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Sea Water Intrusion and Surface Water Salinity and Its Influence on Irrigation Water Quality in Ramisi Area, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JMK, MMA and AC designed the study and wrote the protocol. Authors LMC and JBM wrote the first draft of the manuscript, managed the literature searches, analyses of the study, performed the structural equation modelling and discuss the conclusion. All authors read and approved the final manuscript.

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ABSTRACT

Cane growing is one of the major economic activities in Ramisi, Kwale County besides tourisms and fishing. Although Ramisi Sugar Factory has been defunct for long previously, it has been reinstated and now christened Kwale International Sugar Company Limited (KISCOL). Coast region experience erratic rainfall patterns and limited agricultural land ownership therefore rain fed agriculture is not suitable. The major rivers to supplement experienced unpredictable rainfall patterns in the region are River Ramisi and Mkurumudzi. However, river Ramisi is saline, highly mineralized and unsuitable for domestic and agricultural use according to this study. The river is also affected by seawater intrusion during high tides. KISCOL drilled 37 boreholes to bridge the

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water demand gap for its operations but the water quality is doubtful due to intrusion effects. The aim of the study was to determine the suitability of water sources in Ramisi in terms of salinity and contaminant levels, risk of salt water intrusion and microbial load. Water samples were purposefully collected from drilled boreholes, River Ramisi and Mkurumudzi then analyzed for organic constituent parameters (pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO) and electrical conductivity). The Physical parameters included; (Turbidity, total alkalinity, total hardness, calcium hardness, magnesium hardness, chlorides and salinity, free carbon dioxide, sulphates, metals) and microbial load using Standard Methods for the Examination of Water and Wastewater quality (21st Edition) at the Kwale Water and Sewerage Company laboratories in Kwale County, and at the Coast Water Services Board laboratories in Mombasa County. The pH of the water sources ranged from 6.5 to 8.5 with exceeding limits for conductivity, chlorides, TDS, turbidity (25 NTU) and TDS (1,237.6667 mg/l). Magnesium, Iron, Sodium and Potassium and nutrients were below the permissible levels for irrigation water. Thus river Mkurumudzi and groundwater sources are not at risk of sea water intrusion, but river Ramisi is suffering from the effects of sea water intrusion during high tides and is unsuitable for cane irrigation and probably any other crop. Most surface water sources were contaminated with total coliforms including *E. coli* hence not suitable for domestic use.

Keywords: Cane growing; rainfall pattern; water intrusion; heavy metals; contamination.

1. INTRODUCTION

Kenya's Gross Domestic Product (GDP) and per capital income depends on agriculture. Among the key agricultural activities is cane growing for sugar production. Kenya produces about 60% of sugar for her domestic consumption and the deficit is met by importing. The country, however, has the potential and capacity to produce sufficient sugar for local consumption as well as surplus for export. There has been a steady increase in the domestic sugar demand from about 460,000 tonnes in 1988 to about 730,000 tonnes in 1998 [1]. However, there is only a marginal increase in production within the same period with increase in demand. The government has adopted an economic policy of liberation, geared towards providing an enabling environment for greater investment in the sugar industry by both local and foreign investors. Among the foreign investors is Kwale International Sugar Company Limited (KISCOL), which re-established cane growing and sugar production factory at Ramisi in Msambweni district after the collapse of the former Ramisi Sugar Company in 1988 that had operated for 67 years.

A major challenge, however, is the limited agricultural land and availability of water as rain fed agriculture is not sustainable owing to erratic rainfall patterns. Koromojo Dam built to bridge the water requirements deficit for cane production served principally as a livestock watering point since 1988. River Ramisi draining the area has been found to be saline, highly mineralized and unsuitable for domestic and agricultural use [2,3] and is affected by seawater intrusion during high tides. The only fresh water tributary of the Ramisi is the Mkanda stream, while the other streams originate from regions of active volcanic activity [2].

The sandstones and shales over which the rivers flow dip to the South East lead to the groundwater directed by the bedding planes towards the Msambweni area [4]. Further, groundwater recharge on the beach at low tides leads to springs of freshwater discharging copious amounts of freshwaters into the sea [5]. Groundwater resources in coastal areas are always in danger of contamination by sea water intrusion [6]. Although a variety of chemical buffer reactions occur at the fresh/saline interface, mixing of the two is to a large extent a combination of physical processes that are accelerated drastically by nearby abstraction [1]. The likelihood of sea water intrusion is further increased by the highly porous nature of the underlying coral limestone formation and reduced rates of groundwater recharge as urban centres and roads are paved [5]. Therefore, safe yield of groundwater aquifers should allow acceptable levels of impact and protects the higher value uses that have a dependency on the water [7].

Salts in soil and/or water can reduce water availability to the crop affecting yields. Electrical conductivity (EC) or total dissolved solids (TDS) measure salinity of the soil water, directly affected by the EC of the irrigation water [8]. The infiltration rates are particularly sensitive to SAR and salinity [9,5] and soil solution SAR and salinity are closely linked to the SAR and salinity of the irrigation water [10]. Thus when salt levels are too high, salinity hazard may exist if salt accumulates in the crop root zone to a concentration that causes a loss in yield [11]. The microbial safety of water is of particular concern to effluent irrigation.

