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Assessment of Yatta Canal Water Quality for Irrigation, Machakos County, Kenya

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Abstract

Water is one of the most important global requirements for every activity in life but if it is polluted/contaminated, then it creates direct problems of alkalinity/salinity/toxicity through irrigation to agricultural farms and affects on the quality and nutritional value of cultivated crops. Water quality of Yatta Canal was studied from January to December, 2015 within Machakos County of Kenya. Twenty sampling stations were selected at an interval of 1 km along this canal and water samples were collected once in a month during the wet and dry seasons to monitor its suitability for irrigation. Annual average values of temperature, pH, total dissolved solids, turbidity, dissolved oxygen, and electrical conductivity show significant ($P<0.05$) seasonal variation. Annual average chemical concentrations of the water during wet and dry seasons are; Nitrates 13.1 ± 0.47 mg/l vs 4.8 ± 0.13 mg/l; Phosphates 0.02 ± 0.001 mg/l vs 0.02 ± 0.001 mg/l; Potassium 3.8 ± 0.098 mg/l vs 2.8 ± 0.031 mg/l; Sulphates 10.7 ± 0.31 mg/l vs 7.2 ± 0.25 mg/l; Bicarbonates 46.9 ± 1.20 mg/l vs 79.9 ± 2.06 mg/l; Chlorides 14.3 ± 0.59 mg/l vs 2.0 ± 0.10 mg/l; Sodium 14.7 ± 0.436 mg/l vs 17.7 ± 0.200 mg/l; Calcium 5.9 ± 0.124 mg/l vs 8.1 ± 0.058 mg/l; Magnesium 2.2 ± 0.020 mg/l vs 2.9 ± 0.029 mg/l, Sodium Adsorption Ratio 1.30 ± 0.030 me/l vs 1.35 ± 0.020 me/l and Iron 0.49 ± 0.007 mg/l vs 0.64 ± 0.041 mg/l respectively. These chemical parameters also show significant ($P<0.05$) seasonal variation. Most of the physical and chemical levels are within the permissible limits as recommended by FAO and also by Kenya's National Environment Management Authority with the exception of turbidity (100.2 NTU) and nitrate concentration (13.1 mg/l) only during the wet season. Based on the results, the canal water is safe for irrigation during dry season.

Keywords: Irrigation; Water quality; Yatta canal; Kenya

Introduction

In Kenya, rainfed agriculture is one of the main economic activities for the production of crops. Due to erratic rainfall in most of the arid and semi arid areas, the risk of crop failure is common within small scale farmers who suffer due to lack of water for irrigation. Wherever irrigation is possible, it is necessary to monitor the water quality in order to ensure sustainable crop yields. In dry season, high nutrient enrichment causes eutrophication which is the indication of toxicity in water bodies especially in small dams, canals or slow flowing shallow rivers due to seasonal water level fluctuations and high rate of evaporation in arid and semi-arid areas. Water quality shows current status about the concentration of various solutes at a given place and time [1]. The water quality parameters provide a basis for judging the suitability of water for its designated uses and to improve existing conditions [2].

Irrigation water quality is a key environmental issue faced by the agricultural sector [3]. Agricultural practices with agrochemicals result to chemical pollution of water bodies and over time cumulative effects lead to the depletion of water quality [4]. Sources of water pollution associated with agricultural systems include pesticides, insecticides, herbicides, animal dung/ manure, nitrates, phosphates and other chemical fertilizers, heavy metals, pathogens and sediment load. These pollutants cause potential ecological imbalances and direct health hazards to local people who depend on the water and products from agriculture [5,6].

This canal is a main water resource and the only single water supply for irrigation and domestic uses within the arid and semi-arid area of Yatta Constituency in Machakos County, Kenya [7]. During the pre-colonial era in December 1953, excavation of the canal from the proposed intake along Thika River began using Mau Mau detainees in order to supply water for domestic, irrigation and livestock use [8,9]. African Land Development Board (ALDEV) financed the construction and completed this canal for operation on 18th September 1959 [8]. Increasing demand for water due to population growth and agricultural activities has led to massive siltation in the canal over the years. This has subsequently reduced the flow rate especially during dry season [10]. Increased use and infiltration of agrochemicals, poor farming, and irrigation practices as well as rainfall variability has led to contamination of the canal water. Therefore, the study was conducted to analyze the levels of physico-chemical parameters to monitor the irrigation water quality of canal during wet and dry seasons.

