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Spatial and seasonal variations in surface water quality of the Mkondoa River, Tanzania

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Surface water quality was examined to determine spatial and seasonal variations in the Mkondoa River, in an agricultural area at Kilosa, Tanzania. Five sampling stations were chosen spatially along the river continuum to reflect a consideration of all possible activities that are capable of affecting the quality of the river water. Triplicate samples of physical water parameters were collected on a monthly basis at each station for four months from February 2015 to May 2015, covering part of the dry season (February - March) and part of the wet season (April - May). Temperature showed significant variation in both space and time ($p < 0.001$), while DO and BOD showed significant variation only with respect to time ($p < 0.001$). The pH values varied significantly ($p < 0.001$) temporally, but not spatially. Temperature, DO and pH showed lower mean values during the wet season relative to the dry season. In contrast, the concentration of BOD was high during the wet season and lowest in the dry season. Water quality index (WQI) indicated that water quality was fair (77±0.98) in the upstream reach of the Mkondoa, marginal (55±0.86) in the midstream reach and poor (33±0.45) in the downstream reach. There were significant relationships ($p < 0.001$) between physical parameters and WQI. The results suggested that the water quality of Mkondoa River is degraded towards downstream reach, and provided critical information for water resource conservation in agricultural watersheds of Tanzania.

Key words: Water quality, physical parameters, water quality index, agricultural watersheds.

INTRODUCTION

Rivers are important freshwater systems across the world, providing main water resources for various uses including agricultural, domestic, recreational and industrial purposes. In recent years, rivers are amongst the most vulnerable water bodies to pollution as a consequence of unprecedented development.

Anthropogenic influences like urbanization, industrialization, agricultural activities as well as natural sources like precipitation rate, weathering processes and soil erosion degrade the surface water (Ramadhan, 2007; Najafpour et al., 2008; Bu et al., 2010; Shimba and Jonah, 2016). Thus, the water quality of these water

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resources is a subject of ongoing concern and has resulted in an increasing demand for monitoring river water quality.

Aquatic systems worldwide are reported to be much polluted due to agricultural activities, untreated sewage disposal and industrial effluents being disposed directly into the rivers. Wastes usually contain a wide variety of organic and inorganic pollutants including plastics, heavy metals, pesticides and suspended solids (Machiwa, 1992; Rose, 2011). Pollutants entering a river system normally result from many transport pathways including storm water runoff, discharge from ditches and creeks, vadose zone leaching, groundwater seepage and atmospheric deposition (Rose, 2011). Because of the anthropogenic activities, fresh water resources are deteriorating day-by-day at a very fast rate (Ramadhan, 2007).

The quality of water is described by its physical, chemical and microbiological characteristics (Venkatesharaju et al., 2010). Water quality varies both spatially and temporally. River discharge and pollutant concentration in water bodies vary with temporal variations in precipitation, surface runoff, interflow and groundwater flow (Vega et al., 1998). Seasonal changes in surface water quality are used to interpret temporal variations in river pollution caused by natural or anthropogenic inputs from point and non-point sources (Ouyang et al., 2006; Fan et al., 2012). Therefore, seasonal changes in surface water quality must be considered when establishing a water quality management program (Ouyang et al., 2006).

Although, a number of studies have been conducted to understand the physico-chemical characteristics of Tanzania freshwater bodies (Steinbach, 1974; Ngoile et al., 1978; Machiwa, 1992; Kandoro, 1997; Mmochi and Mberek, 1998; Elias et al., 2014; Kaaya et al., 2015), little is known about the status of water quality of the Mkondoa River. Due to continuing agricultural practices along the Mkondoa River, a better understanding of the seasonal and temporal variations of the physical variables can lead to specific management of this stream. The purpose of this study was to understand the seasonal cycle of these parameters and to use them to support the management of water quality of this economically, ecologically and environmentally important agricultural watershed.