Previous studies in the area [12] have excluded the Ramisi area, concentrating on Tiwi, Ukunda and Msambweni parts of the Coastline. All these studies, except [13], expressed concern of imminent sea water intrusion and recommended that groundwater abstraction should be limited and further drilling controlled. As the more easily accessed surface water resources are already being used, pressure on groundwater is growing due to the availability of cheap drilling and pumping technologies and energy subsidies distorting decisions about exploiting groundwater [4]. The digging of unlicensed boreholes in the area coupled with massive over abstraction, has brought into focus the need for a sober look at the sustainable use of groundwater and hence the need for conducting this study.

Although groundwater exploitation has potential for boosting water supplies in Kenya, its use is limited by poor water quality, overexploitation, saline intrusion along the coastal areas, and inadequate knowledge of the occurrence of the resource [14]. Availability of water is critical to the overall success of KISCOL operations. It is for this reason that 37 boreholes were drilled to bridge the water demand gap. However, the suitability and quality of water produced from the bore holes for agricultural and domestic uses is uncertain. Therefore, this study was undertaken to assess the suitability of the KISCOL proposed water sources for sustainable domestic use and irrigation to produce the required volume of raw materials to fulfill the company's demands.

2. MATERIALS AND METHODS

2.1 Study Area Sampling and Sample Collection

Sampling was done at the KISCOL nucleus area, straddling 15,000 acres of land and bound approximately by latitudes 3.6° and 4.6° S and longitudes 38.6° and 39.6° E and running along the Indian Ocean. River Ramisi was sampled at three representative points. Koromojo Dam, on River Mkurumudzi, was also sampled to complete surface water analysis. 11 groundwater sources within 3 km of the Indian Ocean's shores, and also within the latitudes and longitudes described were sampled (Fig. 1). Surface water samples were collected beneath the surface in quiescent areas. The sampling container was opened beneath the water surface with the mouth directed toward the current to avoid collecting surface scum. Grab samples, as opposed to composite samples, was the only mode of sample collection. Water samples from boreholes were accessed through hand pumps that consumers utilize to draw water. However, for samples for microbiological analysis, sterilization of the draw-off points through heating with a gas stove was necessary. 1-Litre plastic sampling bottles were used for physico-chemical parameters and sterilized glass bottles for microbiological parameters using standard procedures [15].

2.2 Analysis of the Samples

2.2.1 Analyzed parameters

The pH, Biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO) and electrical conductivity were measured using digital probes and TDS estimated as (EC × 0.65) ppm.

2.2.2 Turbidity

Fuller's earth method was used to estimate turbidity. 100 mg of Fuller's Earth was suspended in 100 ml distilled water to give approximately 1,000 Jackson Turbidity Units (JTU). A set of dilutions of this standard were prepared to yield the desired turbidities in 10 ml volumes in test tubes and compared with water samples. 10 ml of well mixed sample was placed in clean test tube and compared with standards and visualized which standard was closest in turbidity to the water sample.

2.2.3 Total alkalinity

100 ml of water sample was measured in a conical flask and 2 drops of Phenolphalein indicator added to the water with the appearance of a reddish pink colour. The water sample was titrated with 0.02N Sulphuric acid until the pink tinge just disappears. 2 drops of the mixed

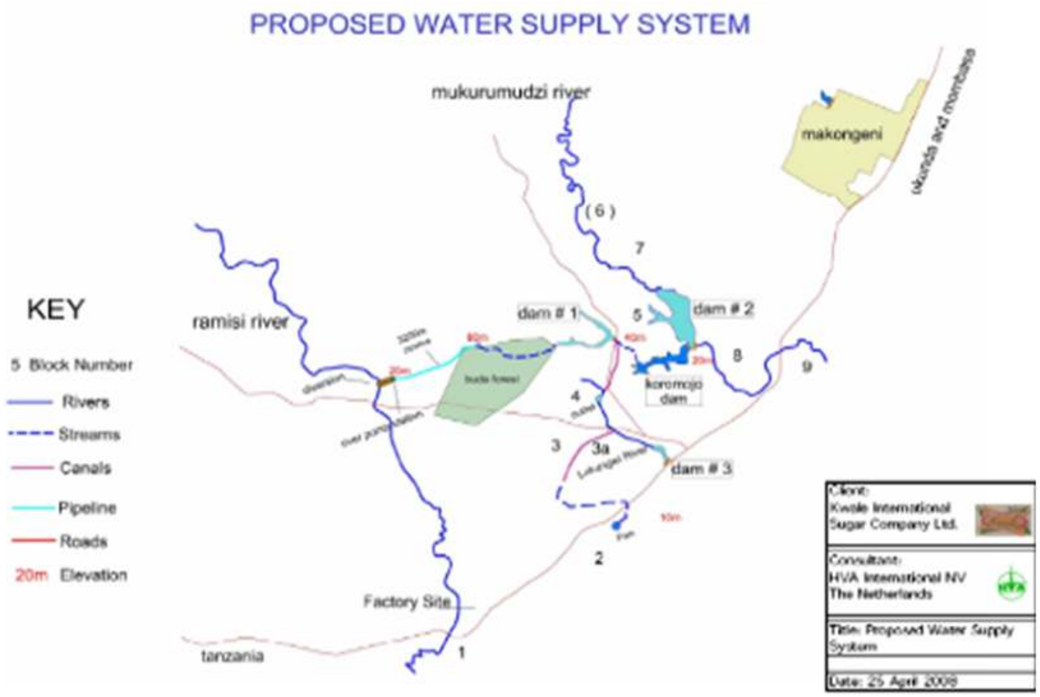

Fig. 1. Map showing a profile of Rivers Ramisi and Mkurumudzi and the proposed water supply network (KISCOL, 2010)

