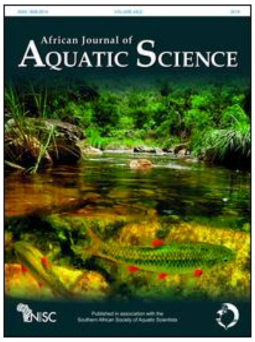

African Journal of Aquatic Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/taas20

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To cite this article: GK Robert , CN Onyari & JG Mbaka (2020): Development of a Water Quality Assessment Index for the Chania River, Kenya, African Journal of Aquatic Science, DOI: 10.2989/16085914.2020.1809338

To link to this article: https://doi.org/10.2989/16085914.2020.1809338

Published online: 15 Nov 2020.

African Journal of Aquatic Science 2020: 1–11
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This is the final version of the article that is published ahead of the print and online issue

AFRICAN JOURNAL OF AQUATIC SCIENCE
ISSN 1608-5914 EISSN 1727-9364
https://doi.org/10.2989/16085914.2020.1809338

Development of a Water Quality Assessment Index for the Chania River, Kenya

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Human-related activities are known to have deleterious effects on the water quality of aquatic ecosystems, but there is limited information on the impact of these on rivers in tropical regions, such as the Chania River in Kenya. The Chania River is an important source of water for humans and animals and provides habitat for a variety of flora and fauna. This study used a Water Quality Index (WQI) to assess the suitability of the water for human use based on selected physico-chemical parameters (nitrates, Total Dissolved solids (TDS), potassium, sulphates, chlorides, copper, manganese, pH and phosphates). Sample collection was done between October 2018 and February 2019 over the dry and the wet seasons. Generally, the WQI indicated that water quality was fair to good in the dry season (19.67 to 30.10) but fair to poor in the wet season (23.17 to 89.15). It is recommended that the riparian zone of the Chania River be protected from anthropogenic disturbances in the County Kiambu.

Keywords: human activities, impacts, riparian zone, Thika town, Water Quality Index

Introduction

The water quality of pristine rivers is influenced by geochemical factors and the prevailing climate, based on location (Qu et al. 2019). However, human activities, such as discharge of industrial effluents, agricultural and urban runoff have detrimentally affected the quality of river waters (Laaffat et al. 2015). The contaminants released into rivers are of concern because they pose a threat to the supply of water for humans and wildlife, and affect habitat conditions for a range of aquatic and semi-aquatic organisms (Santos et al. 2014). Reduced water quality reduces ecosystem health and services, hampers human use, and hinders sustainable development (Lopez et al. 2013; Kostyla et al. 2015).

Water is a unique medium with the ability to assimilate a wide range of substances, which means that it can easily become contaminated (Jinturkar et al. 2010), requiring expensive water treatment to restore it for safe human use (Karkra et al. 2016). Developing countries, such as Kenya, are grappling with increasing water quality deterioration, as urban and agricultural populations expand and wastewater volumes released into the nation's rivers increase (Besada and Werner 2015). Thus, it is vital that river water quality is monitored continuously through the regular assessment of selected chemical, biological and physical properties (Jang et al. 2013; Karkra et al. 2017), and that this information is used to inform better management practices.

This is especially true for Kenya, where concern over water pollution to rivers in the country has been raised since the 1990s (Githinji et al. 2019), and which has abundant water resources of insufficient quality (Notter et al. 2007) to achieve the Sustainable Development Goals (SDGs) (Barasa et al. 2018) for health, water and food security. The literature on water quality of the Chania River is limited despite the important agricultural activities along its banks and that it supplies water to the growing Thika Town and other peri-urban areas around Nairobi City (Batjes et al. 2014). Other studies in Kenya have linked river pollution to surrounding anthropogenic activities (Masese and McClain 2012). For example, Mbaka et al. (2014) linked water abstraction and grazing to a decline in water and habitat quality in Honi and Naro Moru rivers, and Njuguna et al. (2017) mapped poor water quality in the River Nairobi using a Water Quality Index (WQI). Both attributed poor water quality to industrial effluents, domestic sewage, agricultural activities and solid waste.

Water quality may be assessed in different ways (Zahedi et al. 2017). Some water quality determinations are based on a comparison of observed parameter values against established water quality guidelines for different uses or purposes. This physico-chemical approach is useful to identify sources of contamination and to check compliance but is less helpful in comparing sites with different water quality impacts (Debels et al. 2005). The use of a WQI is one of several methods that allow sites to be compared by reducing a set of water quality variables into a single dimensionless number that ranks water quality from poor to good and so that the results are easily interpreted (Hosseini-Moghari et al. 2015). The first comprehensive WQI was developed by Horton (1965) and was subsequently improved by Brown et al. (1970), Cude (2001) and Krishan and Singh (2016). WQIs are useful, because they are easily understood by stakeholders (Akoteyon et al. 2011; Bharti 2011) and effortlessly incorporated into water resource plans (Nikoonahad et al. 2010). Different WQIs are used depending upon the intended use of the water being tested (Zahedi et al. 2017). The Canadian Council of Ministers of the Environment WQI (CCMEWQI; Khan et al. 2003), US National Sanitation Foundation WQI (NSFWQI; Brown et al. 1970), British Columbia WQI (BCWQI) and Oregon WQI (OWQI; Abbasi 2002; Debels et al. 2005; Kannel et al. 2007) are some of the numerous water quality indices available.

For this study, the Weighted Arithmetic Mean Method described by Tyagi et al. (2013) was used to calculate WQI, because the relative influence of each parameter was shown and reflected in the final WQI score, which is essential in water quality management and assessment. Additionally, the method required evaluation of fewer parameters than others. The purpose was to assess the water in the Chania River for its suitability for human use and consumption, and these results will feed into water-resource planning discussions with managers, decision-makers and stakeholders.

Materials and methods

Study area

The Chania River originates on the slopes of Kinangop Mountain in the Aberdare Range; the second largest water tower in Kenya (CGK 2016). The catchment covers Kiambu, Murang'a and Nyandarua counties and lies between 0°45′10.8″ N and 1°02′24″ N and 36°34′48″ E and 37°04′12″ E (Figure 1; Ng'ang'a et al. 2017). The Chania River is the most important river flowing through this catchment, because its supplies water to a large agricultural area, and to the town of Thika and its surroundings (Njuguna et al. 2019).

The prevailing rainfall pattern in the study area is bimodal. Long rains are experienced from mid-March to May and the short rains from mid-October to November. The average annual rainfall is a function of altitude, where higher regions receive 2 000 mm and lower areas, such as at the town of Thika, receive as little as 600 mm. The