MATERIALS AND METHODS

Study site

The Mkondoa River runs through the Kilosa Estate, 6.8333° S, 36.9833° E, situated in the Kilosa District, Morogoro Region (Figure 1). Mixed crops of coconut, banana, vegetables and maize cover most of the area. The estate employs modern farming techniques using mechanical equipment, synthetic fertilizers, herbicides and insecticides to ensure optimal yields. The estate is currently testing seeds and farming methods to prove the viability of the project and to select the best methods for the estate to ensure optimal production when the farm is fully operational. These farm units, while supporting the development of the area, contribute to the pollution of the environment due to their effluents. The Mkondoa River drains the length of the Kilosa Estate and hence the impact of various activities on the watershed is expected in the area. The most upstream sampling station (SS1), located in a forested area where human impacts are minimal, was consequently selected as a reference site; the description of other sampling stations (SS2-SS5) is provided in Table 1.

Sampling design

Triplicate samples of physical water parameters were collected on a monthly basis at each station for four months from February 2015 to May 2015, covering part of the dry season (February to March) and part of the wet season (April to May).

Water quality assessment

Water quality parameters including pH, biological oxygen demand (BOD), dissolved oxygen (DO), and temperature were recorded *in situ.* Temperature (°C), BOD (mg l^{-1}) and DO (mg l^{-1}) were measured using a hand held salinometer (Model: YSI # 85/10 FT, USA), while pH was measured using a hand held pH/mV meter (Model: SX 711). Water quality index was calculated according to the Canadian Council of Ministries of the Environment Water Quality Index (CCME WQI) method (Canadian Conference on Medical Education (CCME), 2001).

Statistical analysis

Physical parameters, except for pH, were expressed as means ±SE for each sampling station; pH was expressed as median. One-way analysis of variance was used to test for differences between stations for each parameter. Multiple comparisons of means were done *post hoc* using Duncan's multiple range test (DMRT) (Zar, 2001) to distinguish the stations and sampling occasions that differed significantly from one another. Analysis of variance (two-way ANOVA) was used to test for significant differences between seasons and environmental variables. Relationships between environmental variables and water quality index were determined by a Pearson rank correlation test.

RESULTS AND DISCUSSION

Spatial distribution

The mean water temperatures ranged between 26.8±0.22 and 30.8±0.42°C (Table 2). There were significant differences in temperatures in both space and time ($p < 0.001$), as evidenced by ANOVA. The lowest temperature was recorded at Station SS1 and this differed significantly ($p < 0.001$) from the rest of the stations. The highest temperature was recorded at Station SS4 which is probably due to the heating effect as this station was devoid of forest cover.

Temperature, being one of the most important water physical parameter, is closely related to latitude, altitude and season (Shimba and Jonah, 2016). The significantly lower temperature recorded at Station SS1 was due to good cover by riparian vegetation at that station. Vegetation cover limits solar radiation reaching the water, thus contributing to minimal fluctuations of temperature