indicator was added and the sample further titrated until the pink tinge reappears. The total alkalinity was calculated using the formula below;

Total alkalinity mgCaCO3/l

$$= A \times B \times 50{,}000/\text{ml of sample}$$

Where: A = ml of acid used to final pinkish end point, B = concentration of acid.

2.2.4 Total hardness

The EDTA titration method was adopted for total hardness estimation. 50 ml of sample in conical flask will be mixed with 2 ml of buffer solution. 2 ml of Eriochrome Black T indicator was added producing a reddish colour. The water sample was titrated with 0.01M EDTA until the reddish tinge changes to a blue colour and total hardness calculated using the formula below.

Total Hardness $mgCaCO_3/l$

$$= A \times B \times 1{,}000/\text{ml of sample}$$

Where: A = ml of EDTA used, B = $mgCaCo_3$ equivalent to 1ml EDTA titrant

2.3 Calcium Hardness

50 ml of sample in conical flask was mixed with 2 ml of NaOH solution, 2 drops of Murexide indicator added to produce a pink colour. The water sample was titrated with 0.01 M EDTA until the pink tinge changes to a purple colour and calcium hardness calculated using the formula below.

$$mgCaCO_3/l = A \times B \times 400.8/\text{ml of sample}$$

Where: A = ml of EDTA used, B = $mgCaCo_3$ equivalent to 1 ml EDTA titrant

2.4 Magnesium Hardness

The hardness due to Mg^{2+} was simply calculated from values of Total and Calcium Hardness as follows; mgMg/l = [Total Hardness – Calcium hardness × 0.244]

2.4.1 Chlorides and salinity

50 ml of water sample was measured into a conical flask and 0.5 ml of K_2CrO_4 indicator solution added. The sample was then be titrated with $AgNO_3$ to a pinkish yellow end point.

Reagent blank value is established after the end point is reached and chloride concentration calculated using the formula below

$$mgCl^-/l = (A - B) \times N \times 35{,}450/ml \text{ of sample}$$

Where: A = ml of $AgNO_3$ for sample, B = ml of $AgNO_3$ for blank, N = Normality of $AgNO_3$
Salinity is calculated as a function of Chloride content as follows; $mgNaCl/l = mgCl^- /l \times 1.65$

2.4.2 Free carbon dioxide

Potentiometric titration to pH 8.3 was the method used. A suitable sample was peppered into titration flasks and pH measured. If pH was above 4.0 5-mL increments of 0.02*N* sulfuric acid were added to reduce pH to 4 or less, electrodes removed and 5 drops of 30% H_2O_2 added and boiled for 2 to 5 min. Cooled to room temperature and titrated with standard NaOH to pH 8.3. It was titrated to preselected end-point pH without recording intermediate pH values. As the end point is approached, smaller additions of NaOH were made ensuring that the pH equilibrium is reached before making the next addition. Calculation;

$$mg\ CO_2/L = A \times N \times 44000/mL \text{ sample}$$

Where: A = ml NaOH titrant used, B = normality of NaOH, C = ml H_2SO_4 used and D = normality of H_2SO_4

2.5 Sulphates

Turbidimetric method will be used to estimate the sulphate level. Sulphate standards of 5, 10, 15, 20, 25, ppm in 50 ml will be prepared from the stock solution. The turbidity of the sample and standards will be measured in the Nephelometer. To 50 ml of sample and standards, 2.5 ml of conditioning reagent will be added and stirred and while stirring, a spoonful of $BaCl_2$ crystals will be added. Solution will be stirred for further 60 seconds and turbidity measured once again for sample and standards. A calibration curve of Nepheloturbidimetric Units (NTU) against concentration of the standards will be plotted. The concentration of the water sample will then be deduced from the calibration curve using the formula;

$mgSO_4^{2-}/l$ = turbidity after addition of $BaCl_2$ – initial turbidity/ slope in calibration curve

2.6 Metals

Flame atomic absorption spectrometry was used. Standard solutions of known metal concentrations were prepared in water with a matrix similar to the sample. Standards that bracket expected sample concentration and were within the method's working range were used. For samples containing high and variable concentrations of matrix materials, the major metal species in the sample and the dilute standard was made similarly. If the sample matrix is complex and components cannot be matched accurately with standards, use was made of the method of standard additions. All data was reported as ppm metal (i.e. milligrams metal per litre). Samples were filtered prior to use and the sample aspirated into the flame. Since the spectrometer uses a different lamp for each metal to be analysed, complete analysis of one metal was done (calibration curve and duplicate sample measurements) before commencing analysis of another metal. Metals to be determined by AAS included Manganese, Iron, Sodium, Potassium and Calcium.