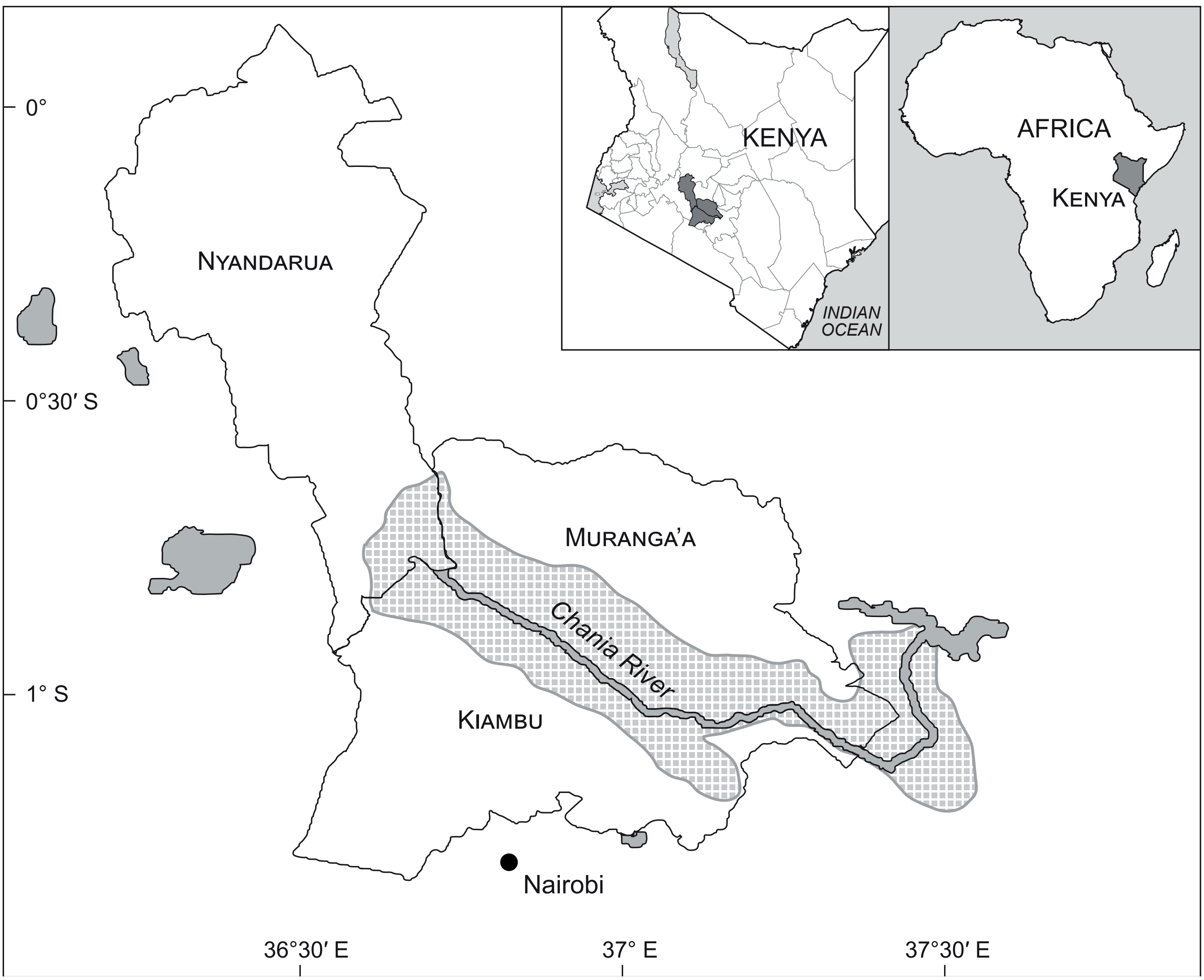

Figure 1: Map of study area showing sampling sites along a section of the Chania River (Source: Department of Geomantic Engineering and Geospatial information Systems, Kenya)

annual average for the area is 1 200 mm. Temperature ranges from 7 °C in the upper highlands of the Lari Constituency to 34 °C in the lower midland zones of Thika town, with an annual average of 26 °C (CGK 2016).

Sampling sites

Seven sites were selected along the Chania River based on the prevailing anthropogenic activities and ease of access. The distances between the sites varied between 1 and 2.5 km and the total length of river studied was 10 km. All the sites on the Chania River had different surrounding land uses. Site 1 had an indigenous forest and dense vegetation cover and served as the control site. In contrast, Sites 2 and 3 had coffee and flower plantations on either side of the river, and horticultural fields on both banks. Sites 4 and 5 had farmed fields, coffee plantations on the left bank and residential houses on the right bank, and Sites 6 and 7 are dotted with residential houses, industries and other commercial activities on both sides. The descriptions and geographical locations of the study sites are presented in (Tables 1 and 2).

Field sampling and analytical procedures

Water samples were collected four times in the entire sampling period of the wet (October and November 2018) and the dry season months (January and February 2019). The samples were collected in triplicate at a depth of about 20 cm. This resulted in 21 samples per month and 84 samples over the study period. The samples were collected in pre-cleaned polypropylene bottles washed with distilled water. Temperature, electrical conductivity pH and Total Dissolved Solids (TDS) were measured in situ using a thermometer, conductivity, pH and TDS meter, respectively. Nitrites were analysed using the sulphanilic acid method; nitrates and sulphates using the spectrophotometric method, as well as phosphates using the ascorbic acid method. The atomic absorption spectroscopy method was used to measure for manganese and copper concentrations. The atomic emission spectroscopy method and argentometric method were employed in the determination of potassium and chloride, respectively. The methods of chemical analysis are described by APHA (2002) and summarised in (Table 3).

Water Quality Index (WQI)

Nine water quality parameters were used in the calculation of the WQI: nitrates, TDS, potassium, sulphate, chloride, copper, manganese, pH and phosphate, which

Table 2: Sites and their geo-referenced locations and respective altitudes

Sampling site	Coordinates	Altitude (m asl)
Site 1	1°55′08″ S, 37°15′50″ E	1 519 m
Site 2	1°57′50″ S, 37°23′13″ E	1 509 m
Site 3	1°58′59″ S, 37°29′13″ E	1 498 m
Site 4	1°03′18″ S, 37°42′47″ E	1 492 m
Site 5	1°05′38″ S, 37°51′54″ E	1 481 m
Site 6	1°05′17″ S, 37°07′16″ E	1 474 m
Site 7	1°05′56″ S, 37°04′48″ E	1 460 m

Table 3: The measured parameters and method used in measurement

Parameter	Unit	Analytical procedure
Temperature	°C	Thermometer
TDS	mg l^{-1}	TDS meter
Turbidity	NTU	Turbidity meter
Conductivity	µS cm^{-1}	Conductivity meter
pH	–	pH meter
Nitrite	mg l^{-1}	Sulphanilic acid method
Nitrate	mg l^{-1}	Spectrophotometric
Sulphate	mg l^{-1}	Spectrophotometric
Total phosphate	mg l^{-1}	Ascorbic acid method
Potassium	mg l^{-1}	Atomic emission spectroscopy
Manganese	mg l^{-1}	Atomic absorption spectroscopy
Copper	mg l^{-1}	Atomic absorption spectroscopy
Chloride	mg l^{-1}	Argentometric

Table 1: Description of the sampling sites and their codes

Site codes	Description
Site 1	Chania River at Karimenu, forested zone. This site is located in a forested area. There were trees and shrubs on both banks and there were no human settlements near the river.
Site 2	Chania River just before Chania Estate Bridge and located next to Penta flowers factory. There were trees and shrubs near the river, people washed clothes and abstracted water, but no domestic animals were observed. Residential homes are present within 150 metres from the river. Agricultural activities were observed near river.
Site 3	Chania River after Chania Estate Bridge at Chania Coffee factory. Residential homes released domestic water into river; the coffee factory also released effluents; people washed clothes, bathed and swam in the river; motorbikes were washed in the river; there are agricultural activities and associated fertilizer and pesticides being applied.
Site 4	Chania River just before the onset of Ngoingwa Estate is a residential area that releases domestic effluents into the river; there are agricultural activities; people wash clothes and bathe in the river and water is abstracted.
Site 5	Chania River after Ngoingwa Estate, but just before Thika town. Mainly a residential area that releases effluents into the river; there is subsistence farming and raising of livestock; people wash clothes in the river and have removed some of the riparian vegetation.
Site 6	Chania River just before the intake weir of Thika town and the intake weir of Kiambu Water and Sewerage Company (KIWASCO). The riparian plants have been removed on both banks, garbage washes into the river from the adjacent road leading to Nairobi and people wash their motorbikes into the river.
Site 7	Chania River just after Thika town at Biafra. Industrial and domestic effluents are released into river; a Hindu crematorium disposes of ashes into the river; Delamare pineapple farm is situated here and much of the riparian vegetation has been removed.

was calculated using the Weighted Arithmetic Mean method (Chauhan and Singh 2010; Rao et al. 2010). The method follows three steps (Alobaidy et al. 2010).

The first step involves assigning a weight (w_i) to each parameter according to its perceived importance to water quality and human health (Avvannavar and Shrihari 2008; Saeedi et al. 2010). Table 4 shows the assigned weights and the World Health Organization recommended standards for drinking water quality (WHO 2011). The assigned weights range from two to five (Srinivasamoorthy et al. 2008; Varol and Davraz 2015). Nitrates and manganese were assigned the highest weights; phosphate, sulphate, chloride, TDS, copper, and pH were assigned intermediate weights and potassium the lowest.

The second step involves the computation of the relative weight (W_i) using Equation 1.

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

where W_i is the relative weight, w_i is the assigned weight of each parameter and n is the number of parameters.

The third step involves calculating a quality rating scale (q_i) for each parameter, using Equation 2. This is done by dividing the concentration of each parameter (C_i) in each water sample by its respective set standard (S_i) and the result multiplied by 100. The standard (S_i) used was from WHO (2011):

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \quad (2)$$

where q_i is the quality rating, C_i is the concentration of each parameter in each water sample and S_i is the WHO set drinking water standard for each parameter.