Materials and Methods

Study area

Yatta Canal is 60 km long located between longitudes (0.80 W, 1.270 E) and latitudes (36.660 N, 37.100 S) at an altitude of about 1525 m above sea level in Yatta Constituency of Machakos County, Kenya (Figure 1). Main soil types are Acrisols, Luvisols, Ferralsols, Alfisols, Ultisols, Oxisols and Lithisols [11-13] of low fertility and many are highly erodible. Yatta Constituency covers land area of 1,057 Km^2 with 147,579 people [14,15] and experience arid climates due to erratic precipitation and has low agricultural potential due to frequent droughts.

About 70% population in Yatta depends on agriculture for their livelihoods and poverty level is 67.5% [14]. Most of the farmers practice

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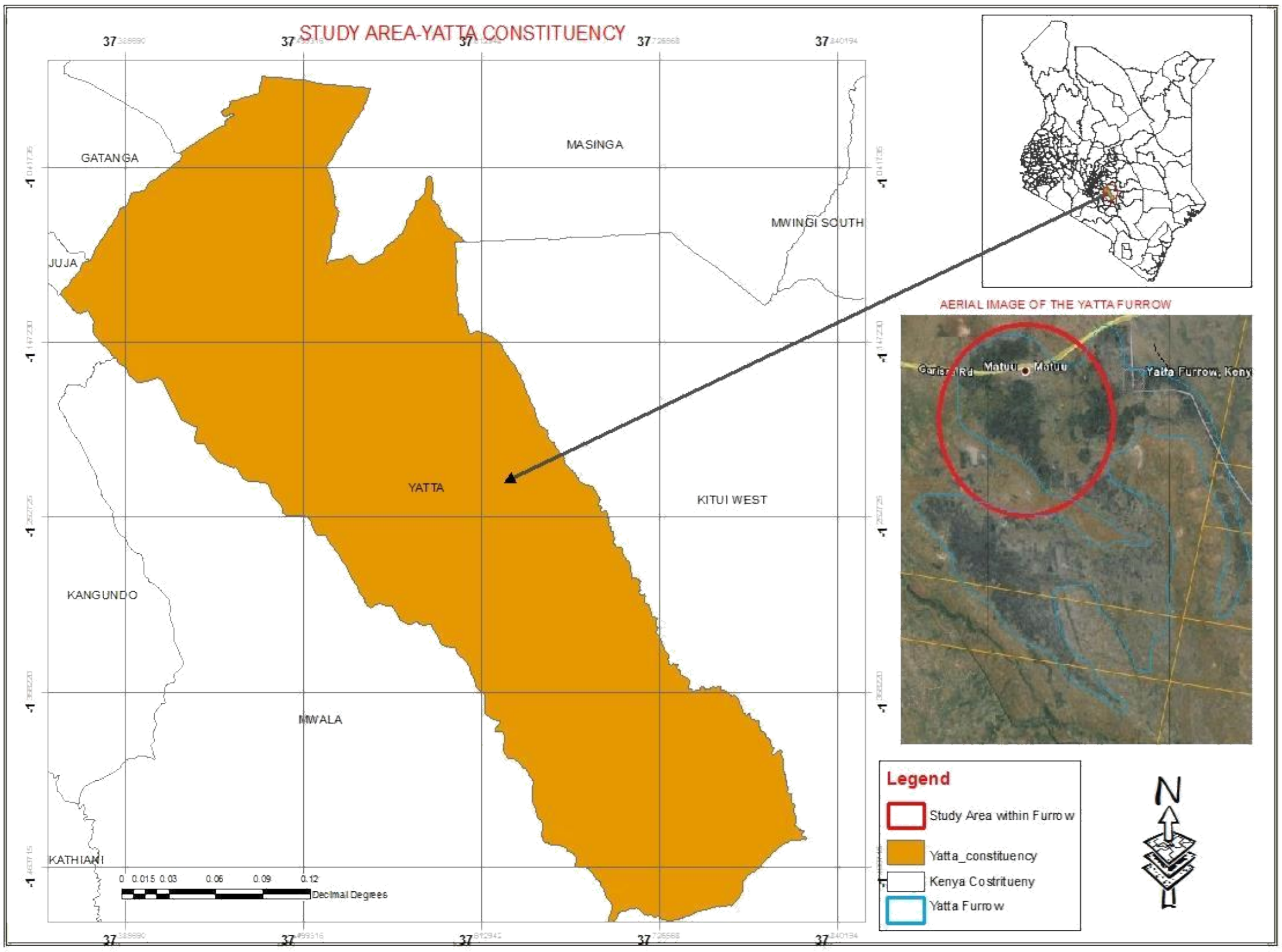