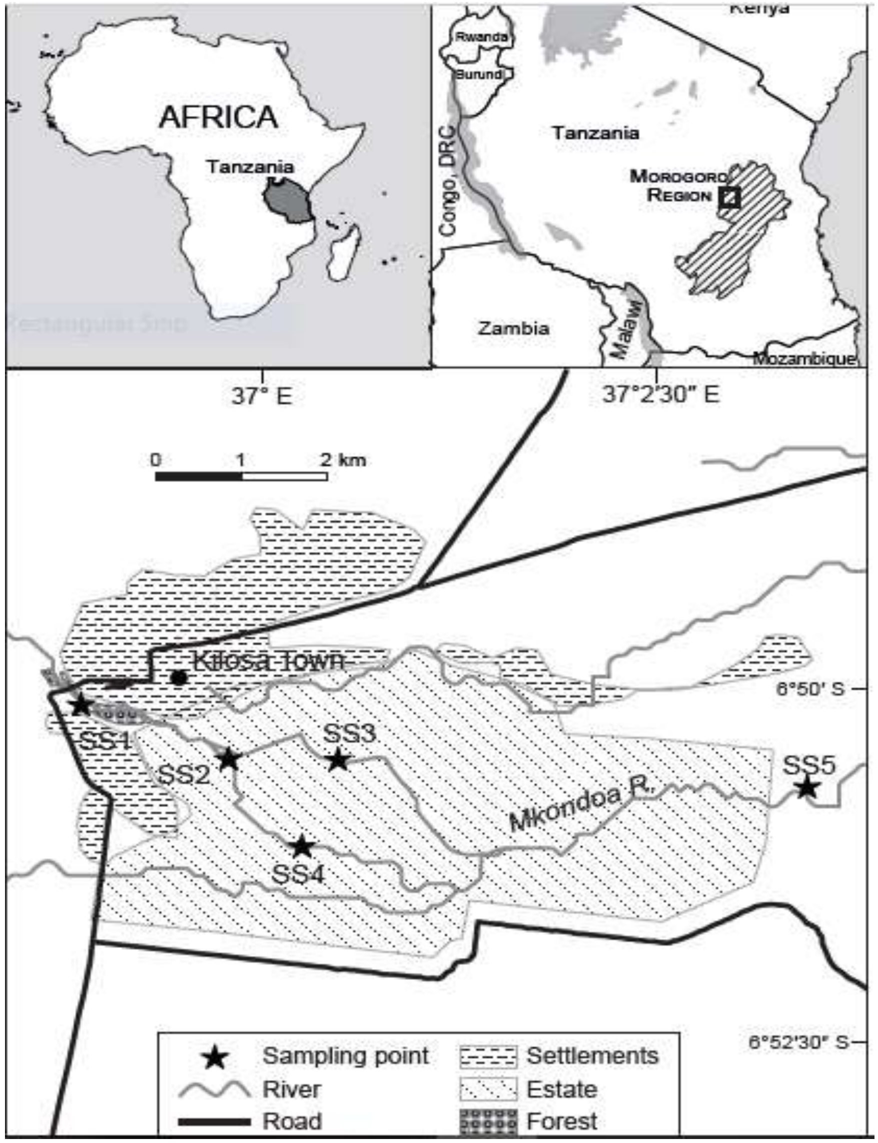

Figure 1. Map of the Mkondoa River, Kilosa, showing locations of sampling sites.

Table 1. Description of the sampling stations along the Mkondoa River.

Sampling station	Site description and land use in immediate catchment area
SS1	Reference site. The most upstream site, located in a forested area; minimal human impacts.
SS2	An area between upstream and midstream reaches. Cattle grazing along the river banks; cattle water drinking points.
SS3 and SS4	Midstream reaches. River banks devoid of forest cover. Areas of mechanized agriculture, intensive farming for beans, maize and vegetables; application of fertilizers, pesticides and herbicides.
SS5	Downstream reach. Eroded, devoid of vegetation; additional human impacts include washing, waste-dumping.

(Masese et al., 2009; Shimba and Jonah, 2016). The range of temperatures seen in Stations SS2 – SS5 was probably due to the heating effect of the sun. This conforms to the studies on other rivers in other parts of Tanzania, Karanga River (Elias et al., 2014) and Pangani and Wami Rivers (Kaaya et al., 2015).

Table 2. Mean (±SE) physical characteristics and median pH at the five study stations (SS1–SS5) on the Mkondoa River in February–May 2015.

