applied to assess groundwater resources in Langata sub-county (Nairobi) for portability by Ochungo *et al.* (2019) through sampling thirty nine boreholes where the groundwater quality was categorized as good quality with WQI of 53.18. Ustaoğlu *et al.* (2020), in assessment of stream quality and health risk in Turnasuyu stream in Turkey where the water quality index parameter gave an average of 18.97 which falls within excellent water quality which is considered good for drinking and does not pose a potential hazard to human health. However, application of water quality index in health risk assessment by domestic use of river water by Njuguna *et al.* (2020) reported that water the quality index was unreliably risk assessment tool because it did not correlate well with hazard quotient and hazard index besides portraying all sampling sites as bearing suitable water for drinking. In water quality assessment of rivers in Lake Chaohu basin in China using water quality index reported by Wu *et al.* (2021), the rivers in the basin was rated as moderate at mean water quality index value of 69.1. Ewaid *et al.* (2020) developed and evaluated a water quality index for Iraqi rivers and applied it to assess the Tigris river, the Diyala river, Euphrates river, and Diwaniyah river as case study and yielded an average annual water quality index of the Tigris river as 73.25 which can be categorized as good, and water quality index values of 69.52 for the Diyala river, 60.9 for Euphrates river, and 66.75 for Diwaniyah river which gave the conclusion that Iraqi waters are generally good for drinking and domestic use.

Dissolved minerals affect the taste of drinking water and are measured as total dissolved solid (TDS). Devesa and Dietrich (2018) reported that most water consumers and trained professionals are generally unable to differentiate the taste of tap water at room temperature when the difference in TDS between the waters is $\Delta TDS < \approx 150$ mg/L. Pure water is a poor conductor of electricity but with the dissolved minerals; its electrical conductivity gets improved indicating a relationship between TDS and conductivity.

On the other hand, different metals and metalloids are present in different water systems but some trace metals such as cadmium whose presence even in minute concentrations is a precursor for detrimental health effects on humans and the aquatic life (Shrestha *et al.,* 2021). Because of their non-biodegradability, toxicity, ability to accumulate in water systems and river sediments, heavy metals are hazardous (Zaynab *et al.,* 2022). Some heavy metals known to be toxic to humans include mercury, arsenic, cadmium, chromium, copper, lead, and zinc. Although copper, chromium, and zinc are essential micronutrients, they are toxic at elevated levels (Bjørklund *et al.,* 2020; Michalczyk and Cymbaluk-Płoska, 2020). In the water system, there exists an equilibrium distribution of metals between water and sediments; however, this equilibrium is perturbed by changes in the physio-chemical parameters such as pH and redox potentials (Debnath *et al.,* 2021).

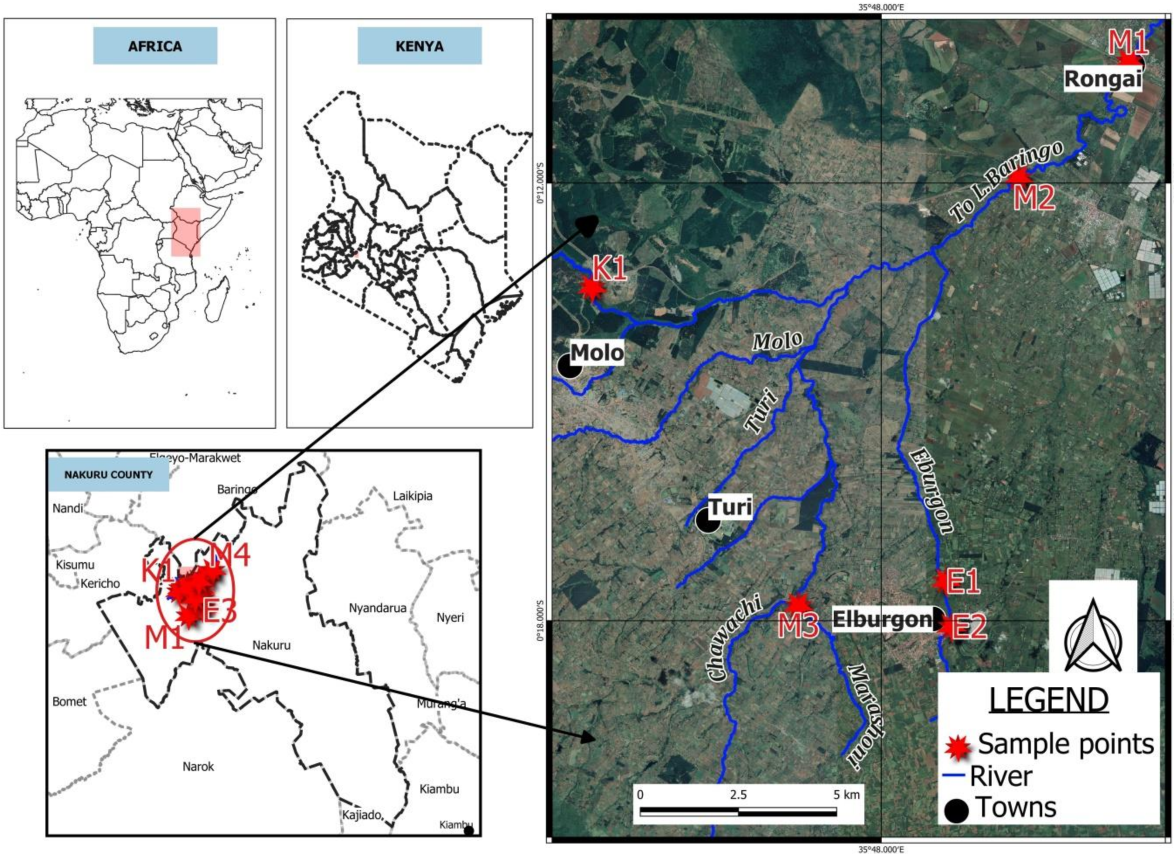

Figure 1. The sampled sites in the Molo water basin

Suspended particles in water form complexes with dissolved metal ions as precipitates which accumulate and settle as sediments (Pohl, 2020). At low pH, the metal ions in solution get adsorbed on fine particles in water which grows in size and ultimately settle as sediments (Debnath *et al.,* 2021). Molo water basin is located in an agriculturally rich area and relatively populated centres such as Eburgon, Kibunja, Salgaa and Molo. Rivers Molo and Elburgon, and its tributaries are likely to be polluted by domestic effluent discharge, combustion events, oil spills, timber treatment, and accidents around the Salgaa stretch of the Eldoret –Nakuru highway, and agricultural activities.