Figure 1: Map of Kenya shows Yatta Constituency in Machakos County, Kenya (Source: Machakos County Integrated Development Plan [15]).

small scale agriculture and cultivate during the short rains but use canal water for irrigation depending on the need. Main cultivated crops in this area are; *Zea mays* (maize), *Phaseolus vulgaris* (beans), *Pennisetum glaucum* (millet), *Sorghum vulgare* (sorghum), *Manihot esculenta* (cassava), *Mangifera indica* (mango), *Citrullus lanatus* (water melon), *Phaseolus vulgaris* L. (French bean), *Musa acuminata* (banana) and *Lycopersicon esculentum* L. (tomato). To supplement household incomes, people also practice cattle herding, poultry and bee keeping (Figure 1).

Data collection and analysis

Water samples were collected once in a month from twenty sampling stations along the canal at intervals of 1 km from the main intake (Figure 2) to analyze physical and chemical characteristics during wet and dry seasons of the year 2015. Systematic grid sampling method was used to identify the water sample collection points within mid depth of the canal. Prior to water sampling, the bottles were cleaned with 10% nitric acid and rinsed with distilled water. They were then rinsed three times with the canal water at the time of sampling. Water samples were collected midstream at the depth of 20 cm using a long-handled water scooper and filled in the 500 ml plastic bottles with screw caps. Samples for the analysis of metals were immediately acidified to pH value of 2.0 using reagent grade nitric acid to reduce adsorption of metals onto the walls of the plastic bottles [16]. The sample bottles were labelled, kept in an icebox, and transported for laboratory analysis within 24 hours of collection.

Water temperature and electrical conductivity were measured using a portable multi electrode water testing kit (Portable OakTon 510 series) equilibrated to 25°C while pH was measured using a calibrated pH meter. Dissolved oxygen was measured using an Oxygen meter while turbidity and total dissolved solids were determined using Turbidity and Digital TDS meters respectively. Major cations (Na^+, Ca^{2+}, Mg^{2+}, Fe^{2+} and K^+) were determined using Flame Photometer Model 410. Sulphates, nitrates and phosphates were measured using UV Visible spectrophotometer. Chlorides were determined by titration against $AgNO_3$ solution to pinkish yellow end point using K_2CrO_4 as indicator solution while HCO_3^- were determined by titrating water samples against H_2SO_4 to phenolphthalein and methyl orange indicator end points [17]. Paired t-test was done to compare variations in the average annual values of the physical and chemical characteristics of canal water during wet and dry seasons to note the significant differences at $p \leq 0.05$ level [18].

Results and Discussion

Physical parameters

The annual average values of physical characteristics of the canal water are mentioned (Table 1). Water temperature is between 21°C