In the calculation of WQI, subindex (SI_i) is determined first for each parameter (Equation 3):

$$SI_i = w_i \times q_i \quad (3)$$

The WQI is derived from the summation of the different sub-indices, as indicated in Equation 4:

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

Table 4: Physico-chemical parameters, prescribed values by the World Health Organization (WHO 2011), weights assigned (w_i) and corresponding relative weights (W_i)

Parameter	w_i	WHO standard	W_i
Nitrate	5	50	0.152
TDS	3	1 000	0.091
Potassium	2	30	0.061
Sulphate	4	250	0.121
Chloride	3	250	0.091
Copper	4	1	0.121
Manganese	5	0.4	0.152
pH	4	7.5	0.121
Phosphate	3	5	0.091
	Total = 33		

The WQI values obtained were classified into five water quality classes; 0–25 indicates excellent water quality, 26–50 indicates good water quality, 51–75 indicates poor water quality, 76–100 indicates very poor quality of water and >100 indicates water that is unsuitable for drinking purposes (Tyagi et al. 2013; Table 5).

Data analysis

The mean seasonal values of the replicate samples collected were calculated in Microsoft Excel. A paired *t*-test ($p < 0.05$) was used to compare the mean dry-season and wet-season concentrations for each variable across sites to see whether these differed down the river. The data were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 9.2 (Ferreira 2011) and means separated using Least Significant Difference (LSD) at $p < 0.05$ confidence level

Results

Physico-chemical parameters

The mean and range of each physico-chemical parameter measured in the Chania River are presented in Table 6. Temperatures varied significantly among the sites in both seasons (Table 6, Figure 2). Site 7 had the highest temperature; 20.43 ± 0.15 °C for the wet season and 23.43 ± 0.33 °C for the dry season ($p < 0.05$). However, in the dry season, only Site 1 (20.43 ± 0.27 °C) and Site 3 (20.15 ± 0.50 °C) were significantly cooler. Temperature increased with reducing altitude in both seasons at all sites, except for Site 3. The temperature across all sites ranged from 16.60 ± 0.17 °C to 20.43 ± 0.15 °C in the wet season and 20.15 ± 0.50 °C to 23.43 ± 0.33 °C in the dry season (Table 6).

TDS mean values were higher in the dry season and especially high at Site 7 (53.61 ± 1.10 mg l^{-1}). Site 3 (16.37 ± 0.28 mg l^{-1}) recorded the lowest in the same season. In the wet season, the highest mean value was recorded at Site 7 (51.90 ± 0.58 mg l^{-1}) and the lowest at Site 2 (10.96 ± 0.39 mg l^{-1}) (Table 6). Mean turbidity values were highest in the wet season and especially high at Site 7 (278.48 ± 1.84 NTU). The highest turbidity in the dry season was also recorded at Site 7 (76.22 ± 1.16 NTU) and the lowest at Site 3 (17.54 ± 0.70 NTU). In the dry season, the results revealed that turbidity values were significantly different between Site 1 to Site 5 ($p < 0.05$), but not between Sites 6 and 7 (Table 6, Figure 3).

With regard to heavy metals (manganese and copper), higher mean values were recorded in the wet season at the more downstream sites (Sites 5 to 7) (Table 6, Figure 4a). Manganese levels in the wet season increased with

Table 5: Water Quality Index (WQI) classes for drinking purpose

Class number	WQI Range	Water type
1	0–25	Excellent
2	26–50	Good
3	51–75	Poor
4	76–100	Very poor
5	>100	Unsuitable for drinking purpose

distance downstream but this trend was not observed in the dry season (Figure 4a). The highest values for manganese in the wet and dry seasons were at Site 7 (1.78 ± 0.07 mg l^{-1} and 0.26 ± 0.02 mg l^{-1}, respectively). Manganese concentrations ranged from 0.21 ± 0.02 mg l^{-1} to 1.78 ± 0.07 mg l^{-1} and 0.11 ± 0.01 mg l^{-1} to 0.26 ± 0.02 mg l^{-1} in the wet and dry seasons, respectively. The manganese value for the wet season was four times (0.72 mg l^{-1}) that of the dry season (Table 6). The mean copper concentrations varied significantly among the sites in both seasons (Table 6). Sites 6 (0.22 ± 0.03 mg l^{-1}) and 7 (0.22 ± 0.01 mg l^{-1}) had the highest copper levels in the wet season, but not significantly so. Mean copper concentrations ranged from 0.11 ± 0.01 mg l^{-1} to 0.22 ± 0.01 mg l^{-1} and 0.04 ± 0.01 mg l^{-1} to 0.16 ± 0.02 mg l^{-1} in the wet and dry seasons, respectively (Table 6).

Sulphate concentrations ranged between 21.97 ± 0.49 mg l^{-1} in the wet season and 62.48 ± 0.87 mg l^{-1}

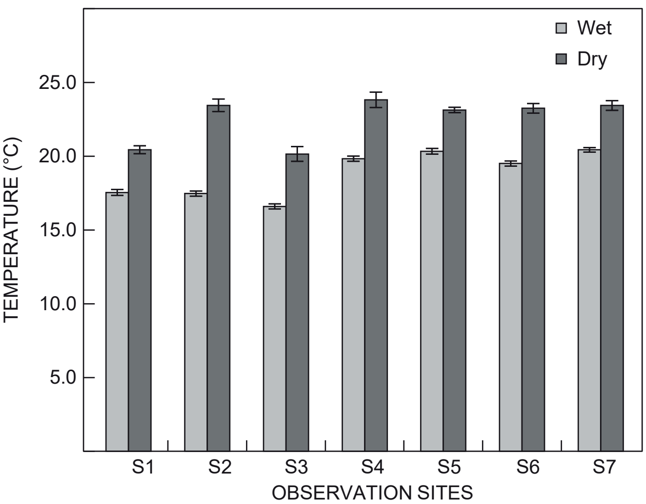

Figure 2: Temperature levels during the wet and dry seasons

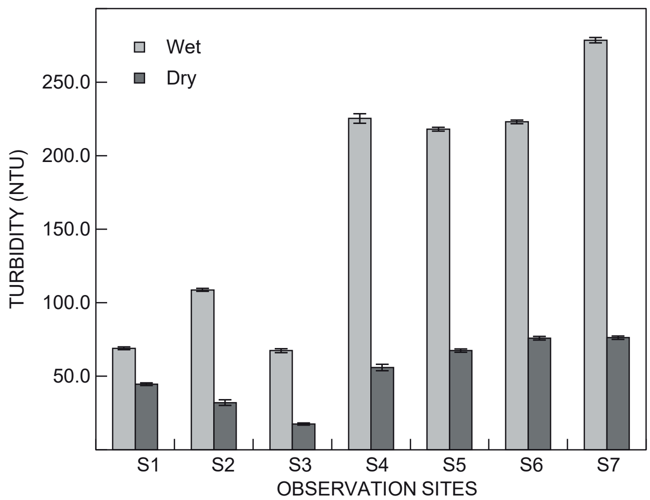

Figure 3: Turbidity concentration in the wet and dry seasons

Table 6: Physico-chemical properties of water in study sites along part of the Chania River