Materials and methods

This research focused on the Molo water basin which forms part of the Lake Victoria water basin. The Molo river water basin is approximately 35 km west of Nakuru town and has an average elevation of 2200 m above sea level. The economic activities in the area are mainly agriculture, construction and lumbering. The water basin comprises river Eburgon, River Molo and Kibunja tributary. The larger river Molo drains its water into Lake Baringo and serves the residents of Nakuru and Baringo counties. The sampling points were located and marked using a geographical positioning system (GPS) version 4.82 (Table 1).

Sample collection

The water and sediment samples were collected from six sampling points located using a global information system (GIS): Kibunja tributary (K1), Rongai town (M1), Salgaa bridge (M2), river Molo (M3), river Elburgon downstream (E1) and river Elburgon upstream (E2) in three replicates. Sampling containers were washed with 10 % v/v nitric acid, rinsed several times with deionized water, and washed 3-4 times with water from the exact site of sampling before the sample was collected. Concentrated nitric acid was added to water samples in one of the bottles for metal analysis to preserve the water samples. Sediments were collected from the same sampling points as the water samples in duplicate using a core sampler. The samples were placed into plastic containers (for heavy metals and inorganic samples). All samples were transported in an icebox to the laboratory where they were refrigerated at 4 °C awaiting the analysis (Tuit and Wait, 2020).

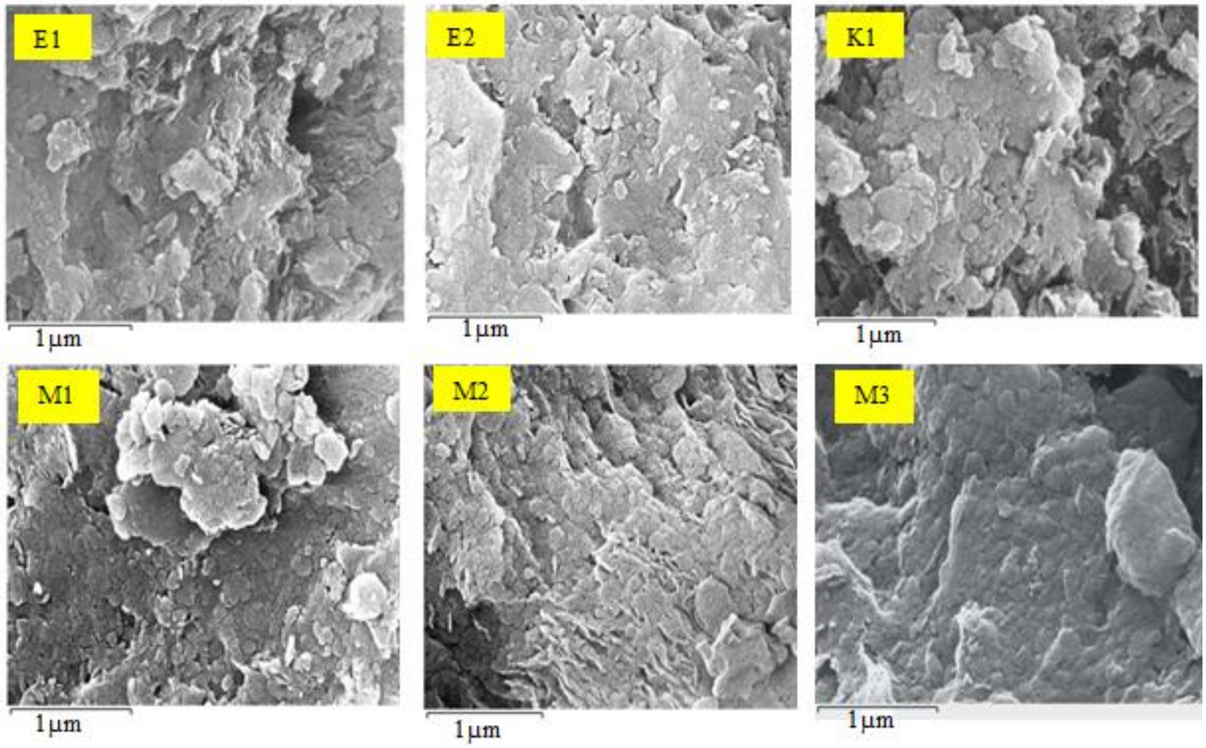

Figure 2. Scanning electron micrographs of sediments collected from various sampling points in the Molo water basin

Water analysis

All the chemicals used in this study were of analytical grade, purity > 99%. The reagents and analytical procedures utilized in this study follows the procedure of Laurence *et al.,* (2018) and (Rice *et al.*, 2017). Temperature, pH, electrical conductivity, salinity and TDS were determined in situ at the sampling points while concentrations of heavy metals were determined in the laboratory for both water and sediments. The concentration of chlorides, fluorides, phosphates, sulphates, hydrogen carbonate, and total carbonate in surface water were determined automatically by a titroline processor using appropriate reagents and electrodes. The detailed procedure for analysis of these components is described elsewhere in literature (Baird, 2017).

Atomic absorption spectrophotometer (Shimadzu AA-7000 series) was used to profile the levels of Cu, Cr, Pb, Mn and Fe in the water samples whereas K, Ca, Na, and Mg were profiled using biobase FP640 flame photometer. Sediment samples were air-dried and sifted through a 2 mm sieve and 10g were added to 0.4 M solution of $Na_4P_2O_7.10H_2O$ in 50% H_2O_2 in H_2O. The suspension obtained was diluted using hot water and sifted through a 0.5 mm sieve. The sediment remaining in the sieve was washed, dried at 105^{o}C, and finally sifted through a 0.2 mm sieve. The particle size and morphology of the sediment was investigated using a scanning electron microscope coupled to an energy dispersive X-ray spectrometer (SEMEDX) operating at 25 kV (Nenadović *et al.,* 2010).

Scanning electron spectroscopy of sediment

Water bottom sediment was collected from the Molo river water basin in sterilized plastic bags, air-dried and sieved through a 2mm sieve and thereafter sifted. About 10g samples were added to 0.4M solution of $Na_4P_2O_7.10H_2O$ in the H_2O_2/H_2O solution and the suspension obtained were diluted using hot water and sifted through a 0.5 mm sieve. The remaining sediment in the sieve was washed, dried at 105^{o}C, and finally sifted through a 0.2 mm sieve and its topology investigated using a scanning electron microscope coupled with an energy dispersive X-ray spectrometer (SEMEDX) operated at 25 kV. The sediment sample was adhered to aluminum SEM stubs with carbon tape and subsequently gold coated in a Quorum Q150 RES sputter coater in accordance with the procedure reported by Jebet *et al.,* (2018).