Parameter	SS1	SS2	SS3	SS4	SS5
pH	7.30	7.60	7.90	9.00	9.04
Temperature (°C)	26.8±0.22	27.8±2.8	27.8±0.70	30.8±0.42	29.8±0.01
BOD (mg l^{-1})	2.83±0.50	3.05±0.78	4.332±0.65	5.856±0.75	7.98±0.57
DO (mg l^{-1})	7.023±0.76	5.762±0.58	3.587±0.89	2.340±0.87	1.284±0.44
Conductivity (µs cm^{-1})	147.0±0.97	454.0±0.89	590.0±0.78	638.0±1.84	680.0±0.49

The pH ranged between 7.3 and 9.04 (Table 2). The pH values varied significantly ($p < 0.001$) temporally, but not spatially. There was a general increase in pH values downstream the Mkondoa River. Generally, lower mean values of pH were recorded at Station SS1, and this may be due to its location on the upstream reach where there was high freshwater input which resulted in a low pH characteristic of surface water. Elias et al. (2014) reported similar observation where pH values increased downstream of the Rau River.

DO concentrations ranged from 1.284 to 7.023 mg l^{-1} (Table 2). There were no significant differences in DO concentrations between the sampling stations (p=0.214). The highest mean concentration of DO was at Station SS1 and the lowest at Station SS5. There was a gradual decrease in DO concentrations downstream the Mkondoa River. Changes in the water quality of streams can reflect increased nutrient loads associated with agricultural runoff (Emere and Narisu, 2007; Elias et al., 2014; Shimba and Jonah, 2016). In this study, the observed decreases in dissolved oxygen concentrations from SS1-SS5 indicated a potential increased organic load in the stream.

The lower mean DO concentration at Station SS5 was probably due to the location of that station. Station SS5 was located at the downstream reach just after the midstream reach where there were areas of mechanized agriculture, intensive farming for beans, maize and vegetables; application of fertilizers, pesticides and herbicides. The use of fertilizers at the midstream reach increased the runoff of nutrients such as phosphates and nitrates into the downstream. This increases the phytoplankton growth and subsequent decomposition processes when the phytoplankton die, resulting in low DO in the water column (Sullivan et al., 2010).

The concentrations of BOD were in the range of 2.83 to 7.98 mg l^{-1} (Table 2). BOD showed significant variation only with respect to time ($p < 0.001$). There was a gradual increase in BOD concentrations downstream of the Mkondoa River, with Station SS5 recording the highest mean concentrations. The BOD values were inversely related to DO values, suggesting that the decomposition of organic material by microorganisms has occurred. These results can be clearly observed in this study, where there was a progressive decrease in DO but a gradual increase in BOD downstream. The spatial differences in mean BOD along the river continuum could be explained by the ongoing anthropogenic influence which includes mechanized agriculture. The water in the upstream reaches of the river was clear. Sedimentation and accumulation of waste further downstream resulted in higher BOD values, reaching their highest levels at Station SS5. The water quality decreased with distance downstream, with the middle reaches exhibiting intermediate values. The lowest BOD values, obtained at Station SS1, could be attributed to low sedimentation as a result of minimal human impacts.

Seasonal variability

In general, lower mean temperature values were recorded during the heavy rainfall period, that is, the wet season (April – May). Values ranged from 26.8 to 27.8°C. In contrast, higher mean values (29.8 – 30.8°C) were recorded during the dry season (February – March) (Figure 2). This occurred because during the wet season, the weather conditions are usually cloudy and rainy resulting in cooler temperatures. This trend also occurred in other tropics rivers including Karanga and Rau (Elias et al., 2014), Pangani, Wami and Ruvu (Kaaya et al., 2015). The lower mean pH levels were recorded during the wet season (April-May) and higher pH levels in the dry season (February – March) (Figure 2). The recorded lower pH values might have been influenced by the agricultural runoff including fertilizers, pesticides and insecticides. These findings can be attributed to seasonal effects of non-point sources of pollution, which are mobilized during the rainy season through runoff and leaching, especially from agricultural areas (Kilonzo et al., 2014; Kaaya et al., 2015; Shimba and Jonah, 2016).