2.7 Microbiological Levels

The Petri film of *E. coli*/ Coliform Count Plate was placed on a flat surface. The top film was lifted, the pipette held perpendicular to the plate and 1mL of sample carefully dispensed onto the centre of the bottom film. The top film was rolled down onto the liquid, avoiding the entrapment of air bubbles under the top film. The plastic all-purpose spreader was oriented with the smooth side down (ridge side up) and placed on the top film over the liquid sample. The centre of the spreader was pressed gently to distribute the sample evenly while avoiding sliding or twisting the spreader on the film. The spreader was removed and the plate left undisturbed for one minute to allow the gel to solidify. Inoculated plates were incubated in a horizontal position (clear side up) at 35℃ for 24 hours. The plates were incubated for a further 24 hours at 35℃ to detect any additional *E. coli* growth.

2.8 Data Analysis

Analysis results obtained was compared against regulatory guideline values for irrigation water to draw inferences regarding their suitability for intended purpose. Raw data acquired in the study was analysed by the MS Excel's ANOVA function to obtain descriptive and inferential statistics.

3. RESULTS

3.1 Physical and Chemical Properties of KISCOL Proposed Water Source

The proposed water sources had fairly good physical composition, with most parameters tested falling within the regulatory limits cited by [16]. Most surface water sources had higher turbidities compared to their ground water counterparts (Table 1).

A few of the sources returned pH values just above or just below the 6.5-8.5 guideline values, but that is not a worrying feature for utilization of the sources. Turbidity values for Koromojo Dam, Kidzumbani Spring and Gonjora well exceeded the 25 NTU permissible levels for domestic water use. Other physico-chemical properties such as salinity and sea water intrusion have a significant bearing on the focus of the study.

Makambani Borehole slightly surpasses the 1,200 mg/l maximum permissible limit for TDS, while River Ramisi exceeds limits for Conductivity, Chlorides, TDS and therefore Salinity. All the other sources returned values within the bounds of the regulatory limits. Data analysis for conductivity returns a p-value of 8.43×10^{-5} and an F factor of 18.2 against an F critical figure of 4 indicate that both of these are indicative of highly significant differences between the EC of surface water and that of ground water. Surprisingly though, it is apparent that surface water salinities are much higher than ground water salinity.

3.2 Analysis of Metals

Analysis results for metals indicate that most water sources would have mostly trace amounts that would not exceed the regulatory standards stipulated by [16]. The Sodium Adsorption Ratio (SAR) figures were not calculated because most water sources indicated trace amounts that did not exceeds the regulated standards [16], although they are critical for irrigation water and within the scope of this study.

River Ramisi surpassed guideline values for Magnesium, Iron, Sodium and Potassium. Koromojo Dam, Kidzumbani Well and Gonjora Well also exceeded the maximum permissible value for Iron while both KISCOL boreholes exceeded the Potassium levels.

3.3 Hardness and Associated Parameters

This set of parameters was analysed to find out the levels of water hardness, alkalinity and free carbon dioxide. The Total Hardness and Total Alkalinity have a bearing on the scaling and utility of water in plant machinery.

Table 1. Physico-chemical properties of KISCOL proposed water sources

Sampling site	Physical parameter ± SE		
	pH	**Colour (Hazen)**	**Turbidity (NTU)**
Koromojo dam	7.6700±0.5380	71.6667±0.5380	125.0000±44.7886
Mkurumudzi river	8.4167±0.9804	63.3333±14.3433	4.3333±1.4343
Mkanda stream (Mkurumudzi)	8.4100±0.7162	33.3333±14.3433	2.6667±1.4343
Ramisi river (Upstream)	8.6300±0.8638	63.3333±28.6865	20.0000±15.1116
Ramisi River (Midstream)	8.7433±0.9954	81.6667±14.3433	34.0000±6.5729
Ramisi River (Downstream)	8.2800±0.0896	53.3333±7.1716	3.3333±1.4343
Ramisi River (Bridge)	8.2933±0.3308	51.6667±7.1716	4.6667±5.1715
Vidungeni Shallow Well	7.4400±0.2865	5.0000±0.0000	3.0000±2.4843
Kidzumbani Spring	6.6200±0.5599	196.6667±14.3433	80.0000±4.9687
Makambani Borehole	7.6633±1.1970	0.0000±0.0000	0.0000±0.0000
Milalani Pry School Borehole	8.5967±0.5645	10.0000±0.0000	0.0000±0.0000
Kingwede Borehole	8.3933±0.8349	1.6667±7.1716	0.0000±0.0000
Barabarani Shallow Well	7.2800±0.6300	30.0000±0.0000	0.3333±1.4343
Gonjora Well	6.7400±0.1629	367.0000±32.8645	70.6667±8.7247
Tuliani Borehole	6.4467±0.0379	0.0000±0.0000	0.0000±0.0000
KISCOL existing Borehole	7.5267±0.9571	0.0000±0.0000	0.3333±1.4343
KISCOL new Borehole	6.2400±0.0896	0.0000±0.0000	16.6667±8.7247
Kibaoni Shallow Well	8.6967±0.5743	0.0000±0.0000	0.0000±0.0000