Water quality index

The water quality of a water system can be expressed using a water quality index (WQI) which is a dimensionless quantity obtained from selected parameters of the water system using equation 1.

$$\mathrm{WQI} = \mathrm{W_{pH}Q_{pH}} + \mathrm{W_{DO}Q_{DO}} \ldots\ldots\ldots\ldots \mathrm{W_{Zn}Q_{Zn}} \tag{1}$$

WQ for each parameter is given by equation 2

$$\mathrm{WQ} = \mathrm{wiQi} \tag{2}$$

Where $\mathrm{wi} = \frac{k}{Si}$ and $\mathrm{Qi} = 100\frac{\mathrm{Vi}}{\mathrm{Si}}$ where Si is recommended standard, Vi is the measured value of the given parameter and k is given by $\mathrm{k} = \frac{1}{\sum\frac{1}{\mathrm{Si}}}$. Based on this, the calculated water quality indices of the various sampling points are given in the table below.

Water pollution index

Water pollution index (WPI) can accommodate more number of parameters and consequently providing more reliable results as compared to WQI because it is flexible for n number of parameters (Hossain and Patra, 2020). WPI determination begins with the calculation of pollution load index PLi of the i^{th} parameter or the standardized value of a particular parameter using equation 3.

$$\mathrm{PLi} = 1 + \frac{\mathrm{Ci-Si}}{\mathrm{Si}} \tag{3}$$

where, Ci is the measured concentration or value of the i^{th} parameter, Si is the standard or the highest permissible limit concentration or value for the respective parameter. In cases where the measured value of a parameter is zero, it is excluded from the total n parameters. The equation for calculating the PLi value of pH is dictated by the prevailing pH value. A pH value of 7 is considered neutral and when the prevailing pH value is less than 7, equation 4 is used for pH PLi calculation.

$$\mathrm{PLi(pH)} = \frac{\mathrm{Ci-7}}{\mathrm{Sia-7}} \tag{4}$$

where, Ci is the measured pH value and Si_a is the maximum acceptable pH value. When the prevailing pH value is greater than 7, equation 5 is used for PLi calculation.

$$\mathrm{PLi(pH)} = \frac{\mathrm{Ci-7}}{\mathrm{Sib-7}} \tag{5}$$

where Ci is the measured pH value and Si_b is the minimum acceptable pH value. Where PLi for each of the parameters has been calculated, water pollution index (WPI) with n number of parameters is evaluated through the aggregation of all the pollution loads and dividing it with n using expression 6. Table 4 presents various classification of water quality determined using the water pollution index parameter.

$$\mathrm{WPI} = \frac{1}{n}\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{PLi} \tag{6}$$

Table 1. Geographical information system coordinates of the sampled points

Sampling point	Location	Elevation (m)
M1	S0°10′20, E35°51′24	1876
M2	S0°11′56, E35°49′53	1906
M3	S0°17′48, E35°46′52	2444
E1	S0°16′52, E35°50′55	2169
E2	S0°18′5, E35°48′58	2404
K1	S0°13′26, E35°44′2	2399

Results

The data presented in Table 2 shows that most of the parameters analysed were within the World health organization (WHO) set limits except for potassium and sodium which were evidently more than the WHO limits in the E1, M1, M2, M3 and K1 sampling points and sodium at M1 and M2. This can be associated with various agricultural activities in the Molo water basin. Chromium was more than the WHO limit in M1, M2 and M3 whereas Mn exceeded the WHO limit in E2 and M2 sample points. Besides, Zn was above the recommended limit at M3 and K1 sampling points.

Table 2. Results of the water basin physico-chemical parameters, anions, cations and heavy metal analysis

	Sampling points						
Parameter	E1	E2	M1	M2	M3	K1	WHO limits
pH	7.66	7.86	7.96	8.45	7.75	7.85	8.5
σ (µS/cm)	300.33	223.67	231.67	230.67	152.67	164.33	1500
TDS (mg/L)	196.00	146.33	151.33	150.67	100.33	107.00	1000
salinity	282.67	213.67	221.33	219.67	148.00	158.67	1000
K(mg/L)	80.00	Nd	76.00	420.00	620.00	92.00	100
Na(mg/L)	104.10	19.00	100.00	1220.00	1800.00	146.00	200
SO_4^{2-} (mg/L)	6.50	5.50	5.00	86.00	60.00	26.00	500
NO_3^- (mg/L)	10.66	3.08	6.16	4.32	2.09	1.73	50
F (mg/L)	0.80	0.30	4.50	5.30	4.50	5.30	1.50
Cl (mg/L)	50.00	Nd	75.00	110.00	75.00	110.00	250
Mg (mg/L)	0.10	0.60	4.00	17.00	12.00	4.00	100
Ca (mg/L)	25.00	21.00	7.00	52.00	44.00	7.00	250
Al (mg/L)	0.00843	0.034	0.0085	0.0852	0.013	0.0134	0.2
Zn (mg/L)	2.15	2.14	3.48	0.10	12.70	8.78	5
Cu (mg/L)	0.3615	0.0116	0.6167	0.8704	0.7006	0.2657	2
Cr (mg/L)	0.03615	0.00116	0.06167	0.08704	0.07006	0.02657	0.05
Pb (mg/L)	0.00487	0.00751	0.002275	0.00714	0.0058	0.000954	0.01
Mn (mg/L)	0.118	0.509	0.382	0.657	0.00459	0.317	0.4
Fe (mg/L)	0.2729	0.274	0.033	0.928	0.691	0.474	0.3

Legend: Nd – Not detected

Iron was also higher than the acceptable WHO limit at sampling points M2, M3 and K1. These data when compared with WHO standards indicates general water pollution in the Molo water system. Based on WQI calculations, the sampling point K1 has excellent drinking water quality with a calculated water quality index value of 23.12 (Table 3 and 4). On the other hand, M1 with calculated water quality index of 39.86 is slightly polluted whereas E1, E2 and M3 reported water quality index values of 51.17, 62.64 and 73.20, respectively, and are categorized as moderately polluted water (Table 3). The sample point M2 had elevated concentrations of heavy metals which translated to a water quality index value of 94.82 which falls in the polluted category. Of the six sampling points, there was none whose drinking water quality was excessively polluted thus allowing the general categorization of the water basin as suitable for drinking. Heavy metals are the major contributor in raising the WQI above 25 units, especially lead because it had the highest $W_{Pb}Q_{Pb}$ at 56.72, 53.68 and 43.60 for E2, M2 and M3 sampling sites.