Factor	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Temperature wet (°C)	17.54 ± 0.20^{d}	17.46 ± 0.18^{d}	16.60 ± 0.17^{e}	19.83 ± 0.18^{bc}	20.33 ± 0.19^{ab}	19.50 ± 0.18^{c}	20.43 ± 0.15^{a}
Temperature dry (°C)	20.43 ± 0.27^{b}	23.45 ± 0.42^{a}	20.15 ± 0.50^{b}	23.82 ± 0.52^{a}	23.13 ± 0.18^{a}	23.24 ± 0.33^{a}	23.43 ± 0.33^{a}
TDS wet (mg l^{-1})	30.80 ± 0.49^{b}	10.96 ± 0.39^{f}	19.30 ± 0.29^{e}	23.91 ± 0.57^{d}	27.80 ± 0.58^{c}	24.86 ± 0.23^{d}	51.90 ± 0.58^{a}
TDS dry (mg l^{-1})	25.75 ± 0.35^{c}	17.96 ± 0.48^{d}	16.37 ± 0.28^{e}	26.03 ± 0.26^{c}	36.86 ± 0.52^{b}	36.41 ± 0.68^{b}	53.61 ± 1.10^{a}
Turbidity wet (NTU)	**69.03 ± 0.92^{e}**	**108.73 ± 1.01^{d}**	**67.43 ± 1.35^{e}**	**225.25 ± 3.27^{b}**	**217.97 ± 1.26^{c}**	**222.97 ± 1.24^{b}**	**278.48 ± 1.84^{a}**
Turbidity dry (NTU)	**44.62 ± 0.88^{d}**	**32.10 ± 1.91^{e}**	**17.54 ± 0.70^{f}**	**55.96 ± 2.15^{c}**	**67.42 ± 1.15^{b}**	**75.87 ± 1.22^{a}**	**76.22 ± 1.16^{a}**
Conductivity wet (µS cm^{-1})	54.60 ± 0.22^{b}	19.19 ± 0.66^{g}	34.04 ± 0.45^{f}	40.85 ± 0.35^{e}	51.36 ± 0.57^{c}	45.21 ± 0.40^{d}	92.54 ± 1.45^{a}
Conductivity dry (µS cm^{-1})	46.65 ± 0.42^{e}	39.45 ± 0.29^{f}	31.81 ± 0.47^{g}	51.64 ± 3.18^{d}	62.51 ± 1.86^{c}	67.22 ± 0.52^{b}	96.79 ± 1.14^{a}
pH wet	6.83 ± 0.19^{a}	6.60 ± 0.18^{a}	**5.98 ± 0.20^{c}**	**5.88 ± 0.17^{c}**	**6.26 ± 0.16^{bc}**	**6.32 ± 0.16^{abc}**	**6.20 ± 0.14^{bc}**
pH dry	7.37 ± 0.15^{ab}	6.53 ± 0.17^{c}	7.06 ± 0.06^{b}	7.43 ± 0.14^{a}	7.67 ± 0.09^{a}	7.37 ± 0.03^{ab}	7.46 ± 0.17^{a}
Chloride wet (mg l^{-1})	4.84 ± 0.13^{bc}	2.88 ± 0.16^{e}	4.21 ± 0.03^{d}	5.05 ± 0.08^{b}	4.64 ± 0.09^{c}	4.38 ± 0.03^{d}	6.04 ± 0.05^{a}
Chloride dry (mg l^{-1})	3.27 ± 0.07^{d}	2.62 ± 0.04^{e}	1.91 ± 0.03^{f}	2.15 ± 0.03^{f}	4.45 ± 0.14^{c}	4.83 ± 0.03^{b}	5.61 ± 0.15^{a}
Sulphate wet (mg l^{-1})	21.97 ± 0.49^{f}	24.80 ± 0.65^{e}	37.46 ± 0.83^{d}	36.68 ± 2.57^{d}	49.24 ± 0.29^{b}	45.67 ± 0.23^{c}	62.48 ± 0.87^{a}
Sulphate dry (mg l^{-1})	26.39 ± 0.93^{f}	28.85 ± 0.60^{f}	36.62 ± 0.71^{e}	72.42 ± 1.29^{b}	41.02 ± 0.75^{d}	50.47 ± 0.22^{c}	82.00 ± 1.15^{a}
Phosphate wet (mg l^{-1})	0.08 ± 0.02^{c}	0.19 ± 0.01^{c}	0.29 ± 0.02^{c}	1.57 ± 0.04^{b}	2.26 ± 0.17^{a}	1.35 ± 0.02^{b}	2.43 ± 0.11^{a}
Phosphate dry (mg l^{-1})	0.38 ± 0.02^{c}	0.20 ± 0.01^{e}	0.08 ± 0.01^{f}	0.12 ± 0.02^{f}	0.26 ± 0.01^{d}	1.34 ± 0.46^{a}	0.83 ± 0.05^{b}
Nitrate wet (mg l^{-1})	2.60 ± 0.05^{a}	1.58 ± 0.07^{c}	2.04 ± 0.05^{b}	1.37 ± 0.04^{c}	0.81 ± 0.20^{de}	0.61 ± 0.24^{e}	0.91 ± 0.21^{d}
Nitrate dry (mg l^{-1})	0.78 ± 0.04^{c}	0.66 ± 0.03^{d}	0.77 ± 0.04^{c}	0.82 ± 0.02^{c}	0.82 ± 0.03^{c}	1.05 ± 0.04^{b}	1.30 ± 0.07^{a}
Nitrite wet (mg l^{-1})	0.15 ± 0.02^{d}	0.19 ± 0.01^{c}	**0.23 ± 0.01^{b}**	**0.29 ± 0.01^{a}**	**0.25 ± 0.01^{b}**	**0.23 ± 0.01^{b}**	**0.25 ± 0.01^{b}**
Nitrite dry (mg l^{-1})	**0.31 ± 0.02^{b}**	**0.24 ± 0.02^{c}**	0.31 ± 0.02^{b}	0.30 ± 0.01^{b}	0.33 ± 0.02^{b}	0.28 ± 0.01^{bc}	0.47 ± 0.02^{a}
Manganese wet (mg l^{-1})	**0.21 ± 0.02^{e}**	**0.30 ± 0.01^{d}**	**0.33 ± 0.01^{d}**	**0.63 ± 0.02^{c}**	**0.90 ± 0.03^{b}**	**0.86 ± 0.03^{b}**	**1.78 ± 0.07^{a}**
Manganese dry (mg l^{-1})	**0.11 ± 0.01^{c}**	**0.21 ± 0.01^{ab}**	**0.15 ± 0.02^{bc}**	**0.22 ± 0.02^{a}**	**0.15 ± 0.02^{c}**	**0.14 ± 0.02^{c}**	**0.26 ± 0.02^{a}**
Copper wet (mg l^{-1})	0.11 ± 0.01^{d}	0.16 ± 0.01^{c}	0.12 ± 0.01^{d}	0.18 ± 0.01^{bc}	0.21 ± 0.01^{ab}	0.22 ± 0.03^{a}	0.22 ± 0.01^{a}
Copper dry (mg l^{-1})	0.05 ± 0.01^{c}	0.06 ± 0.01^{c}	0.04 ± 0.01^{c}	**0.11 ± 0.01^{b}**	**0.16 ± 0.02^{a}**	**0.10 ± 0.01^{b}**	**0.11 ± 0.01^{b}**
Potassium wet (mg l^{-1})	1.88 ± 0.11^{b}	0.48 ± 0.05^{f}	1.32 ± 0.02^{e}	1.42 ± 0.06^{d}	1.69 ± 0.04^{c}	1.83 ± 0.03^{b}	2.09 ± 0.03^{a}
Potassium dry (mg l^{-1})	2.13 ± 0.02^{b}	0.90 ± 0.04^{e}	1.68 ± 0.03^{c}	1.66 ± 0.02^{c}	1.74 ± 0.03^{c}	2.75 ± 0.08^{a}	1.40 ± 0.05^{d}

*Values in bold type values that were outside the recommended threshold limits by the World Health Organization (WHO 2011); means with the same letter (i.e. a, b, c, etc.) are not significantly different between sites.