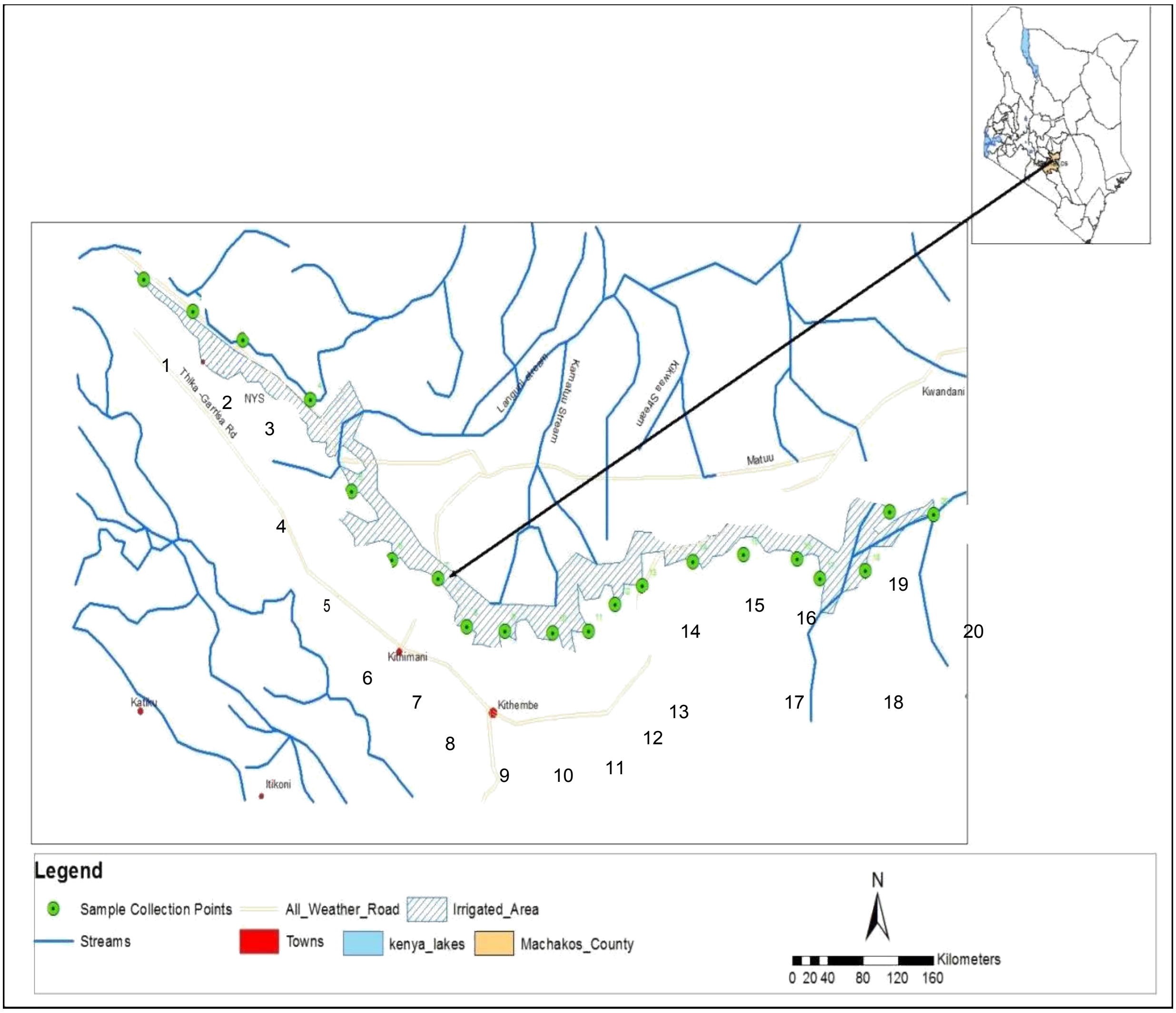

Figure 2: Map of study area shows sampling stations (1-20) selected along Yatta Canal flowing in Yatta Constituency of Machakos County, Kenya (January-December 2015).

to 24.5°C (mean value of 22.6 ± 0.19°C) during the wet and 24.8°C to 26.1°C (mean value of 25.4 ± 0.08°C) in dry seasons respectively. Using paired t-test, mean temperature values show significant seasonal variation (P=0.001, T=15.304). The canal water temperature is higher during dry than wet season due to slow water flow and increased solar radiation. Variations in water temperatures are influenced by land use changes, slow flow rate, intensity and duration of solar radiation and fluctuations in precipitation [19-21].