Table 3. A summary of calculated $wiQi$ for each parameter and the cumulative WQI for each sampling point

	Sampling points					
Parameter	E1	E2	M1	M2	M3	K1
pH	0.039105	0.050954	0.056879	0.085911	0.044437	0.050362
σ	0.000101	7.51E-05	7.78E-05	7.74E-05	5.13E-05	5.52E-05
TDS	0.000148	0.000111	0.000114	0.000114	7.58E-05	8.08E-05
salinity	0.000214	0.000161	0.000167	0.000166	0.000112	0.00012
K	0.006043	-	0.00574	0.031723	0.046829	0.006949
Na	0.001966	0.000359	0.001888	0.023037	0.033989	0.002757
SO_4^{2-}	1.96E-05	1.66E-05	1.51E-05	0.00026	0.000181	7.86E-05
NO_3^-	0.003221	0.000931	0.001861	0.001305	0.000631	0.000523
F	0.268556	0.100708	1.510627	1.779183	1.510627	1.779183
Cl	0.000604	-	0.000906	0.001329	0.000906	0.001329
Mg	7.55E-06	4.53E-05	0.000302	0.001284	0.000906	0.000302
Ca	0.000302	0.000254	8.46E-05	0.000628	0.000532	8.46E-05
Al	0.159182	0.642017	0.160504	1.608818	0.245477	0.25303
Zn	0.064957	0.064655	0.10514	0.003021	0.383699	0.265266
Cu	0.068261	0.00219	0.11645	0.164356	0.132293	0.050172
Cr	10.92184	0.350466	18.63208	26.297	21.16691	8.027474
Pb	36.78378	56.72406	17.18339	53.9294	43.8082	7.205693
Mn	0.557044	2.402842	1.803312	3.101507	0.021668	1.496465
Fe	2.290279	2.299511	0.276948	7.788124	5.799131	3.977986
$\mathbf{WQI = \sum wiQi}$	**51.17**	**62.64**	**39.86**	**94.82**	**73.20**	**23.12**

WPI were rated as indicated in Table 6. From Tables 5 and 6, the WPI calculations showed that E1 and E2 had the lowest WPI values of 0.38 and 0.30, respectively which falls under excellent waters whereas M1and K1 reported WPI values of 0.53 and 0.64, respectively and can be classified as good waters. Sampling points M2 and M3 on the other hand indicated highly polluted waters with WPI values of 1.30 and 1.46 calculated, respectively. High levels of chromium, lead, manganese, potassium and iron in M2 and M3 may be responsible for the observed pollution rating in the two sampling points. E1, E2, M1, and K1 may be considered good sources of water for domestic and other uses among the six sampling stations. The average water pollution index of this sub-water basin is 0.77 which lies in the bracket of moderately polluted water.

Table 4. Categorization of water suitability from sampling point based on WHO classification

WQI Rating	**Classification**	**Sampling point classification**
0 – 25	Excellent	K1
25 – 50	Slightly polluted (good)	M1
50 – 75	Moderately polluted (poor)	E1, E2 and M3
75 – 100	Polluted (very poor)	M2
>100	Excessively polluted (unsuitable)	

Table 5. WPI of the various sampling points based on calculation using data from Table 1

		PLI per sampling point					
Parameter	Si	E1	E2	M1	M2	M3	K1
pH	8.5	1.094286	1.122857	1.137143	1.207143	1.107143	1.121429
σ	1500	0.20022	0.149113	0.154447	0.15378	0.10178	0.109553
TDS	1000	0.196	0.14633	0.15133	0.15067	0.10033	0.107
salinity	1000	0.28267	0.21367	0.22133	0.21967	0.148	0.15867
K	100	0.8	-	0.76	4.2	6.2	0.92
Na	200	0.5205	0.095	0.5	6.1	9	0.73
SO_4^{2-}	500	0.013	0.011	0.01	0.172	0.12	0.052
NO_3^-	50	0.2132	0.0616	0.1232	0.0864	0.0418	0.0346
F	1.5	0.533333	0.2	3	3.533333	3	3.533333
Cl	250	0.2	-	0.3	0.44	0.3	0.44
Mg	100	0.001	0.006	0.04	0.17	0.12	0.04
Ca	250	0.1	0.084	0.028	0.208	0.176	0.028
Al	0.2	0.04215	0.17	0.0425	0.426	0.065	0.067
Zn	5	0.43	0.428	0.696	0.02	2.54	1.756
Cu	2	0.18075	0.0058	0.30835	0.4352	0.3503	0.13285
Cr	0.05	0.723	0.0232	1.2334	1.7408	1.4012	0.5314
Pb	0.01	0.487	0.751	0.2275	0.714	0.58	0.0954
Mn	0.4	0.295	1.2725	0.955	1.6425	0.011475	0.7925
Fe	0.3	0.909667	0.913333	0.11	3.093333	2.303333	1.58
$\sum$ PLI		**7.22**	**5.65**	**10.00**	**24.71**	**27.67**	**12.23**
WPI = $\frac{1}{n}\sum_{i=1}^{n}$ PLi		**0.38**	**0.30**	**0.53**	**1.30**	**1.46**	**0.64**

Table 6. Water classification as per WPI

WPI value	**Category**	**Sampling points categorization**

< 0.5	Excellent water	E1 and E2
0.5 – 0.75	Good water	M1 and K1
0.75 − 1	Moderately polluted water	
>1	Highly polluted water	M2 and M3

Sediment elemental composition and topology

In all the sediments as reported in Table 7, oxygen atoms was the most prevalent owing to its presences in most organic and inorganic compounds followed by silicon. Notably sediment morphology was also determined using energy dispersive X-ray spectroscopy (EDX) and the findings showed the absence of heavy metal pollutants of concern which include lead, mercury, arsenic and cadmium however it showed presence of manganese and iron. Ideally, oxygen was the most abundant element in the sediments sampled in the Molo water basin, with E2, M1, and M3 posting the highest oxygen levels, respectively. On the other hand, the highest carbon level was noted in E2, M1 and M3, correspondinly. Silicon was the third most abudant element in all the sediment samples followed by aluminium. The other elements such as potassium, calcium, titanium, manganese, and iron were found in significantly low amounts. The low concentrations of essential elements (K, Na, Ca, and Mg) could be attributed to their relatively high solubilities in water. This corresponds to their high concentrations in the water-phase as reported in Table 2, *vide infra.*