Table 2. Physico-chemical properties of KISCOL proposed water sources

Sampling site	Physico-chemical property ± SE			
	Conductivity (µs/cm)	**TDS (mg/l)**	**Chlorides (mg/l)**	**Salinity (mg/l)**
Koromojo dam	276.6667±7.9860	170.4033±6.4857	45.6667±2.8687	75.3500±4.7333
Mkurumudzi river	264.0000±6.5729	166.3200±8.3904	35.3333±5.7373	58.3000±9.4666
Mkanda stream (Mkurumudzi)	404.6667±7.9860	250.1667±3.3465	79.0000±13.8321	130.3500±22.8230
Ramisi river (Upstream)	5,646.6667±127.4857	3,521.4833±14.9063	1,552.3333±87.3527	2561.3500±144.1320
Ramisi River (Midstream)	5,613.3333±94.0551	3,483.6800±73.8033	1458.6667±19.2969	2406.8000±31.8399
Ramisi River (Downstream)	35,300±496.8652	21,870.0000±390.4425	9193.3333±199.2630	15169.0000±328.7839
Ramisi River (Bridge)	33,733.3333±717.1631	20,826.0000±382.1988	10566.6667±379.4870	17435.0000±626.1536
Vidungeni Shallow Well	67.0000±8.9574	41.2633±2.9868	8.0000±0.0000	13.2000±0.0000
Kidzumbani Spring	52.0000±28.6506	25.0300±4.3935	7.6667±1.4343	12.6500±2.3666
Makambani Borehole	2,056.6667±287.9390	1,237.6667±6.2521	363.3333±14.3433	599.5000±23.6664
Milalani Pry School Borehole	495.0000±31.1285	304.0967±12.9088	18.3333±3.7949	30.2500±6.2615
Kingwede Borehole	590.3333±29.1136	363.0633±29.5227	19.3333±2.8687	31.9000±4.7333
Barabarani Shallow Well	272.6667±43.7646	171.0467±3.6245	75.3333±10.0403	124.3000±16.5665
Gonjora Well	65.6667±7.5897	39.1667±1.2922	7.3333±1.4343	12.1000±2.3666
Tuliani Borehole	512.3333±10.0403	314.8333±3.2659	134.6667±8.7247	222.2000±14.3957
KISCOL existing Borehole	415.0000±10.8289	228.1900±4.2802	32.3333±1.4343	53.35002.3666
KISCOL new Borehole	129.0000±16.2908	61.3067±3.0735	53.8767±9.4684	88.8965±15.6228
Kibaoni Shallow Well	812.3333±7.9860	501.5067±2.0913	75.3333±1.4343	124.3000±2.3666

Table 3. Analysis of metals of KISCOL proposed water sources

Sampling site	**Metallic property ± SE**					
	Iron (mg/l)	**Manganese (mg/l)**	**Calcium (mg/l)**	**Magnesium (mg/l)**	**Sodium (mg/l)**	**Potassium(mg/l)**
Koromojo dam	4.2130±1.0960	0.0167±0.0143	10.8000±0.8957	5.8233±0.5849	38.7000±0.8957	1.5333±0.7590
Mkurumudzi river	1.2400±0.2450	0.2000±0.0000	11.2000±3.5829	5.7833±0.2008	34.1333±2.2949	1.5000±2.2949
Mkanda stream (Mkurumudzi)	1.1300±0.3520	1.6333±0.9406	13.6000±5.2583	9.8467±0.3126	56.3333±1.1202	2.3667±0.5172
Ramisi river (Upstream)	1.2200±0.6330	0.0000±0.0000	74.6000±20.9318	0.0367±0.0379	1,206.4000±5.2348	17.3333±12.2549
Ramisi River (Midstream)	1.6570±0.9230	0.0000±0.0000	54.9333±42.4219	24.3933±0.2254	1,185.2333±26.711	14.3333±6.2521
Ramisi River (Downstream)	0.5330±0.4850	0.0000±0.0000	263.3667±48.8000	1,030.8±22.4920	5,910.6667±51.775	79.6667±3.7949
Ramisi River (Bridge)	0.7230±0.7280	0.0000±0.0000	305.5667±26.7366	650.203±66.072	5,949.0000±75.558	81.6667±7.1716
Vidungeni Shallow Well	0.3000±0.1140	0.0200±0.0000	3.6333±1.8646	1.8467±0.2308	6.3267±0.3569	0.7333±0.1434
Kidzumbani Spring	2.5170±0.3980	0.0533±0.0143	0.0000±0.0000	1.6433±0.6723	5.3300±0.4962	0.2667±0.2869
Makambani Borehole	0.0000±0.0000	0.0000±0.0000	53.0667±2.8794	73.0833±1.7864	260.0000±17.3903	1.4667±0.2869
Milalani Pry School Borehole	0.0000±0.0000	0.0000±0.0000	30.6667±0.6252	14.7033±2.2840	47.4667±0.2869	0.9667±0.7590
Kingwede Borehole	0.0000±0.0000	0.0000±0.0000	36.6667±2.1419	8.7700±1.0543	77.5333±2.7365	0.2667±0.2869
Barabarani Shallow Well	1.3970±0.9720	0.0200±0.0000	8.3667±0.5737	2.1800±0.5616	48.5333±0.1434	1.4000±0.2484
Gonjora Well	1.8670±0.6760	0.0000±0.0000	1.6000±0.2484	0.7200±0.4950	10.9667±1.1928	0.4000±0.2484
Tuliani Borehole	0.3600±0.7320	0.0000±0.0000	5.6333±0.8725	6.9400±0.2800	97.4667±4.3905	1.5667±0.6252
KISCOL existing Borehole	0.0000±0.0000	0.0000±0.0000	46.1667±3.7704	21.2367±0.3762	93.5000±5.5994	51.2000±18.2171
KISCOL new Borehole	0.1800±0.3230	0.5267±0.5178	13.6000±3.3607	0.7133±0.5249	65.8667±3.8833	32.6333±26.6754
Kibaoni Shallow Well	0.0000±0.0000	0.0000±0.0000	33.1000±8.1757	26.3967±0.5075	96.5667±6.0870	1.8333±0.1434