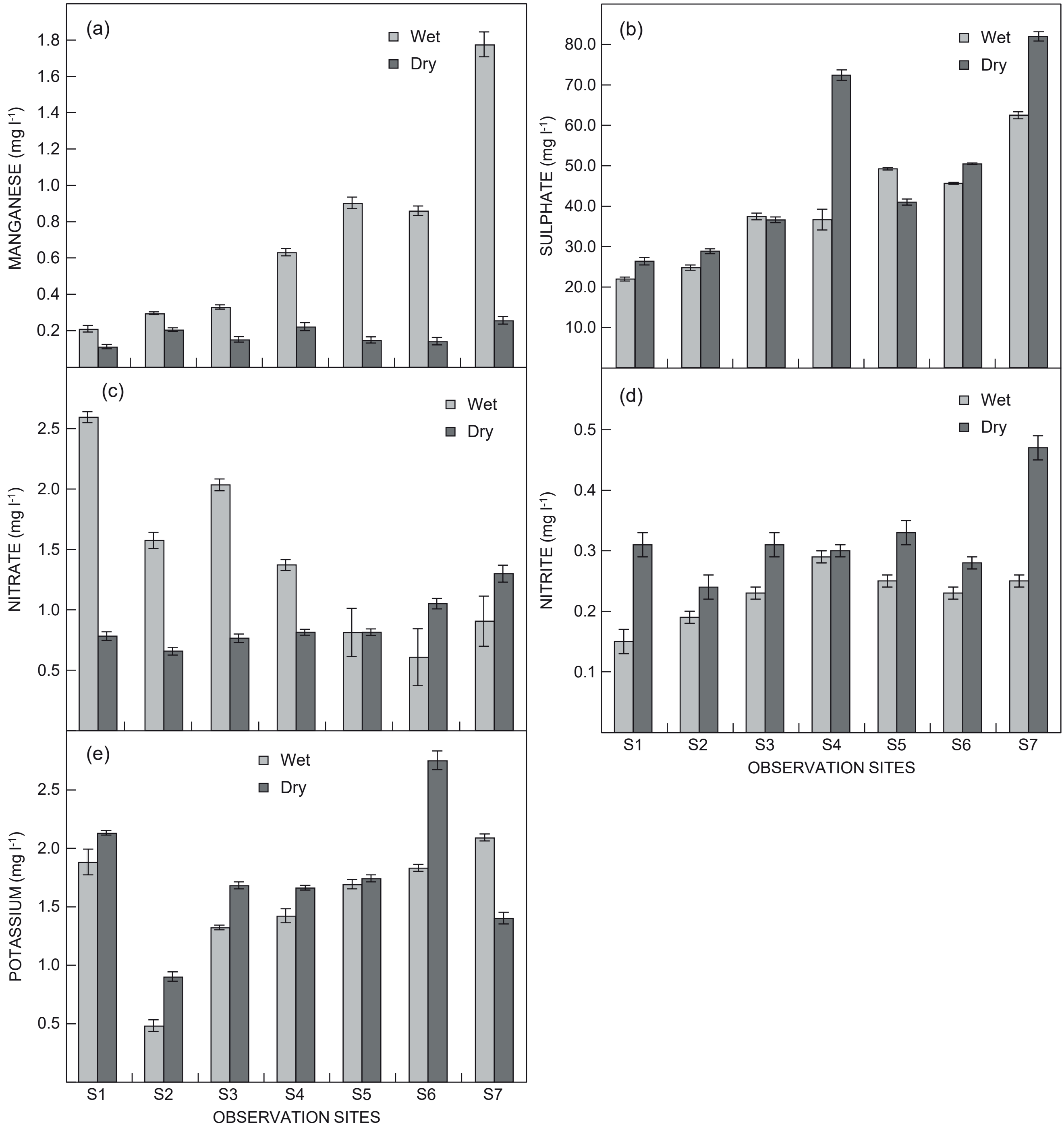

Figure 4: Manganese (a), sulphate (b), nitrate (c), nitrite (d) and potassium (e) concentrations during the wet and dry seasons

and 26.39 ± 0.93 mg l^{-1} to 82.00 ± 1.15 mg l^{-1} in the dry season, but did not vary significantly between the sites in either season (Figure 4b). Phosphate concentrations ranged from 0.08 ± 0.02 mg l^{-1} to 2.43 ± 0.11 mg l^{-1} in the wet season and 0.08 ± 0.01 mg l^{-1} to 1.34 ± 0.46 mg l^{-1} in dry the season. Phosphate concentrations also did not vary significantly between the sites in the wet season but did in the dry season. Nitrate concentrations were higher in the wet season (0.61 ± 0.24 mg l^{-1} to 2.60 ± 0.05 mg l^{-1}) than in the dry season (0.66 ± 0.03 mg l^{-1} to 1.30 ± 0.07 mg l^{-1}) especially at upstream sites (Sites 1 to 4), but there was no clear seasonal variation across the study sites (Figure 4c). Nitrite levels were higher in the dry season (0.24 ± 0.02 mg l^{-1} to 0.47 ± 0.02 mg l^{-1}) than the wet season, especially at Site 7 (0.47 ± 0.02 mg l^{-1}; Table 6, Figure 4d). Similarly, potassium (0.90 ± 0.04 mg l^{-1} to 2.75 ± 0.08 mg l^{-1}) showed an increasing trend towards the downstream sites (Site 4 to 7; Table 6, Figure 4e).

Water Quality Index (WQI)

The mean of the WQI values indicate that the suitability of the river water for human use deteriorated (44.67) in the wet season relative to the dry season (23.75), particularly at the more downstream sites (Sites 4 to 7; Table 7, Figure 5). In the wet season, the WQI values were excellent (23.17) at Site 1 and poor (>50) and very poor (>76) at the most downstream sites (Sites 5 to 7). In the dry season, WQI was between excellent (19.67–24.69) at Sites 1, 2, 3, 5 and 6, and good (26.30–30.10) at Sites 4 and 7, but there was no specific trend with respect to the sites. The mean WQI for all sites and both seasons was as good (34.22; Table 7).

Discussion

Physico-chemical parameters

The lower mean water temperatures at the upstream site (Site 1: Karimenu) relative to those at the more downstream sites correlated with the fact that temperatures typically decline with declining altitude; a concept referred to as lapse rate (Kattel et al. 2013) and also matched the vegetation cover that increased with increasing altitude. Vegetation cover over the stream reduces the amount of light, and consequently the water temperature (Garman and Moring 1991; Steedman et al. 1998; Bowler et al. 2012). The higher mean water temperature recorded in the dry season, particularly at Site 4, Site 6 and Site 7 is partly a natural phenomenon, correlated with higher mean ambient temperatures (Kalny et al. 2017), wider stream widths and less shading, but in this case it was probably exacerbated by clearing of riparian plants. Higher temperatures may also result from the release of warm or hot industrial and domestic effluents (e.g., wastewater, cooling water) (Bogan et al. 2003; Verones et al. 2010).

The high concentration of TDS at Site 7 is expected in line with the River Continuum Theory (Curtis et al. 2018), which suggests that turbidity in natural systems is expected to increase in a downstream direction. However, in the Chania River, downstream sites experienced increased agricultural and industrial activities (also reported by Greathouse and Pringle 2006; Daphne et al. 2011), which suggests that at least some of the contribution to elevated TDS concentrations might be traced back to anthropogenic disturbances (Anhwange et al. 2012). Site 7, in particular, received industrial and domestic effluents from the incremental catchment area, as well as ashes from a Hindu crematorium, which were deposited into the river twice per month. Such human activities increase the suspended and dissolved matter in lotic systems and modify other chemical factors, such as trace metals and nutrients, reducing water quality (Ha and Pokhrel 2001; Arnold 2016). This is also illustrated by the fact that there were higher TDS values downstream in the dry season than in the wet season when runoff is expected to transport more suspended and dissolved substances from surrounding areas. These factors were probably also responsible for the higher conductivity values at Sites 4 to 7.

Turbidity mean values were relatively higher in the wet season than the dry season in all the sites; especially in the downstream sites (Sites 4 to 7). Similar results were observed by Yang et al. (2014) and Ogamba et al. (2015) that showed that overland flow in the wet season, transport suspended matter (e.g. soil, organic matter) into rivers, thereby contributing to the decline in water transparency and quality. Riparian zones along riverbanks (e.g. at Site 1) slow runoff carrying suspended matter from entering rivers and this drops sediments and pollutants into the fringing riparian zone, thereby reducing sedimentation and pollution in the river (Liu et al. 2019). Sites 6 and 7 where clearing of riparian vegetation has taken place are also those with a greater number of anthropogenic disturbance (washing clothes, animals trampling, etc.) that together contribute to increased turbidity levels.