Table 7. Sediment elemental composition

	Sampling points					
Element	**E1**	**E2**	**K1**	**M1**	**M2**	**M3**
C	12.07±1.04	24.42±0.21	15.51±1.43	17.70±1.27	11.93±1.14	17.79±0.18
O	25.76±0.4	32.62±0.27	37.10±0.69	48.30±0.78	42.96±0.61	44.23±0.21
Al	2.92±0.08	7.93±0.10	7.02±0.15	8.19±0.15	9.13±0.15	7.21±0.09
Si	9.27±0.15	24.18±0.17	25.04±0.45	16.66±0.28	27.57±0.39	24.64±0.15
K	0.23±0.04	3.40±0.07	4.98±0.11	1.33±0.05	6.06±0.11	3.07±0.06
Ca	0.63±0.05	0.71±0.05	0.98±0.06	0.53±0.04	Nd	0.17±0.03
Ti	0.24±0.05	0.31±0.05	0.63±0.06	0.70±0.05	0.32±0.05	Nd
Mn	4.76±0.13	4.42±0.11	0.39±0.07	Nd	Nd	Nd
Fe	43.94±0.57	4.70±0.12	7.34±0.18	6.58±0.15	2.03±0.10	2.90±0.08

Legend: Nd – Not detected

From the micrographs in Figure 2, the sediments present interesting similarities but differ markedly in elemental composition. The micrograpghs also shows sedimens tightly bound together flaky sheets rolling over each other which is an indication of sequential settling from the water phase. With the exception of K1 microcraph which has a number of dark spaces, the other micrographs show minimal dark spaces signifying low porosity of the sediments. Generally, the characteristics obtained from the micrographs are atributed to presence of clay particles in the sediments which are known to have particle sizes below 2µm, posses low porosity and are cohesive. This can be observed in sediments collected from M2 and M3 which show some polymeric behaviour. Although E1, E2,K1, and M1 also exhibit polymeric characteristics, some particulate nature of sediments are clear. Notably, the sediments sampled from the Molo water basin have an average size which is far much less than $1\mu m$.

Discussion

This contribution has shown that nitrates and phosphates were within the WHO limit in all the sampling points of the Molo water basin. Nitrate concentration was below the WHO limit in all the sampling points therefore issues of eutrophication and blue baby syndrome may not be a problem in the water basin, although more studies need to be conducted periodically. Low phosphate levels indicate minimal domestic effluent rich in detergents that may accumulate at the water basin. Nevertheless, water quality cannot be assessed by examining the data collected from the basin without further analysis using the state-of-the-art procedures – water quality index and water pollution indices.

Water quality is an expression that indicates the suitability of water for various uses and processes, which varies from region to region, and time to time as reported by Abdul Maulud *et al.* (2021) in their study of spatial and water quality during dry and rainy seasons at Kelantan river Basin in Malaysia where they found that the water quality varied from region to region and season to season (Adelagun *et al.,* 2021; Ram *et al.,* 2021). Moreover, Tian *et al.* (2019) in assessing the water quality of the upper and the middle streams of the Luanhe river, Northern China, noted a significant seasonal and locational variation of water quality. Each of the various uses or processes will have their own demands and influences on water quality. These demands and influences are the requirements for physical, chemical or the biological characteristics of water. Water quality can be defined by a range of variables which limit water use. It is affected by a wide range of natural and human influences, with the most important of the natural influences being geological, hydrological and climatic factors. It is measured by several factors, such as the concentration of dissolved oxygen (DO), bacteria levels, the amount of salt (salinity), or the amount of material suspended in the water (turbidity), the concentration of microscopic algae and quantities of pesticides, herbicides, and heavy metals present in the water system (Devi *et al.,* 2017; Ewaid *et al.,* 2020; Zeinalzadeh and Rezaei, 2017). It is clear from Table 2 that Zn and Cr are the major heavy metals pollutants in the Molo water basin. Their concentrations in most sampling points especially in M1, M2, and M3, and for Cr, in M1, M3, and K1 are way above the WHO allowable limits. TDS correlates with conductivity within a factor of 0.5 to 0.75 depending on the level of salinity (Grossi; M'nassri *et al.,* 2019). This correlation is approximate because the organic fraction of the dissolved solids does not conduct electricity and the ionic mobility of the conductive species is variable (Arora and Dagar, 2019). The amount of dissolved salt gives salinity of the water which also forms part of the TDS. The nature of substances dissolved in the water determines the pH of the water which in turn determines how corrosive the water can be. The prevailing pH of water also affects bioavailability of the substances dissolved (do Nascimento *et al.,* 2021; Ondrasek and Rengel, 2021).

Water quality index on the other hand is a robust water assessment parameter. It was originally developed by Horton in 1965 to measure water quality by using 10 most regularly used water parameters but has been modified by different experts over time (Abbasi and Abbasi, 2012). It is a mathematical tool that simplifies the complexity of water quality data sets into a single dimensionless number that gives the water quality status of a given water system (Banda and Kumarasamy, 2020). WQI provides a single number that represents overall water quality at a certain location and time, based on some selected water parameters which allows for comparison of water quality between different rivers or water of the same river from different seasons or sampling points (Lkr *et al.,* 2020; Teshome, 2020; Wu *et al.,* 2018). This number gives the combined impact of the many different factors that characterize the quality of water and enables comparison of the water quality in the different sampling points (Sharma *et al.,* 2020). It tells whether the overall quality of water bodies poses a potential threat to various uses of water such as water being a habitat for aquatic life, use in agriculture and livestock, recreation and aesthetics, and drinking water supplies (Akter *et al.,* 2016; Liou *et al.,* 2004; Nazeer *et al.,* 2014). Notably, heavy metals are the main contributors for the high water indices realized in the water basin. In view of this, heavy metals are very important parameters in checking the quality of water in a given source. The average WQI of the water sub-basin is 57.47, and lies in the bracket of moderately polluted water. This value gives an overall picture of the state of water in the Molo water basin. Generally, the most polluted water in the basin is those located in M2. This is conceivable if we consider that this is an area with possibly rich agricultural activity. The WQI obtained from this study compares well with the results previously reported by (Robert, 2021) in water quality assessment index for the Chania River, Kenya where the highest WQI value was 89.15 and the lowest value was 19.67. Assessment of the water quality of the Nyando river using the water quality index (WQI) method gave the lowest calculated WQI value at 51.88 and the highest WQI at 101.13 (George *et al.,* 2019). Although these data were obtained from different geographical locations in Kenya, it is evident the data from the river Molo sub-basin agree with the WQI data reported in rivers Chania and Nyando.

Generally, water quality index (WQI) is reliable in assessing the general water quality of a given source by taking into consideration a limited number of physio-chemical parameters but becomes unreliable when dealing with a large number of parameters or data sets as those reported in this study (Garcia *et al.,* 2018). Therefore, water pollution index (WPI) is applied for physical, chemical (major metal ions) or even for biological quality assessment of water sources based on the available water quality standards for use (Tanjung and Hamuna, 2019). It gives the combined effect of general physico-chemical parameters as well as heavy metals with respect to their permissible limits thus bridging the gap left by WQI which does not factor in heavy metals in predicting the quality of water sources (Widodo *et al.,* 2019). Considering the Molo water basin, it is evident that M2 and M3 are the most polluted waters with water pollution indices of 1.3 and 1.46, respectively. All other sampling points within the basin are classified as excellent waters. This observation is remarkably consistent with the water status predicted using the water quality index (WQI) parameter.