Lower mean DO concentrations were recorded during the wet season (April – May), ranging from 1.284 to 2.34 mg l^{-1}. Higher mean concentrations (3.587 – 7.023 mg l^{-1}) were recorded during the dry season (February – March) (Figure 2). Similar observations were also reported in East African Rivers, River Nyando (Raburu, 2003), Moiben River (Masese et al., 2009), Mara River (Kilonzo et al., 2014) in Kenya; Karanga and Rau Rivers (Elias et al., 2014), Pangani, Wami and Ruvu Rivers (Kaaya et al.,

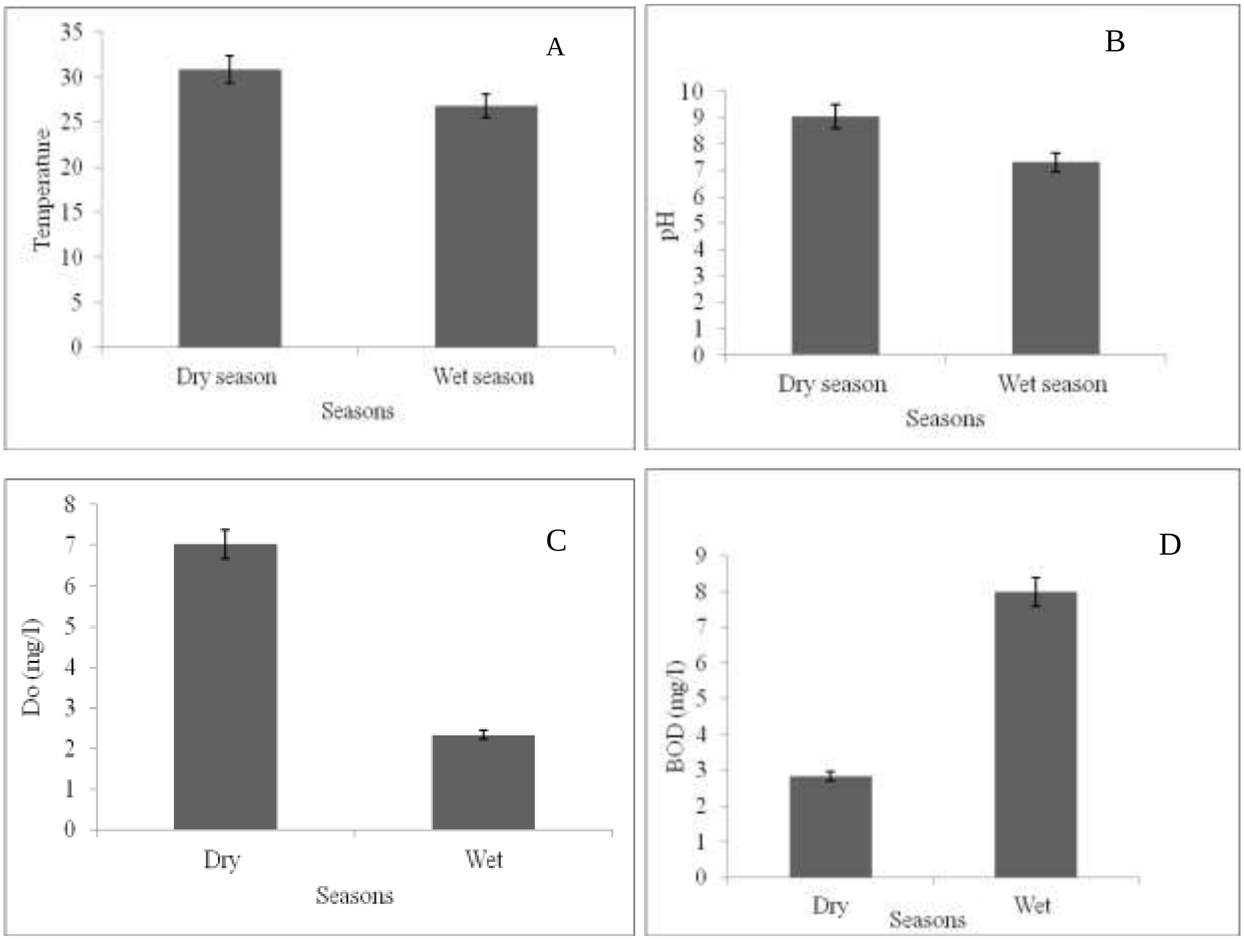

Figure 2. Seasonal variations of physical parameters (mean±SE) and median pH of the Mkondoa River in February–May 2015: A) temperature; B) pH; C) DO; D) BOD.