The pH values vary from 6.85 to 7.54 (mean value of 7.2 ± 0.04) during wet and 6.73 to 8.01 (mean value of 7.4 ± 0.08) in dry seasons. These levels however show significant (P=0.003, T=3.416) seasonal variation. The slight difference in mean pH value is due to dilution from rain water and the stirring effect of incoming surface runoff from streams and agricultural farms resulting in mixing of water in canal. High temperatures and decomposition of organic matter during dry season decrease the amount of dissolved oxygen but increase the amount of carbon dioxide which reflects on high levels of carbonates and bicarbonates to show high pH levels. Similar observation was reported in Jebba lake Nigeria [22].

During the study period, total dissolved solids exhibit wide variation between wet and dry seasons. Mean TDS values are 439.4 ± 8.41 mg/l during wet and 319.3 ± 8.10 mg/l in dry season. These values differ significantly (P=0.001, T=-30.452) across the sampling seasons. The concentrations are significantly high during wet season due to erosion of particulate matter and sediments from agricultural fields into the canal water. Similar results were also noticed due to surface runoff from agricultural farms along water sources [23,24].

Mean turbidity values of the canal water are 100 ± 3.41 NTU and 47.7 ± 5.51 NTU in wet and dry seasons respectively. Paired t-test shows significant (P=0.001, T=-7.60) seasonal variation during the study period. Low turbidity values during dry season are attributed to the slow flow rate which allows suspended particles and silt to settle. Poor cultivation practices, deforestation and soil erosion have also been identified as main factors that lead to increased turbidity and sediment loads in water sources [25].

Dissolved oxygen values are between 4.2 mg/l to 8.6 mg/l (average value of 6.6 ± 0.33 mg/l) during wet and 3.7 mg/l to 8.1 mg/l (average value of 6.0 ± 0.38 mg/l) in dry seasons. Paired t-test results show a

Sampling stations	Temp (°C)		pH		Total dissolved solids (mg/l)		Turbidity (NTU)		Dissolved oxygen (mg/l)		Electrical conductivity (dS/m)	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
1	22.4	26	7.36	7.37	435.7	300.0	105.2	45.7	8.0	8.1	0.16	0.17
2	22.1	25	6.97	7.18	416.3	279.3	108.1	30.5	7.5	8	0.18	0.16
3	21	25.2	6.85	6.95	402.0	277.7	86.1	25.9	8.2	8	0.17	0.12
4	21.7	25.2	7.0	6.73	390.0	272.3	71.5	24.4	8.5	8.2	0.16	0.12
5	21.9	24.8	6.94	7.02	388.1	290.4	103.2	26	8.6	7.8	0.16	0.13
6	21.4	25.2	7.17	7.3	391.0	303.0	123.7	23.7	8.6	8	0.16	0.16
7	22.3	25.4	7.23	7.22	406.3	284.0	122	25.5	8.0	7.2	0.16	0.14
8	22.5	25.9	7.18	7.26	413.3	335.3	114.4	63.6	6.9	4.2	0.16	0.12
9	22.5	26.1	7.16	7.43	428.0	318.0	84.7	41.3	6.6	7.3	0.16	0.12
10	22.3	25.5	7.28	7.45	434.3	304.7	108.7	41	6.2	6.7	0.16	0.12
11	22.4	25.1	7.41	7.43	432.7	312.0	119.6	46.7	7.2	6.4	0.16	0.12
12	22.3	25.2	7.47	7.4	434.3	303.0	92.9	31.2	6.4	5.7	0.16	0.13
13	22.6	25.1	7.28	7.24	462.3	304.0	103.4	30	5.8	5.5	0.16	0.13
14	22.8	25.1	7.16	7.46	457.3	316.3	98.4	28.3	5.7	4.7	0.16	0.12
15	22.8	25.1	7.14	7.57	460.7	336.3	101.7	42	5.3	4.4	0.16	0.12
16	22.8	25.3	7.07	7.87	470.7	354.7	80.1	73.4	5.4	3.7	0.16	0.12
17	22.9	25.3	7.15	8.01	475.7	359.7	76.9	83.2	4.8	4.5	0.16	0.13
18	23.6	25.5	7.33	7.99	473.7	363.3	86.2	88.4	5.0	4.1	0.17	0.13
19	24.5	25.3	7.54	7.97	502.0	383.3	106.0	91	4.4	4.4	0.17	0.16
20	24.5	26	7.45	7.78	512.7	388.7	111.6	91.3	4.2	3.7	0.18	0.14
Mean ± SE	22.6 ± 0.19	25.4 ± 0.08	7.2 ± 0.04	7.4 ± 0.08	439.4 ± 8.41	319.3 ± 8.10	100.2 ± 3.41	47.7 ± 5.51	6.6 ± 0.33	6.0 ± 0.38	0.16 ± 0.002	0.13 ± 0.003