Surface erosion, mining and various human activities including agriculture and wood treatment in a water basin introduces suspended solids and particulate matter which can be deposited as sediments, and may contain minerals and organic mater. In a water system, the deposited sediment acts as a source and sink for organic matter and heavy metals depending on the river chemistry such as pH, salinity and dissolved oxygen. Sediment is also important for the development of aquatic ecosystems especially because sediment particle size and arangement affect sediment porosity, which is an important factor influencing sediment oxygen conditions. The presence of carbon and oxygen in all the sampling points in the Molo water basin may be an indication of the presence of organic pollutants of environmental concern. Such organic pollutants may include benzo[a]pyrene, pesticides, phenols and dioxins. These are serious organic pollutants usually associated with endocrine malfucntions, cancer, mutagenesis, and other biological defects. High levels of oxygen in sediments may be attributed to metal oxides, metal carbonates and metal complexes.

Sediments act as a sinks for a significant number of toxic substances and should therefore be investigated alongside the water-phase. Sediments contain a record of previous pollution, which makes sediment analysis and important component in understanding the mineral deposits in the river basin and monitoring pollution of rivers and other water bodies elsewhere in the world (Gayathri *et al.,* 2021; Li *et al.,* 2018). Heavy metals immobilized in the sediment become mobilized at points exposed to the water phase (Pal and Maiti, 2020). Metals in the river system exist in different chemical forms associated with organic, residual, exchangeable, carbonate fractions and those bound to, for instance iron oxides, manganese oxides, chromates, metal chlorides, and metal sulphates (Geng *et al.,* 2020). Factors including physical and chemical equilibrium, pH, redox reactions, oxidation states of elements and sediment attributed organic matter control heavy metal distribution and accumulation in sediments (Li and Gong, 2021). The mobility and bioavailability of metals in river systems is largely dependent on sediment transport dynamics which is influenced by several factors such as pH, redox potential, organic matter, temperature, dissolved organic carbon, salinity, composition of the sediment, particle size, and grain texture (Debnath *et al.,* 2021).

Heavy metals accumulate in vital body organs such as kidneys, liver and the brain resulting in the disruption of normal biological functioning of the organism. High levels of heavy metals in the environment have been associated with a number of health issues such as metal induced oxidative stress, carcinogenesis, and neurotoxicity, inhibition of enzymes and replacement of essential nutrients through mimicking processes (Bhat *et al.,* 2019; Okereafor *et al.,* 2020). Depending on the amount exposed to, and the period of exposure to heavy metals, the health impacts include impaired intellectual development, gastrointestinal, cardiovascular, neurological, renal respiratory and haematological effects (Yang and Massey, 2019). In view of these health effects, WHO, the European Commission (EC) and US EPA have defined limits of parameters beyond which the quality of water is considered unsuitable for a specific use. Heavy metal toxic load (HTML) is also important in determining the limit at which an organism's immune system breaks down on exposure to heavy metals. HTML gives the concentrations of heavy metals above which etiological risks occur (Balali-Mood *et al.,* 2021; Engwa *et al.,* 2019).

Generally, water-based pollution is one of the leading causes of death in the twenty-first century. According to the Lancet Commission on Pollution and Health, pollution-related diseases caused an estimated 9 million premature deaths in 2015, accounting for ≈ 16% of all fatalities worldwide. This number is three times higher than the combined deaths from HIV/AIDS, TB, and malaria, and fifteen times higher than the total number of deaths from all wars and other types of violent acts around the globe (Landrigan *et al.,* 2018a; Landrigan *et al.,* 2018b). Experts also project that, under the current climate change scenario, nearly half of the world's population, including between 75 million and 250 million people in Africa, will be living in areas of significant water stress by 2030 (Ahuja, 2021; Nhamo *et al.,* 2019). Among the possible pollutants of water, heavy metals and persistent organic pollutants (POPs) have attracted a lot of attention because of their toxicity even at low concentrations.

Conclusion

This study has found that the physico-chemical properties observed in the Molo river basin indicate a strong influence from heavy metals. This correlates very well with the water quality parameters; WQI and WPI reported which show that the water of the Molo river basin is significantly polluted. The high levels of heavy metals oberved in the water basin compromise the water quality because they can bioacumulate and biomagnify in living organisms to cause serious public health problems. The high concentration of heavy metals may be atributed to agricultural activities, soil erosion, and weathering of rocks in the study area. Water quality index and WPI data specifically in this basin agreee to a larger extent and are therefore complementary in water quality assessment.. The sediment chemistry in the study area has also predicted serious possible pollution levels likely to be caused by hazardous organics based on the high levels of carbon and oxygen incorporated in sediments. This may point to the presence of benzo[a]pyrene, dioxins, phenols, and benzene and its derivatives among other pollutants. Most sediments indicate the presence of high amounts of iron and aluminium suggesting that there is an iron and an aluminium point source which is most likely to be anthropogenic. Generally, the water basin is moderately polluted as corroborated by the two methods used to evaluate the water quality status – Water quality index and water pollution index. The findings of the Molo water basin can be extrapolated to other water basins and water bodies in different geographical locations around the world.

Declaration

Availability of data and materials

The data associated with the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgement

The authors are grateful to the Department of Chemistry and the Directoratte of research and outreah of Egerton University for facilitating the success of this study.

References

Abbasi, T., & Abbasi, S. A. (2012). Approaches to wqi formulation. In *Water quality indices* (1st ed., pp. 9-24): Elsevier.

Abdul Maulud, K. N., Fitri, A., Wan Mohtar, W. H. M., Wan Mohd Jaafar, W. S., Zuhairi, N. Z., & Kamarudin, M. K. A. (2021). A study of spatial and water quality index during dry and rainy seasons at kelantan river basin, peninsular malaysia. *Arabian Journal of Geosciences, 14*(**2**): 1-19.

Adelagun, R. O. A., Etim, E. E., & Godwin, O. E. (2021). Application of water quality index for the assessment of water from different sources in nigeria. In *Wastewater treatment* (pp. 267-281): IntechOpen.

Adimalla, N., & Qian, H. (2019). Groundwater quality evaluation using water quality index (wqi) for drinking purposes and human health risk (hhr) assessment in an agricultural region of nanganur, south india. *Ecotoxicology and Environmental Safety, 176*: 153-161.

Ahuja, S. (2021). Water quality worldwide. In *Handbook of water purity and quality* (pp. 19-33): Elsevier.