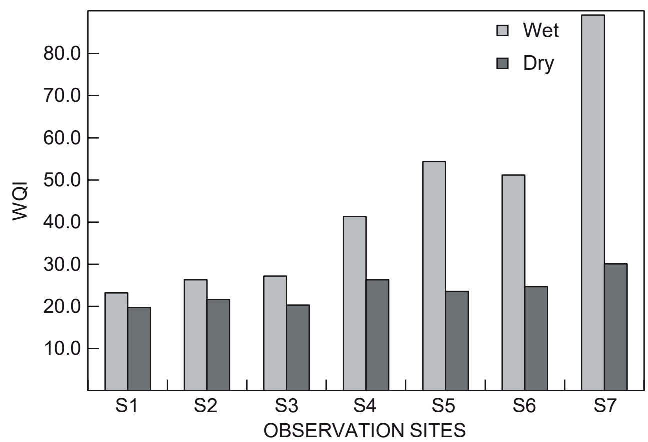

Figure 5: Water Quality Index (WQI) mean values during the wet and dry seasons

Table 7: Water Quality Index (WQI) values for the wet (WQI_w) and dry (WQI_d) seasons, combined seasons ($WQI_{combined}$) and water type categories for the different study sites

Sampling site	WQI_w	Water type	WQI_d	Water type	$WQI_{combined}$	Water type
Site 1	23.17	Excellent	19.67	Excellent	21.41	Excellent
Site 2	26.31	Good	21.64	Excellent	23.79	Excellent
Site 3	27.20	Good	20.29	Excellent	23.71	Excellent
Site 4	41.34	Good	26.30	Good	33.94	Good
Site 5	54.35	Poor	23.57	Excellent	39.09	Good
Site 6	51.15	Poor	24.69	Excellent	37.92	Good
Site 7	89.15	Very poor	30.10	Good	59.68	Poor
Entire river	44.67	Good	23.75	Excellent	34.22	Good

The high mean values for heavy metals, such as manganese and copper in the wet season, suggest that these chemicals are transported from the surrounding areas by runoff. These chemical substances were also at higher concentrations at downstream areas (Sites 5 to 7), where removal of riparian vegetation compromised chemical water quality (Dosskey et al. 2010). Njue et al. (2016) and Chua et al. (2019) evaluated the effect of riparian vegetation on river water quality and found that rivers with less riparian vegetation had high concentrations of dissolved organic carbon, total phosphorous, dissolved manganese, potassium, sulphate, sulphur, cadmium, lead, copper and total nitrogen concentrations when compared with less disturbed riparian areas. The authors also suggested that protecting riparian vegetation and restoring degraded riparian zones would assist in improving stream water quality. Conversely, Guo et al. (2015) discovered that riparian grassland had the highest nutrient concentrations showing that maintenance of vegetation (e.g. grassland) near riparian areas intercept and infiltrates runoff, trapping nutrients and reducing river pollution. Lack of a clear seasonal pattern for sulphate, phosphate and nitrate suggests that runoff is not the only important pathway for their presence in rivers, human activities (effluent input), natural sources, or transformation of the nutrients are also important (Rapport 1999; Baldwin 2013; Bouwman et al. 2013).

Mean values for physico-chemical variables, such as total dissolved solids, conductivity, chloride, sulphate, phosphate, nitrate, nitrite and potassium, were lower than the recommended water quality standards by the World Health Organization (WHO 2011), but turbidity (>15 NTU), manganese (>0.1 mg l^{-1}) and copper (>0.1 mg l^{-1}) were not (Table 6, Table 8). High turbidity may reduce the utility of water by humans, as a result of the high amounts of suspended organic and inorganic matter. Additionally, turbidity may increase water treatment cost, because of the increased amount of chemicals required for the coagulation process (Sahu and Chaudhari 2013). Turbidity in the current study is particularly important within the water treatment context, because some of the highest turbidity values (>200 NTU) were recorded just upstream of the intake weirs of Kiambu Water and Sewerage Company. Manganese and copper should also be maintained within the recommended threshold limits by the WHO (WHO 2011); manganese has been reported to affect the central nervous system in children, impair cognitive abilities and adaptive behaviours among other effects (Ljung and Vahter 2007; Dion et al. 2018).

Water Quality Index (WQI)

The WQI of the Chania River in the wet season was in the ‘excellent’ to ‘very poor’ range across all sites, mainly as a result of runoff from agricultural lands and municipal, domestic and industrial wastewaters discharged into the river (Halder and Islam 2015). This was especially evident at downstream sites (Sites 4 to 7), where the water quality deteriorated from good to very poor. However, the index showed that the river water was ‘excellent’ and ‘good’ in the dry season at all sites. The main reasons for the declined water quality in the wet season were inputs of suspended and dissolved substances in the overland runoff, which affected the water quality (Uusitalo et al. 2001; Wei et al. 2013).

Table 8: Water quality parameters and the recommended water quality standards by the World Health Organization (WHO 2011)

Parameter	Unit	WHO
Temperature	°C	–
pH	–	6.5–8.5
TDS	mg l^{-1}	1 000
Conductivity	µS cm^{-1}	500–5 000
Turbidity	NTU	5
Chloride	mg l^{-1}	250
Sulphate	mg l^{-1}	250
Phosphate	mg l^{-1}	5
Nitrate	mg l^{-1}	50
Nitrite	mg l^{-1}	0.2–3
Manganese	mg l^{-1}	0.4
Copper	mg l^{-1}	1–2
Potassium	mg l^{-1}	30

The main sources of contamination in the Chania River were wastewater discharged from Thika Town (Site 7), fertilizers, pesticides and other agrochemicals from coffee plantations, effluent from a coffee processing factory (Site 3); and agricultural activities along its banks (Site 5). River water quality was significantly reduced in the wet season the sites immediately downstream of disturbed parts of the watershed areas, where there where infiltration of runoff is low, there is reduced capacity for retention of solid particles and where the riparian vegetation was disturbed or removed completely (Zhang et al. 2010). The presence of a healthy riparian zone and fewer human-related activities contributed to better water quality at the upstream site (Site 1) in both seasons.

Conclusion and recommendations

The WQI used in this study showed that water quality was relatively better for human use in the dry season than the wet season. Heavy metals, such as copper and manganese, were prevalent at downstream sites in both seasons, probably because they enter the river via solid wastes disposal and point-source effluent discharges. However, the concentrations of other potentially harmful parameters (nitrates and phosphates) were higher in the wet season than in the dry season, despite additional dilution in the former. This suggests that these are entered the river via runoff associated with rainfall events, which increase in the wet season. This suggestion is supported by the fact that the sites with elevated concentrations also lacked a functioning riparian zone, which would have ameliorated the impact of poor-quality runoff on the river (Vidon et al. 2010).

Although the water quality of the Chania River was generally good, there are places where agricultural and industrial activities degraded the water quality to the extent that treatment is required before this water is safe for human consumption. The results point to the urgent need for the implementation of strategies to reduce the pollution load entering the river through regulating the intensity of farming, wastewater treatment prior to disposal of point-source effluents and restoration of riparian zones of the river to enhance protection against non-point source pollutants, particularly in the downstream parts of the river. Failure to this, the indications are that the situation will worsen considerably over time. In addition, the human health risks associated with elevated concentrations of copper and manganese in this area require additional investigations.

Acknowledgments — We thank the University of Embu for supporting this work, by providing guidance in preparation of project proposal. We also acknowledge the Kiambu Water and Sewerage Company for providing equipment, laboratory and working space. We also thank Mr Eric Otieno of the University of Embu for providing guidance in samples analyses. We also thank two anonymous reviewers whose comments greatly improved the paper.

References

Akoteyon IS, Omotayo AO, Soladoye O, Olaoye HO. 2011. Determination of Water Quality Index and suitability of urban river for municipal water supply in Lagos-Nigeria. *European Journal of Scientific Research* 54: 263–271.

Alobaidy A H, Abid HS, Maulood BK. 2010. Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq. *Journal of Water Resource and Protection* 2: 792–798. https://doi.org/10.4236/jwarp.2010.29093.

American Public Health Association (APHA). 2002. *Standard methods for the examination of water and wastewater*. (21st ed). Washington DC: American Public Health Association.

Anhwange BA, Agbaji EB, Gimba EC. 2012. Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis. *International Journal of Science and Technology* 2: 248–254.

Arnold D. 2016. Burning issues: cremation and incineration in modern India. *NTM Zeitshrift für Geschichte der Wissenschaften, Technik und Medizin* 24: 393–419.

Avvannavar SM, Shrihari S. 2008. Evaluation of water quality index for drinking purposes for River Netravathi, Mangalore, South India. *Environmental Monitoring and Assessment* 143: 279–290. https://doi.org/10.1007/s10661-007-9977-7.