Table 1: Mean annual Physical parameters of water collected during wet and dry seasons from twenty sampling stations along Yatta Canal (Jan-Dec 2015) in Machakos County, Kenya.

significant (P=0.006, T=-3.088) seasonal variation. Low levels of dissolved oxygen in the canal water are due to slow flow rate, low turbulence, low aeration, and longer exposure to solar radiation.

Electrical conductivity is between 0.16 ± 0.002 dSm^{-1} and 0.13 ± 0.003 dSm^{-1} in wet and dry seasons respectively and has significant (P=0.001, T=8.868) seasonal variation. The EC values depend on the amount of dissolved materials in water [26]. Higher electrical conductivity is noted in wet season than in dry due to leaching/infiltration of salts and nutrients. High chloride, phosphate and nitrate contents associated with agriculture increase electrical conductivity [27,28]. Variations in conductivity are due to slow flow rate, dissolved solids from agricultural farms, dilution by rainfall, ion exchange between sediments, water and submerged organic matter (Table 1) [29].

Chemical parameters

Annual average values of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{2+}, HCO_3^-, NO_3^-, SO_4^{2-}, PO_4^{3-} and Cl^- ions are presented in Table 2. Mean calcium value is 5.9 ± 0.124 mg/l during wet and 8.1 ± 0.058 mg/l in dry season. Using paired t-test, mean calcium values show significant (P=0.001, T=15.438) seasonal variation. Low levels of calcium are due to dilution during rainy season. Calcium levels in surface water are also influenced by the carbonate balance [30] and organic compounds contaminated with waste water [31] which enter water sources through mineral leaching.

Magnesium concentrations are 2.23 ± 0.02 mg/l and 2.88 ± 0.029 mg/l during wet and dry seasons respectively. The results show significant variation (P=0.001, T=30.301) across the sampling seasons. Magnesium is an essential micronutrient for chlorophyll and acts as a limiting factor for the growth of phytoplankton. Depletion of magnesium reduces phytoplankton population in aquatic ecosystems [32].

Sodium values are 14.7 ± 0.436 mg/l and 17.7 ± 0.2 mg/l during wet and dry seasons respectively. Water quality for irrigation is also determined by the absolute and relative concentration of cations. The proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in a water sample is expressed as SAR which is an important parameter to determine the water quality and responsible for the sodium hazard in irrigation water [33]. SAR values are 1.3 ± 0.030 me/l during wet and 1.35 ± 0.020 me/l in dry seasons. Sodium concentration increases in dry season and decreases in the rainy season due to dilution [34,35].

Potassium levels are 3.8 ± 0.098 mg/l and 2.8 ± 0.031 mg/l during wet and dry seasons respectively. Potassium levels are higher in canal water within wet season due to surface runoff and leaching from agricultural farms to the canal. Using paired t-test, the results show significant seasonal variation (P=0.001, T=-9.506). Potassium concentrations increase in water bodies due to salts and nutrients leached to the water table during rainy season [36].

Nitrate levels are between 3.5 mg/l to 5.8 mg/l during dry and 10.8 mg/l to 18.8 mg/l in wet season with average values of 4.8 ± 0.13 mg/l and 13.1 ± 0.47 mg/l respectively. Mean nitrate concentration shows significant (P=0.001, T=-20.723) variation across the seasons. High nitrate levels in the canal water are due to surface runoff and nutrient leaching from agricultural farms. The use of animal manure and nitrogen fertilizers result in considerable enrichment of surface soils and subsequent runoff contains relatively high levels of nutrients, organic matter and suspended particles during or after rains [37,38]. Nutrients get eroded into surface waters and elevate nitrate concentrations.