Akter, T., Jhohura, F. T., Akter, F., Chowdhury, T. R., Mistry, S. K., Dey, D., Barua, M. K., Islam, M. A., & Rahman, M. (2016). Water quality index for measuring drinking water quality in rural bangladesh: A cross-sectional study. *Journal of Health, Population and Nutrition, 35*(**1**): 1-12.

Arora, S., & Dagar, J. (2019). Salinity tolerance indicators. In *Research developments in saline agriculture* (pp. 155-201): Springer.

Baird, R. B. (2017). Standard methods for the examination of water and wastewater. In (23rd ed.). Washington D.C: Water Environment Federation, American Public Health Association.

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: Mercury, lead, chromium, cadmium, and arsenic. *Frontiers in Pharmacology, 12*.

Banda, T. D., & Kumarasamy, M. (2020). Development of a universal water quality index (uwqi) for south african river catchments. *Water, 12*(**6**): 1534.

Bashir, I., Lone, F., Bhat, R. A., Mir, S. A., Dar, Z. A., & Dar, S. A. (2020). Concerns and threats of contamination on aquatic ecosystems. In *Bioremediation and biotechnology* (pp. 1-26): Springer.

Bhat, S. A., Hassan, T., & Majid, S. (2019). Heavy metal toxicity and their harmful effects on living organisms–a review. *International Journal of Medical Science And Diagnosis Research, 3*(**1**): 106-122.

Bjørklund, G., Dadar, M., Pivina, L., Doşa, M. D., Semenova, Y., & Aaseth, J. (2020). The role of zinc and copper in insulin resistance and diabetes mellitus. *Current Medicinal Chemistry, 27*(**39**): 6643-6657.

Chakraborty, S. K. (2021). Water: Its properties, distribution, and significance. In *Riverine ecology volume 1* (pp. 23-55): Springer.

Debnath, A., Singh, P. K., & Sharma, Y. C. (2021). Metallic contamination of global river sediments and latest developments for their remediation. *Journal of environmental management, 298*: 113378.

Devesa, R., & Dietrich, A. (2018). Guidance for optimizing drinking water taste by adjusting mineralization as measured by total dissolved solids (tds). *Desalination, 439*: 147-154.

Devi, P. A., Padmavathy, P., Aanand, S., & Aruljothi, K. (2017). Review on water quality parameters in freshwater cage fish culture. *International Journal of Applied Research, 3*(**5**): 114-120.

do Nascimento, S. M., de Lima Junior, J. A., Junior, P. M. d. S., Alves, M. H. D., Costa, J. d. N., & Faial, K. d. C. F. (2021). Physico-chemical assessment of waters used to irrigate agricultural lands of amazon. *Australian Journal of Crop Science, 15*(**7**): 1066-1073.

Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanism and health effects of heavy metal toxicity in humans. *Poisoning in the modern world-new tricks for an old dog, 10*.

Ewaid, S. H., Abed, S. A., Al-Ansari, N., & Salih, R. M. (2020). Development and evaluation of a water quality index for the iraqi rivers. *Hydrology, 7*(**3**): 67.

Garcia, C. A. B., Silva, I. S., Mendonça, M. C. S., & Garcia, H. L. (2018). Evaluation of water quality indices: Use, evolution and future perspectives. In *Advances in environmental monitoring and assessment* (Vol. 18, pp. 21-38): Intechopen.

Gayathri, S., Krishnan, K. A., Krishnakumar, A., Maya, T., Dev, V. V., Antony, S., & Arun, V. (2021). Monitoring of heavy metal contamination in netravati river basin: Overview of pollution indices and risk assessment. *Sustainable Water Resources Management, 7*(**2**): 1-15.

Geng, H., Xu, Y., Zheng, L., Gong, H., Dai, L., & Dai, X. (2020). An overview of removing heavy metals from sewage sludge: Achievements and perspectives. *Environmental Pollution, 266*: 115375.

George, Shikuku, V. O., Andala, D. M., Okowa, G. M., & Owuor, J. J. (2019). Assessment of water quality of the nyando river (muhoroni-kenya) using the water quality index (wqi) method. *International Research Journal of Environmental Sciences_, 8*(**2**): 27-33.

Grossi, M. Measurement of water salinity using a capacitively coupled contactless conductivity sensor. *P-ESEM*: 657.

Gunda, T., Hess, D., Hornberger, G. M., & Worland, S. (2019). Water security in practice: The quantity-quality-society nexus. *Water Security, 6*: 100022.

Hossain, M., & Patra, P. K. (2020). Water pollution index–a new integrated approach to rank water quality. *Ecological Indicators, 117*: 106668.

Kadibadiba, T., Roberts, L., & Duncan, R. (2018). Living in a city without water: A social practice theory analysis of resource disruption in gaborone, botswana. *Global environmental change, 53*: 273-285.

Landrigan, P. J., Fuller, R., Acosta, N. J., Adeyi, O., Arnold, R., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., & Breysse, P. N. (2018a). The lancet commission on pollution and health. *The Lancet, 391*(**10119**): 462-512.

Landrigan, P. J., Fuller, R., Hu, H., Caravanos, J., Cropper, M. L., Hanrahan, D., Sandilya, K., Chiles, T. C., Kumar, P., & Suk, W. A. (2018b). Pollution and global health–an agenda for prevention. *Environmental Health Perspectives, 126*(**8**): 084501.

Laurence, M., Kibet, J. K. and Ngari, S. M. (2018). The Degradation of O-ethyltoluene and 1,3,5-Trimethylbenzene in Lake Naivasha Wetland, Kenya. *Bulletin of Environmental Contamination and Toxicology,* **101,** 288-293.

Li, Y., & Gong, X. (2021). Effects of dissolved organic matter on the bioavailability of heavy metals during microbial dissimilatory iron reduction: A review. *Reviews of Environmental Contamination and Toxicology Volume 257*: 69-92.

Li, Y., Zhou, S., Zhu, Q., Li, B., Wang, J., Wang, C., Chen, L., & Wu, S. (2018). One-century sedimentary record of heavy metal pollution in western taihu lake, china. *Environmental Pollution, 240*: 709-716.

Liou, S.-M., Lo, S.-L., & Wang, S.-H. (2004). A generalized water quality index for taiwan. *Environmental monitoring and assessment, 96*(**1**): 35-52.

Lkr, A., Singh, M., & Puro, N. (2020). Assessment of water quality status of doyang river, nagaland, india, using water quality index. *Applied Water Science, 10*(**1**): 1-13.

M'nassri, S., Dridi, L., Schäfer, G., Hachicha, M., & Majdoub, R. (2019). Groundwater salinity in a semi-arid region of central-eastern tunisia: Insights from multivariate statistical techniques and geostatistical modelling. *Environmental earth sciences, 78*(**10**): 1-13.