2015) in Tanzania. This relationship may be due to the flushing of organic matter and pollutants from land during the heavy rainfall periods associated with the wet season. The subsequent decomposition of this organic matter then results in low DO concentrations (Ruggieri et al., 2011; Wu et al., 2009; Kilonzo et al., 2014).

The highest mean BOD concentrations were recorded during the wet season (April-May) (Figure 2). During this period, the river was characterized by large quantities of suspended matter and high sediment loads. The recorded high levels of BOD were probably due to the washing out of organic materials from the land into the river catchment. This observation is similar to the study undertaken at the Nyando River (Raburu, 2003), Mara River (Kilonzo et al., 2014), in Kenya and Pangani and Ruvu Rivers, Tanzania (Kaaya et al., 2015) where the BOD concentrations were high during the wet season. An increase in BOD during the rainy season might have been caused by increased runoff, which transports organic matter and sediments from the catchment into the river (Morris et al., 2003; Masese et al., 2009). Conversely, during the dry season (February-March), lower mean concentrations of BOD (Figure 2) were recorded, suggesting that there were little or no movement of organic matter from the land.

Relationship between physical parameters and water quality index

Spearman's rank correlation was performed to assess the relation between physical parameters and water quality index (WQI) (Table 4). WQI was negatively correlated with temperature and BOD and positively correlated with pH and DO. WQI was lowest during the February dry period. It increased progressively with the onset of the rainy season, but started to decline during peak flows in May. During this period, the river was characterized by large quantities of suspended matter and high sediment loads. Based on WQI assessment, it was found that water quality was fair in the upstream reach of the Mkondoa, marginal in the midstream reach and poor in the downstream reach (Table 3). The water chemistry differed temporally with respect to most of the

Table 3. WQI values and its interpretation.

Stream reach	Water quality index	Water quality status
Upstream	77±0.98	Fair
Midstream	55±0.86	Marginal
Downstream	33±0.45	Poor

Table 4. Spearman's rank correlation between physical parameters and water quality index (WQI).

Parameter	Temperature (°C)	pH	BOD (mg l^{-1})	DO (mg l^{-1})
WQI – Upstream	-0.49*	0.38*	-0.59*	0.43*
WQI – Midstream	-0.58*	0.42*	-0.39*	0.46*
WQI-Downstream	-0.45*	0.37*	-0.45*	0.38*

*Significant correlation at p = 0.05.

parameters. All the physical variables showed significant variation between the dry and rainy seasons. These findings can be attributed to seasonal effects of non-point sources of pollution, which are mobilized during the rainy season through runoff and leaching, especially from agricultural areas (Masese et al., 2009; Kaaya et al., 2015; Shimba and Jonah, 2016).

Conclusion

The results suggested that the water quality of Mkondoa River is degraded towards downstream reach and might be impacted partly by agriculture. There was a negative effect of the ongoing agricultural activities, especially contamination of the surface water as shown by the decrease in water quality index (WQI) downstream. Low WQI values, lower concentrations of DO, which correspond to high BOD values, were found at stations located close to agricultural activities. In addition, attention must also be paid to the effects of seasons on the parameters measured, especially during the wet season where low DO, pH levels, but high BOD levels, were observed. This was thought to be due to the high run-off from the land. Future management should therefore consider long term monitoring of this river catchment as seasonal conditions will also influence the parameters measured.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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