Phosphate levels in canal water are 0.02 ± 0.001 mg/l during both the dry and wet seasons and there's no significant seasonal variation. Phosphates in surface water arise from natural decomposition of rocks and minerals, weathering of soluble inorganic materials, decaying biomass, runoff, sedimentation, anthropogenic activities mainly fertilizers, waste water and septic system effluent, animal wastes, detergents, industrial discharge and surface construction [39,40] (Table 2).

Sampling stations	Ca^{2+} (mg/l)		Mg^{2+} (mg/l)		Na^{+} (mg/l)		K^{+} (mg/l)		Fe^{2+} (mg/l)		HCO_3^- (mg/l)		NO_3^- (mg/l)		SO_4^{2-} (mg/l)		PO_4^{3-} (mg/l)		Cl^- (mg/l)	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
1	6.61	8.12	2.32	3.03	18.1	17.2	3.80	3.09	0.52	0.45	53.3	81.4	14.2	5.33	10.5	6.25	0.020	0.018	18.5	2.60
2	6.42	8.16	2.35	3.08	17.7	16.9	3.74	3.08	0.51	0.40	48.3	76.7	14.6	5.37	9.97	6.15	0.019	0.017	17.7	2.48
3	6.71	8.15	2.23	2.90	17.4	16.1	3.57	2.95	0.48	0.37	40.8	73.7	10.9	5.17	11.0	6.02	0.019	0.022	17.5	2.38
4	6.71	8.18	2.22	2.79	17.0	16.1	3.76	2.83	0.48	0.45	44.7	62.5	12.1	4.99	12.1	5.90	0.019	0.019	15.4	2.32
5	6.58	8.10	2.17	2.71	16.6	16.3	3.80	2.82	0.50	0.47	48.6	59.2	12.4	5.13	11.8	5.84	0.018	0.021	15.0	2.19
6	6.67	8.08	2.18	2.63	17.0	17.1	2.85	2.87	0.50	0.53	51.4	67.6	14.5	5.13	11.1	6.0	0.018	0.021	12.3	2.23
7	6.09	7.97	2.25	2.68	15.8	17.2	2.86	2.81	0.51	0.60	48.5	71.5	12.2	4.92	10.7	6.45	0.021	0.02	11.2	2.20
8	5.40	8.19	2.13	2.89	14.2	17.3	3.47	2.84	0.49	0.57	42.9	76.0	11.2	4.55	9.35	6.66	0.021	0.018	11.3	2.18
9	5.49	8.28	2.26	2.91	14.1	17.6	3.68	2.75	0.50	0.60	44.4	79.5	11.0	4.23	8.8	6.80	0.020	0.018	11.2	1.88
10	5.83	8.43	2.35	3.03	13.9	17.3	3.61	2.80	0.47	0.61	49.3	81.0	13.3	4.04	8.6	7.07	0.019	0.02	11.2	1.78
11	5.67	8.38	2.34	3.06	14.1	17.8	3.49	2.75	0.48	0.61	46.9	83.6	12.6	3.83	9.3	7.14	0.018	0.019	10.7	1.84
12	5.35	8.33	2.27	2.79	13.7	17.8	3.65	2.76	0.48	0.62	41.7	86.8	11.8	3.53	9.9	7.20	0.018	0.019	12.3	1.44
13	5.21	8.35	2.10	2.80	13.1	18.0	3.72	2.74	0.47	0.62	36.7	83.3	11.3	4.07	10.4	7.29	0.019	0.023	13.0	1.41
14	5.19	8.41	2.13	2.85	13.2	18.4	3.83	2.74	0.46	0.67	40.4	84.2	10.8	4.48	11.0	7.27	0.016	0.022	13.5	1.44
15	5.34	7.86	2.13	2.82	12.9	18.5	4.13	2.72	0.46	0.75	44.5	83.7	11.4	4.83	10.5	7.40	0.012	0.024	14.5	1.48
16	5.42	7.76	2.10	2.85	12.3	18.6	4.28	2.75	0.47	0.77	48.4	83.5	12.1	5.02	10.3	7.43	0.013	0.025	14.9	1.60
17	5.70	7.66	2.15	2.82	12.4	18.8	4.02	2.73	0.47	0.80	46.6	88.0	14.6	5.10	12.0	8.44	0.014	0.026	15.1	1.47
18	5.92	7.45	2.20	2.85	12.6	18.5	4.37	2.74	0.51	0.89	47.6	90.5	14.9	5.08	10.5	8.74	0.015	0.022	15.3	1.46
19	6.12	8.07	2.31	2.97	13.2	18.7	4.41	3.09	0.58	1.02	53.2	91.2	16.3	5.52	12.3	9.35	0.018	0.024	16.4	2.35
20	6.42	8.21	2.37	3.07	14.0	18.9	4.48	3.12	0.55	1.01	60.6	93.1	18.8	5.80	14.5	9.60	0.016	0.026	19.1	2.54
Mean ± SE	5.9 ± 0.124	8.1 ± 0.058	2.23 ± 0.02	2.88 ± 0.029	14.7 ± 0.436	17.7 ± 0.2	3.8 ± 0.098	2.8 ± 0.031	0.49 ± 0.007	0.64 ± 0.04	46.9 ± 1.2	79.9 ± 2.06	13.1 ± 0.47	4.8 ± 0.13	10.7 ± 0.31	7.2 ± 0.25	0.02 ± 0.001	0.02 ± 0.001	14.3 ± 0.59	2.0 ± 0.1