Michalczyk, K., & Cymbaluk-Płoska, A. (2020). The role of zinc and copper in gynecological malignancies. *Nutrients, 12*(**12**): 3732.

Nazeer, S., Hashmi, M. Z., & Malik, R. N. (2014). Heavy metals distribution, risk assessment and water quality characterization by water quality index of the river soan, pakistan. *Ecological Indicators, 43*: 262-270.

Nenadović, S., Nenadović, M., Kljajević, L., Pavlović, V., Đorđević, A., & Matović, B. (2010). Soil structure and composition. *Processing and Application of Ceramics, 4*(**4**): 259-263.

Nhamo, L., Matchaya, G., Mabhaudhi, T., Nhlengethwa, S., Nhemachena, C., & Mpandeli, S. (2019). Cereal production trends under climate change: Impacts and adaptation strategies in southern africa. *Agriculture, 9*(**2**): 30.

Njora, B., & YILMAZ, H. (2021). Evaluation of water accessibility, distribution, water use policies and management in kenya. *International Journal of Water Management and Diplomacy, 1*(**3**): 5-16.

Njuguna, S. M., Onyango, J. A., Githaiga, K. B., Gituru, R. W., & Yan, X. (2020). Application of multivariate statistical analysis and water quality index in health risk assessment by domestic use of river water. Case study of tana river in kenya. *Process Safety and Environmental Protection, 133*: 149-158. doi:10.1016/j.psep.2019.11.006

Ochungo, E., Ouma, G., Obiero, J., & Odero, N. (2019). Water quality index for assessment of potability of groundwater resource in langata sub county, nairobi-kenya. *American Journal of Water Resources, 7*(**2**): 62-75.

Okereafor, U., Makhatha, M., Mekuto, L., Uche-Okereafor, N., Sebola, T., & Mavumengwana, V. (2020). Toxic metal implications on agricultural soils, plants, animals, aquatic life and human health. *International journal of environmental research and public health, 17*(**7**): 2204.

Ondrasek, G., & Rengel, Z. (2021). Environmental salinization processes: Detection, implications & solutions. *Science of the Total Environment, 754*: 142432.

Onyango, A. E., Okoth, M. W., & Kunyanga, C. N. (2018). Profiling of physico-chemical characteristics of water sources used for drinking and processing in isiolo county in kenya. *Journal of Environmental and Public Health.*

Pacheco Castro, R., Pacheco Ávila, J., Ye, M., & Cabrera Sansores, A. (2018). Groundwater quality: Analysis of its temporal and spatial variability in a karst aquifer. *Groundwater, 56*(**1**): 62-72.

Pal, D., & Maiti, S. K. (2020). An approach to counter sediment toxicity by immobilization of heavy metals using waste fish scale derived biosorbent. *Ecotoxicology and Environmental Safety, 187*: 109833.

Pohl, A. (2020). Removal of heavy metal ions from water and wastewaters by sulfur-containing precipitation agents. *Water, Air, & Soil Pollution, 231*(**10**): 1-17.

Ram, A., Tiwari, S., Pandey, H., Chaurasia, A. K., Singh, S., & Singh, Y. (2021). Groundwater quality assessment using water quality index (wqi) under gis framework. *Applied Water Science, 11*(**2**): 1-20.

Rice, E., Baird, R., & Eaton, A. (2017). Standard methods for the examination of water and wastewater ed-23rd. *American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Washington DC.*

Robert, C. O. a. J. M. (2021). Development of a water quality assessment index for the chania river, kenya. *African Journal of Aquatic Science, 46:2*: 142-152. doi:10.2989/16085914.2020.1809338

Shrestha, R., Ban, S., Devkota, S., Sharma, S., Joshi, R., Tiwari, A. P., Kim, H. Y., & Joshi, M. K. (2021). Technological trends in heavy metals removal from industrial wastewater: A review. *Journal of Environmental Chemical Engineering, 9*(**4**): 105688.

Tanjung, R. H. R., & Hamuna, B. (2019). Assessment of water quality and pollution index in coastal waters of mimika, indonesia. *Journal of Ecological Engineering, 20*(**2**): 87–94.

Teshome, F. B. (2020). Seasonal water quality index and suitability of the water body to designated uses at the eastern catchment of lake hawassa. *Environmental Science and Pollution Research, 27*(**1**): 279-290.

Tian, Y., Jiang, Y., Liu, Q., Dong, M., Xu, D., Liu, Y., & Xu, X. (2019). Using a water quality index to assess the water quality of the upper and middle streams of the luanhe river, northern china. *Science of the Total Environment, 667*: 142-151.

Tuit, C., & Wait, A. (2020). A review of marine sediment sampling methods. *Environmental Forensics, 21*(**3-4**): 291-309.

Ustaoğlu, F., Tepe, Y., & Taş, B. (2020). Assessment of stream quality and health risk in a subtropical turkey river system: A combined approach using statistical analysis and water quality index. *Ecological Indicators, 113*: 105815.

Walker, M. M. (2019). Negotiating access to water in central mozambique: Implications for rural livelihoods. *Economic Anthropology, 6*(**2**): 222-233.

Widodo, T., Budiastuti, M. T. S., & Komariah, K. (2019). Water quality and pollution index in grenjeng river, boyolali regency, indonesia. *Caraka Tani: Journal of Sustainable Agriculture, 34*(**2**): 150-161.

Wu, Z., Lai, X., & Li, K. (2021). Water quality assessment of rivers in lake chaohu basin (china) using water quality index. *Ecological Indicators, 121*: 107021.

Wu, Z., Wang, X., Chen, Y., Cai, Y., & Deng, J. (2018). Assessing river water quality using water quality index in lake taihu basin, china. *Science of the Total Environment, 612*: 914-922.

Xu, G., Li, P., Lu, K., Tantai, Z., Zhang, J., Ren, Z., Wang, X., Yu, K., Shi, P., & Cheng, Y. (2019). Seasonal changes in water quality and its main influencing factors in the dan river basin. *Catena, 173*: 131-140.

Yang, F., & Massey, I. Y. (2019). Exposure routes and health effects of heavy metals on children. *Biometals, 32*(**4**): 563-573.

Zaynab, M., Al-Yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., Khan, K. A., & Li, S. (2022). Health and environmental effects of heavy metals. *Journal of King Saud University-Science, 34*(**1**): 101653.

Zeinalzadeh, K., & Rezaei, E. (2017). Determining spatial and temporal changes of surface water quality using principal component analysis. *Journal of Hydrology: Regional Studies, 13*: 1-10.