Table 4. Analysis of Hardness and associated parameters of KISCOL proposed water sources

Sampling site	Physico-chemical parameter ± SE		
	Total hardness ($mgCaCo_3$)	Total alkalinity ($mgCaCo_3$)	Free CO_2 (mg/l)
Koromojo dam	63.0000±23.6990	72.6667±12.5042	10.0000±0.0000
Mkurumudzi river	53.6667±6.2521	74.3333±5.1715	10.0000±0.0000
Mkanda stream (Mkurumudzi)	68.3333±21.4191	71.3333±10.3431	10.0000±0.0000
Ramisi river (Upstream)	179.0000±64.4490	643.0000±118.8588	0.0000±0.0000
Ramisi River (Midstream)	206.3333±43.1968	607.6667±83.5980	0.0000±0.0000
Ramisi River (Downstream)	4.0000±0.0000	3.0000±0.0000	8.5000±6.3527
Ramisi River (Bridge)	3.0000±0.0000	689.6667±141.8533	11.3333±2.8687
Vidungeni Shallow Well	15.6667±1.4343	15.6667±5.1715	9.3333±5.7373
Kidzumbani Spring	7.3333±2.8687	11.0000±6.5729	15.3333±7.1716
Makambani Borehole	436.6667±75.8974	391.3333±137.3662	24.0000±8.6060
Milalani Pry School Borehole	140.0000±24.8433	199.0000±57.8907	25.3333±10.3431
Kingwede Borehole	129.3333±2.8687	208.6667±98.6666	25.3333±10.3432
Barabarani Shallow Well	30.6667±7.5897	26.3333±16.5415	8.6667±2.8687
Gonjora Well	6.6667±5.1715	21.6667±8.7247	7.6667±1.4343
Tuliani Borehole	40.0000±17.9147	50.6667±22.4049	20.3333±8.7247
KISCOL existing Borehole	242.0000±19.7187	239.0000±21.2261	1.3333±2.8687
KISCOL new Borehole	19.6667±20.2337	16.0000±9.9373	2.0000±0.0000
Kibaoni Shallow Well	153.6667±72.6993	280.6667±97.5658	17.3333±5.1715

Except for River Ramisi, all the other sources fell within the limits stipulated under irrigation water quality guidelines. The high alkalinity recorded for River Ramisi at the bridge could be due to anthropogenic point source pollution from farmlands just before the bridge.

3.4 Nutrients

Analysis of nutrients expected to be in minimal amounts in the water sources at KISCOL was undertaken. While most of these nutrients might not have a critical bearing on the irrigation water, they could serve as an indicator of future trends.

Only River Ramisi returned Fluoride and Sulphate levels above the 1.5 mg/l and 2,000 mg/l permissible in irrigation water. All the other samples had levels of nutrients below the permissible levels for irrigation water.

3.5 Microbiological Analysis

The water sources proposed by KISCOL had a significant level of coliform bacteria. However, all the surface water sources had fecal coliform while in the ground water sources only Milalani Primary School Borehole and Tuliani Borehole were contaminated with fecal coliform (Table 6).

There were significant differences in coliform counts between the surface and ground water sources proposed by KISCOL ($p<0.05$). However, the surface water had an average coliform count of 432 per 100 ml (against the regulatory standard of 1,000 per 100 ml) and *E. coli* count of 290 per 100 ml (against the regulatory standard of Nil per 100 ml) attesting to less than desirable quality. Ground water sources returned better figures with an average of 19 per 100 ml coliform count and only 3 per 100 ml for *E. coli*.