Table 2: Mean annual chemical characteristics of water collected during wet and dry seasons from twenty sampling stations (1-20) along Yatta Canal in Machakos County, Kenya (Jan-Dec 2015).

Sulphate levels are 10.7 ± 0.31 mg/l during wet and 7.2 ± 0.25 mg/l in dry seasons. Using paired t-test, mean values show significant ($P<0.05$) variation across the two seasons ($P=0.001$; $T=-11.89$). Higher sulphate levels during rainy season are attributed to surface runoff containing organic fertilizers from agricultural activities along the canal. Discharge of industrial wastes, surface runoff and domestic sewage tend to increase sulphate concentration in surface water [41].

Chloride levels are 14.3 ± 0.59 mg/l during wet and 2.0 ± 0.10 mg/l in dry seasons. Results also show significant seasonal variation ($P=0.001$; $T=-22.458$). High concentration of chlorides during rainy season is attributed to addition of organic wastes of animal origin through surface runoff and use of pesticides on horticultural crops. Sewage water and industrial effluents are rich in Cl^- and discharge of these wastes result in high chloride levels in fresh water bodies/ wetlands [42].

Iron concentrations are 0.64 ± 0.041 mg/l during dry and 0.49 ± 0.007 mg/l in wet seasons and shows significant seasonal variation ($P=0.001$, $T=3.72$). Increased iron concentration in the canal water is attributed to organic matter addition and decomposition during the dry season.

Bicarbonate levels in the canal water range between 36.7 mg/l to 60.6 mg/l during wet and 59.2 mg/l to 93.1 mg/l in dry seasons with average values being 46.9 ± 1.2 mg/l and 79.9 ± 2.06 mg/l respectively. Mean values show significant seasonal variation ($P=0.001$; $T=14.857$). Higher concentration of bicarbonate at 79.9 mg/l and pH 7.4 during the dry season is attributed to decomposition of organic matter in the canal due to slow flow rate. Bicarbonate levels in water also depend on weathering process in catchments, rate of photosynthesis, respiration and organic decomposition in water [43].

During the study period, it was noticed that in wet season, average chemical concentration of potassium, nitrates, sulphates and chlorides are high due to excessive water erosion with chemical fertilizers from the agricultural farms into the canal due to gravity and rate of infiltration but it decreases in dry season due to exposure to solar radiation, oxidation and absorption by algal flora, peripheral swamp vegetation and presence of microphytes.

Conclusion

Based on the chemical analysis, Yatta Canal water is not soft due to chemical contamination especially nitrate which is more than recommended level. pH of canal water between 6-8 may be safe for irrigation but if it fluctuates too much, then it will be the cause of acidic / alkaline soils. In the dry season, water quality for irrigation is within local and international recommended levels [44,45]. It is recommended that farmers should not use large quantities of agrochemicals.

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