Baldwin DS. 2013. Organic phosphorous in the aquatic environment. *Environmental Chemistry* 10: 439–454. https://doi.org/10.1071/EN13151.

Barasa E, Nguhiu P, McIntyre D. 2018. Measuring progress towards sustainable development goal 3.8 on universal health coverage in Kenya. *BMJ Global Health* 3: article e000904. http://dx.doi.org/10.1136/bmjgh-2018-000904.

Batjes NH. 2014. Projected changes in soil organic carbon stocks upon adoption of recommended soil and water conservation practices in the Upper Tana River catchment, Kenya. *Land Degradation & Development* 25: 278–287.

Besada H, Werner K. 2015. An assessment of the effects of Africa's water crisis on food security and management. International *Journal of Water Resources Development* 31: 120–133. https://doi.org/10.1080/07900627.2014.905124.

Bharti N. 2011. Water quality indices used for surface water vulnerability assessment. *International Journal of Environmental* Sciences 2: 154–173.

Bogan T, Mohseni O, Stefan HG. 2003. Stream temperature—equilibrium temperature relationship. *Water Resources Research* 39: article 1245. https://doi.org/10.1029/2003WR002034.

Bouwman AF, Bierkens MFP, Griffioen J, Hefting MM, Middelburg JJ, Middelkoop H, Slomp CP. 2013. Nutrient dynamics, transfer and retention along the aquatic continuum from land to ocean: towards integration of ecological and biogeochemical models. *Biogeosciences* 10: 1–22. https://doi.org/10.5194/bg-10-1-2013.

Bowler DE, Mant R, Orr H, Hannah DM, Pullin AS. 2012. What are the effects of wooded riparian zones on stream temperature? *Environmental Evidence* 1: article 3. https://doi.org/10.1186/2047-2382-1-3.

Brown RM, McClelland NI, Deininger RA, Tozer RG. 1970. A water quality index − do we dare? *Water & Sewage Works* 117: 339–343.

CGK (County Government of Kiambu). 2016. Economic Annual Planning. Report. Nairobi: Government Printers.

Chauhan A, Singh S. 2010. Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and Opinion* 2: 53–61.

Chua EM, Wilson SP, Vink S, Flint N. 2019. The influence of riparian vegetation on water quality in a mixed land use river basin. *River Research and Applications* 35: 259–267.

Cude CG. 2001. Oregon water quality index a tool for evaluating water quality management effectiveness. *Journal of the American Water Resources Association* 37: 125–137. https://doi.org/10.1111/j.1752-1688.2001.tb05480.x.

Curtis WJ, Gebhard AE, Perkin JS. 2018. The river continuum concept predicts prey assemblage structure for an insectivorous fish along a temperate river scape. *Freshwater Science* 37: 618–630. https://doi.org/10.1086/699013.

Daphne LHX, Utomo HD, Kenneth LZH. 2011. Correlation between turbidity and total suspended solids in Singapore rivers. *Journal of Water Sustainability* 1: 313–322.

Debels P, Figueroa R, Urrutia R, Barra R. Niell X. 2005. Evaluation of water quality in the Chillán River (Central Chile) using physicochemical parameters and a modified Water Quality Index. *Environmental Monitoring and Assessment* 110: 301–322. https://doi.org/10.1007/s10661-005-8064-1.

Dion LA, Saint-Amour D, Sauvé S, Barbeau B, Mergler D, Bouchard MF. 2018. Changes in water manganese levels and longitudinal assessment of intellectual function in children exposed through drinking water. *Neurotoxicology* 64: 118–125. https://doi.org/10.1016/j.neuro.2017.08.015.

Dosskey MG, Vidon P, Gurwick NP, Allan CJ, Duval TP, Lowrance, R. (2010). The role of riparian vegetation in protecting and improving chemical water quality in streams. *Journal of the American Water Resources Association* 46: 261–277. https://doi.org/10.1111/j.1752-1688.2010.00419.x.

Ferreira DF. 2011.Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia* 35: 1039–1042. https://doi.org/10.1590/S1413-70542011000600001.

Garman GC, Moring JR. 1991. Initial effects of deforestation on physical characteristics of a boreal river. *Hydrobiologia* 209: 29–37. https://doi.org/10.1007/BF00006715.

Githinji MW, Mwaura F, Wamalwa J. 2019. Land use and water pollution along the altitudinal gradient of the Likii River, Laikipia County, Kenya. *Journal of Environment Pollution and Human Health* 7: 39–52.

Greathouse E, Pringle C. 2006. Does the river continuum concept apply on a tropical island? Longitudinal variation in a Puerto Rican stream. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 134–152. https://doi.org/10.1139/f05-201.

Guo E, Chen L, Sun R, Wang Z. 2015. Effects of riparian vegetation patterns on the distribution and potential loss of soil nutrients: a case study of the Wenyu River in Beijing. *Frontiers of Environmental Science & Engineering* 9: 279–287. https://doi.org/10.1007/s11783-014-0667-8.

Ha SR, Pokhrel D. 2001. Water quality management planning zone development by introducing a GIS tool in Kathmandu valley, Nepal. *Water Science and Technology* 44: 209–221. https://doi.org/10.2166/wst.2001.0427

Halder JN, Islam MN. 2015. Water pollution and its impact on the human health. *Journal of Environment and Human* 2: 36–46. https://doi.org/10.15764/EH.2015.01005

Horton RK. 1965. An index number system for rating water quality. *Journal of Water Pollution Control Federation* 37: 300–306.