4. DISCUSSION

Even though fifteen groundwater sources had been targeted in the project design, only eleven could be found within the 3km distance from the shore, which defined waters likely to be affected by sea water intrusion. To obtain meaningful data that can render clear insights into the status of the samples with regard to the levels of salinity obtaining, the raw data was clustered into groups of River Mkurumudzi, Upstream and Midstream River Ramisi, Downstream and River Ramisi Bridge at the A14 Lunga Lunga Highway and Groundwater.

Electrical conductivity and total dissolved solids are the major indicative chemical parameters for irrigation water salinity [11]. However, due to the observed differences in the nature of surface and groundwater sources, these two were treated separately in an effort to obtain more discernible inferences. Seven surface water and eleven groundwater sampling sites had three replicate analyses undertaken. From the data, it is apparent that salinity levels of groundwater sources approximate closely to those of River Mkurumudzi while there is a huge difference for figures between Upstream and Midstream River Ramisi and Downstream and River Ramisi Bridge. It is also discernible that only the River Ramisi figures exceed the irrigation water maximum guideline value for conductivity of 3000 µs/cm.

Table 5. Analysis of nutrients of KISCOL proposed water sources

Sampling site	Physico-chemical property ± SE			
	Fluorides (mg/l)	**Nitrates (mgN/l)**	**Nitrites (mgN/l)**	**Sulphates (mg/l)**
Koromojo dam	0.4333±0.7986	0.7533±0.1004	0.0767±0.0379	0.0000±0.0000
Mkurumudzi river	0.6333±0.5737	0.7033±0.2656	0.0000±0.0000	1.4667±0.1434
Mkanda stream (Mkurumudzi)	0.1667±0.1434	1.3567±0.2879	0.0000±0.0000	0.7000±0.4969
Ramisi river (Upstream)	5.4000±1.3146	11.9333±4.4186	0.0000±0.0000	9.8000±5.4486
Ramisi River (Midstream)	5.3333±0.7986	13.1667±3.4454	0.0000±0.0000	8.5667±4.3482
Ramisi River (Downstream)	1.3333±0.6252	56.6333±12.9812	0.0000±0.0000	570.0333±7.9511
Ramisi River (Bridge)	1.5000±1.0829	60.7000±8.1757	0.0000±0.0000	562.5000±6.8892
Vidungeni Shallow Well	0.1667±0.1225	0.3433±0.0379	0.0000±0.0000	0.0000±0.0000
Kidzumbani Spring	0.1833±0.0941	0.6167±0.1225	0.0500±0.0430	0.3000±0.0000
Makambani Borehole	0.3633±0.5342	5.5333±1.0040	0.0300±0.0000	34.4333±3.5944
Milalani Pry School Borehole	0.1833±0.1004	1.9667±1.8312	0.0200±0.0000	3.9667±1.0343
Kingwede Borehole	0.1433±0.0517	3.0667±1.2504	0.0200±0.0000	1.8667±1.1740
Barabarani Shallow Well	0.1300±0.0896	0.9267±0.1881	0.0000±0.0000	3.1333±0.6252
Gonjora Well	0.0967±0.0517	0.4300±0.0430	0.0500±0.0248	0.0000±0.0000
Tuliani Borehole	0.1700±0.0248	0.4900±0.3944	0.0000±0.0000	3.6000±1.5515
KISCOL existing Borehole	0.1600±0.0861	0.0333±0.0799	0.0000±0.0000	27.4667±4.8066
KISCOL new Borehole	0.1700±0.1291	0.0133±0.0143	0.0000±0.0000	35.0000±5.1695
Kibaoni Shallow Well	0.1333±0.0379	0.9000±0.0861	0.0000±0.0000	6.4000±1.0829

Table 6. Total and fecal coliform counts in KISCOL proposed surface and ground water sources

Sampling site	Mean coliform cont/100ml±SE	Mean *E. coli* count/100ml ± SE
Surface water sources		
Koromojo Dam	147.6667±103.2217	23.0000±0.0000
Mkurumudzi River	221.6667±47.2893	22.0000±8.6060
Mkanda Stream (Mkurumudzi)	119.3333±40.9976	8.6667±7.9860
River Ramisi Upstream	123.6667±56.9953	13.3333±12.2549
River Ramisi Midstream	435.3333±53.5908	436.6667±51.7154
River Ramisi Downstream	823.3333±37.9487	710.0000±49.6865
River Ramisi Bridge	1150.0000±124.2163	816.6667±37.9487
Ground water sources		
Vidungeni Shallow Well	5.3333±10.3431	0.0000
Kidzumbani Spring	5.3333±2.8687	0.0000
Makambani Borehole	11.0000±4.3030	0.0000
Milalani Pry School Borehole	81.0000±2.4843	15.0000±11.3846
Kingwede Borehole	4.3333±6.2521	0.0000
Barabarani Shallow Well	7.3333±12.2549	0.0000
Gonjora Well	7.3333±14.3433	0.0000
Tuliani Borehole	72.0000±2.4843	18.0000±12.9089
KISCOL existing Borehole	3.3333±2.8687	0.0000
KISCOL new Borehole	0.0000	0.0000
Kibaoni Shallow Well	10.0000±7.4530	0.0000

Considering the World Health Organisation standards as described by Bauder [17] and Ayer and Westcot, [11], it is evident that Ramisi River is an inappropriate source for cane irrigation. The minimum EC recorded was 5,613.3333 µs/cm for Midstream Ramisi River. This is way higher than the recommended limit of 3000µs/cm. With the maximum EC at 35300µs/cm downstream. Ramisi River should only be considered as a viable water source with interventions to radically alter its salinity levels. Further, there is a huge spike in EC as you approach the Indian Ocean (5,613.3333 to 35,300 µs/cm). This can only be explained as a factor of sea water intrusion on the river water, with sea water ingress being experienced during high tides.

As feared at the onset of the study, the data collected attests to very high salinity levels for River Ramisi. From results of the study, it is evident EC values are such that it is inconceivable that KISCOL would consider utilizing this source barring some expensive and time consuming amelioration interventions. The river salinity profile indicates that EC rise drastically 6-folds over a distance of 3 km between the Midstream and downstream sampling points. This drastic rise is indicative of the sea water intrusion that the river suffers from the Indian Ocean, particularly during high tides when the Ocean's water can visibly be noticed rising up the river.

Ramisi River and Mkurumudzi River are the only two surface water sources KISCOL intends to utilize for cane sugar production. Therefore, adopting EC as a yardstick for assessing irrigation water salinity (Ayer, 1985); it is clear that no challenges would emanate from the Mkurumudzi River and its dam, Koromojo. This is because the highest figure returned from the source was 404.6667 µs/cm from the Mkanda Stream, with a mean of 315 µs/cm overall. Both these figures are well below the maximum guideline value of 3000 µs/cm.

The inferential analysis sought to determine whether there are significant differences at 95% confidence level in EC and therefore salinity between the surface and groundwater sources. If significant, the differences can be interpreted to mean that their continued aggravation by avaricious abstraction by the Ramisi sugar factory could irreversibly affect the quality of the waters around the Ramisi area, and in particular its salinity, which is the prime focus of this study. This would mainly be due to sea water intrusion, and to a lesser extent as a factor of the resultant upsetting of the water balance.

Ground water characteristics of the area, salinity in particular, exhibit surprising traits indicative of what can be described as a desirable data set insofar as irrigation water is concerned. Not only are the indicators for salinity (EC and TDS) both depressed, they are less than figures for salinity of River Ramisi in the same locality. In fact, other than the Makambani Borehole the rest of the sources average 341µs/cm. It can therefore be said with authority, that the risk of sea water intrusion as a direct result of over abstraction of ground water is remote.

The salinity levels exhibited are so high that major and expensive interventions would be required to render the water available for the intended uses. Needless to say, this finding deals a major blow to plans by KISCOL to revive the cane plant. This is because the major reliance for water supply for domestic and irrigation uses was first surface sources, represented by Rivers Ramisi and Mkurumudzi, and groundwater as a supplementary source. Sea water intrusion was a concept studied in the project with regard to the potential for fouling up the Msambweni groundwater aquifer as a consequence of over abstraction of groundwater. The threat of sea water intrusion can thus be eliminated in the foreseeable future, even with the drilling of the 37 boreholes contemplated by KISCOL. This is good news for the proponent, considering the apparent low utility value of the Ramisi River as shown by analysis results.

From the observed levels of microbiological organisms, it can be safely concluded that the microbiological quality of the water does not present any challenge to the utilization of the various water sources for irrigation purposes. However, the water sources shall have to be treated before consumption for domestic purposes.

The source of water KISCOL intends to use is good in terms of microbiological contents (Table 6). The worst condition in this respect is again in midstream and downstream Ramisi River. This can be attributed to the socio-economic activities of populations straddling the River at this point in its migration to the sea. There is much more farming and settlement towards the Ocean than there is upstream, accounting for more river pollution.

5. CONCLUSIONS

The study disabuses some of the notions that were held at the outset, and also confirm some notions similarly held. The study results indicate that River Mkurumudzi does not suffer the adverse effects of overly saline waters, while River Ramisi is so saline as to render the waters unavailable for use in cane irrigation and other domestic utility. The study indicates that the prevailing EC numbers are so low as to lay to rest the fears of sea water intrusion on the Msambweni groundwater aquifer. The upshot of the study results suggests that KISCOL should concentrate on developing River Mkurumudzi, and its Koromojo Dam, and the groundwater sources for maximum utility in coming up with the huge volumes of water it requires. River Ramisi can only be utilized after certain interventions as recommended in the following discussion.

6. RECOMMENDATIONS

Salinity control through leaching to reduce the accumulated salts and adequate drainage to control and stabilize the water table is recommended which will help to maintain an acceptable crop yield. Consideration should be given to blending the poorer Ramisi River with the better quality Mkurumudzi River, groundwater supplies, thus increasing the total quantity of usable water available. Future research on the effects of groundwater abstraction from the 37 boreholes after KISCOL has started operating the sugar factory to shed light on the actual effects and not the interpolated effects is paramount. Determination of the interplay of the salinity dynamics between ground and surface waters, their effects on irrigation water quality, and how the two sources can then be utilized in different combinations/ratios to achieve optimal salinity levels for sugarcane irrigation may be a valuable area of research into this industry.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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