Hosseini-Moghari SM, Ebrahimi K, Azarnivand A. 2015. Groundwater quality assessment with respect to fuzzy water quality index (FWQI): an application of expert systems in environmental monitoring. *Environmental Earth Sciences* 74: 7229–7238. https://doi.org/10.1007/s12665-015-4703-1.
Jang CS, Chen SK, Kuo YM. 2013. Applying indicator-based geostatistical approaches to determine potential zones of groundwater recharge based on borehole data. *Catena* 101: 178–187. https://doi.org/10.1016/j.catena.2012.09.003.
Jinturkar AM, Deshmukh SS, Agarkar SV, Chavhan GR. 2010. Determination of water quality index by fuzzy logic approach: a case of ground water in an Indian town. *Water Science and Technology* 61: 1987–1994. https://doi.org/10.2166/wst.2010.095.
Kalny G, Laaha G, Melcher A, Trimmel H, Weihs P, Rauch HP. 2017. The influence of riparian vegetation shading on water temperature during low flow conditions in a medium sized river. *Knowledge & Management of Aquatic Ecosystems* 5: 235–256. https://doi.org/10.1051/kmae/2016037
Kannel PR, Lee S, Lee YS, Kanel SR, Khan SP. 2007. Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment. *Environmental Monitoring and Assessment* 132: 93–110. https://doi.org/10.1007/s10661-006-9505-1.
Karkra R, Kumar P, Bansod BK, Bagchi S, Sharma P, Krishna CR. 2017. Classification of heavy metal ions present in multi-frequency multi-electrode potable water data using evolutionary algorithm. *Applied Water Science* 7: 3679–3689. https://doi.org/10.1007/s13201-016-0514-0.
Karkra R, Kumar P, Bansod BK, Krishna CR. 2016. Analysis of heavy metal ions in potable water using soft computing technique. *Procedia Computer Science* 93: 988–994. https://doi.org/10.1016/j.procs.2016.07.295.
Kattel DB, Yao T, Yang K, Tian L, Yang G, Joswiak D. 2013. Temperature lapse rate in complex mountain terrain on the southern slope of the central Himalayas. *Theoretical and Applied Climatology* 113: 671–682. https://doi.org/10.1007/s00704-012-0816-6.
Khan AA, Paterson R, Khan H. 2003. Modification and application of the CCME WQI for the communication of drinking water quality data in Newfoundland and Labrador. In: *Proceedings of the 38th Central Symposium on Water Quality Research.* Burlington: Canadian Association on Water Quality.
Kostyla C, Bain R, Cronk R, Bartram J. 2015. Seasonal variation of fecal contamination in drinking water sources in developing countries: a systematic review. *The Science of the Total Environment* 514: 333–343. https://doi.org/10.1016/j.scitotenv.2015.01.018.
Krishan G, Singh S. 2016. Assessment of Water Quality Index (WQI) of Groundwater in Rajkot District, Gujarat, India. *Journal of Earth Science & Climatic Change* 7: 5–8. https://doi.org/10.4172/2157-7617.1000341.
Laaffat J, Ouazzani N, Mandi L. 2015. The evaluation of potential purification of a horizontal subsurface flow constructed wetland treating greywater in semi-arid environment. *Process Safety and Environmental Protection* 95: 86–92. https://doi.org/10.1016/j.psep.2015.02.016.
Liu S, Pan G, Zhang Y, Xu J, Ma R, Shen Z, Dong S. 2019. Risk assessment of soil heavy metals associated with land use variations in the riparian zones of a typical urban river gradient. *Ecotoxicology and Environmental Safety* 181: 435–444.
Ljung K, Vahter M. 2007. Time to re-evaluate the guideline value for manganese in drinking water? *Environmental Health Perspectives* 115: 1533–1538. https://doi.org/10.1289/ehp.10316.
Lopez AB, Ramos LJA, Santa CG, Moran Ramirez J, Carranco Lozada SE, Noyola Medrano MC, Pineda Martinez LF. 2013. Water proverty index assessment in semi-arid regions: the case of San Luis Potosi Valley (Mexico). *Revista Internacional de Contaminación Ambienta* 29: 249–260.
Masese FO, McClain ME. 2012. Trophic resources and emergent food web attributes in rivers of the Lake Victoria Basin: a review with reference to anthropogenic influences. *Ecohydrology* 5: 685–707. https://doi.org/10.1002/eco.1285.
Mbaka JG, M'Erimba CM, Thiongo HK, Mathooko JM. 2014. Water and habitat quality assessment in the Honi and Naro Moru rivers, Kenya, using benthic macroinvertebrate assemblages and qualitative habitat scores. *African Journal of Aquatic Science* 39: 361–368. https://doi.org/10.2989/16085914.2014.976168.
Ng'ang'a GJ, Omondi OB, Mourad K. 2017. Soil and sater conservation in Thika-Chania catchment, Kenya. International *Journal of Sustainable Water and Environmental Systems* 9: 59–65.
Nikoonahad A, Moazed H, Kazembeigi F. 2010. Comparing indices for selecting the best index for Karkheh Dam. *Journal of Water Resources Research* 3: 69–73.
Njue N, Koech E, Hitimana J, Sirmah P. 2016. Influence of land use activities on riparian vegetation, soil and water quality: An indicator of biodiversity loss, South West Mau Forest, Kenya. *Open Journal of Forestry* 6: 373–385. https://doi.org/10.4236/ojf.2016.65030.
Njuguna SM, Makokha VA, Yan X, Gituru RW, Wang Q, Wang J. 2019. Health risk assessment by consumption of vegetables irrigated with reclaimed wastewater: A case study in Thika (Kenya). *Journal of Environmental Management* 231: 576–581.
Njuguna SM, Yan X, Gituru RW, Wang Q, Wang J. 2017. Assessment of macrophyte, heavy metal, and nutrient concentrations in the water of the Nairobi River, Kenya. *Environmental Monitoring and Assessment* 189: 454. https://doi.org/10.1007/s10661-017-6159-0.
Notter B, MacMillan L, Viviroli D, Weingartner R, Liniger HP. 2007. Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology* 343: 266–278. https://doi.org/10.1016/j.jhydrol.2007.06.022
Ogamba EN, Iza, SC, Toikumo BP. 2015. Water quality and levels of lead and mercury in Eichhornia crassipes from a tidal creek receiving abattoir effluent, in the Niger Delta, Nigeria. *Continental Journal of Environmental Science* 9: 13–25.
Qu B, Zhang Y, Kang S, Sillanpää M. 2019. Water quality in the Tibetan Plateau: Major ions and trace elements in rivers of the "Water Tower of Asia". *Science of the Total Environment* 649: 571–581. https://doi.org/10.1016/j.scitotenv.2018.08.316
Rao CS, Rao BS, Hariharan AV, Bharathi NM. 2010. Determination of water quality index of some areas in Guntur district Andhra Pradesh. *International Journal of Applied Biology and Pharmaceutical Technology* 1: 79–86.
Rapport DJ. 1999. The transformation from healthy to degraded aquatic ecosystems. *Aquatic Ecosystem Health & Management* 2: 97–103. https://doi.org/10.1080/14634989908656945.
Saeedi M, Abessi O, Sharifi F, Meraji H. 2010. Development of groundwater quality index. *Environmental Monitoring and Assessment* 163: 327–335. https://doi.org/10.1007/s10661-009-0837-5.
Sahu OP, Chaudhari PK. 2013. Review on chemical treatment of industrial waste water. *Journal of Applied Sciences & Environmental Management* 17: 241–257. https://doi.org/10.4314/jasem.v17i2.8
Santos JC, Andrade EM, Araújo Neto JR, Meireles AC, Palácio HA. 2014. Land use and trophic state dynamics in a tropical semi-arid reservoir. *Revista Ciência Agronômica* 45: 35–44. https://doi.org/10.1590/S1806-66902014000100005.
Srinivasamoorthy K, Chidambaram S, Prasanna MV, Vasanthavihar M, Peter J, Anandhan P. 2008. Identification of

major sources controlling groundwater chemistry from a hard rock terrain-a case study from Mettur taluk, Salem district, Tamil Nadu, India. *Journal of Earth System Science* 117: 49–58. https://doi.org/10.1007/s12040-008-0012-3.

Steedman RJ, France RL, Kushneriuk RS, Peters RH. 1998. Effects of riparian deforestation on littoral water temperatures in small boreal forest lakes. *Boreal Environment Research* 3: 161–170.

Su WC, Ahern JF, Chang CY. 2016. Why should we pay attention to “inconsistent” land uses? A viewpoint on water quality. *Landscape and Ecological Engineering* 12: 247–254. https://doi.org/10.1007/s11355-016-0293-7.

Tyagi S, Sharma B, Singh P, Dobhal R. 2013. Water quality assessment in terms of Water Quality Index. *American Journal of Water Resources* 1: 34–38.

Uusitalo R, Turtola E, Kauppila T, Lilja T. 2001. Particulate phosphorus and sediment in surface runoff and drainflow from clayey soils. *Journal of Environmental Quality* 30: 589–595. https://doi.org/10.2134/jeq2001.302589x.

Varol S, Davraz A. 2015. Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). *Environmental Earth Sciences* 73: 1725–1744. https://doi.org/10.1007/s12665-014-3531-z.

Verones F, Hanafiah MM, Pfister S, Huijbregts MA, Pelletier GJ, Koehler A. 2010. Characterization factors for thermal pollution in freshwater aquatic environments. *Environmental Science & Technology* 44: 9364–9369. https://doi.org/10.1021/es102260c.

Vidon P, Allan C, Burns D, Duval TP, Gurwick N, Inamdar S, Sebestyen S. 2010. Hot spots and hot moments in riparian zones: potential for improved water quality management 1. *JAWRA Journal of the American Water Resources Association* 46: 278–298. https://doi.org/10.1111/j.1752-1688.2010.00420.x

Wei Z, Simin L, Fengbing T. 2013. Characterization of urban runoff pollution between dissolved and particulate phases. *The Scientific World Journal* 2013: article 964737. https://doi.org/10.1155/2013/964737.

World Health Organization (WHO). 2011. Guidelines for drinking-water quality. (4th ed). WHO Chronicle 38: 104.

Yang Y, Li Y, Sun Z, Fan Y. 2014. Suspended sediment load in the turbidity maximum zone at the Yangtze River Estuary: The trends and causes. *Journal of Geographical Sciences* 24: 129–142. https://doi.org/10.1007/s11442-014-1077-3.

Zahedi S, Azarnivand A, Chitsaz N. 2017. Groundwater quality classification derivation using multi-criteria-decision-making techniques. *Ecological Indicators* 78: 243–252. https://doi.org/10.1016/j.ecolind.2017.03.015.

Zhang X, Liu X, Zhang M, Dahlgren RA, Eitzel M. 2010. A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. *Journal of Environmental Quality* 39: 76–84. https://doi.org/10.2134/jeq2008.0496.

Manuscript received: 3 June 2019, revised: 3 July 2020, accepted: 10 July 2020
Associate Editor: K Reinecke