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Research Paper

IMPACTS OF JAMBO TANNERY EFFLUENTS ON QUALITY AND USABILTY OF SOLO STREAM WATER, BUSIA DISTRICT, UGANDA

Biwayo Yeku Wegulo and Mbeiza Mutekanga Norah

Biological Sciences Department,
Kyambogo University, P.O. Box 1,
Kyambogo.

Abstract

This research aimed at finding out the impact of Jambo tannery effluents on the physical and chemical parameters of Solo stream water. A total of 15 sampling sites were used during the wet season and during the dry season. The following parameters were determined: Calcium in mg/l, Magnesium in mg/l, Chlorides in mg/l, Chromium in mg/l, Dissolved Oxygen (DO) in mg/l, Biological Oxygen demand (BOD) in mg/l, Chemical Oxygen demand (COD) in mg/l, Turbidity in NTU, Total dissolved Solids (TDS) in mg/l, Total Hardness (TH) in mg/l, and Conductivity in µS/cm. The findings indicated that the tannery's waste water contributed greatly to the poor water quality of Solo stream water as the recordings after the tannery were generally higher than before the tannery discharge point. Chromium levels were negligible before the tannery but rose to far above the permitted levels at and after the tannery. Chromium was significantly different at tannery ($p = 0.005$) and after tannery ($p = 0.015$) at the 95% confidence level using the t test for the wet and dry seasons. BOD and TH were significantly different for the wet and dry seasons before tannery ($p = 0.040$, $p = 0.049$ respectively); at tannery ($p = 0.009$, $p = 0.052$ respectively); and after tannery ($p = 0.037$, $p = 0.049$ respectively). The water quality index averaged at 134.043 and 151.125 before discharge point and at 216.281 and 239.015, after the point of discharge for wet and dry seasons respectively. The Solo stream water did not meet the recommended standards by WHO and ICMR, in terms of different parameters and so was not suitable for use in agriculture, fisheries and domestic consumption. The water quality index values showed that the Solo stream water needed treatment before any form of use. There is therefore need for urgent intervention strategies by all stakeholders in order to alleviate the inevitable consequences of water pollution.

Key words: Stream, Tannery, Effluents, Water Quality, Water use.

INTRODUCTION

Fresh water is of vital concern for mankind and is directly linked to human welfare. The global intake of water is doubling every twenty years and water consumption increasing at a rate twice the population with an estimated 3 billion people to have no access to clean water by 2025 [1]. There has however been widespread degradation of fresh waters due to growing pressure from population growth, need for economic development, climate change and unabated harmful waste disposal. Clean water supplies are therefore continuing to diminish yet safe water is a prerequisite for healthy living, sustainable socio-economic development and conservation of biodiversity. Severe organic pollution is already affecting around one in seven rivers across Latin America, Africa and Asia [2]. Uganda is no exception, and water pollution continues to be on the rise following unchecked industrialization which has led to disposal of wastes into lakes, rivers, streams and swamps, more so in the urban areas. Un disputed however, is the fact that the aspect of water quality is important in agriculture, industry and tourism. When plants are irrigated with polluted water, the pollutants may contaminate the plants and become carried through the food chain [3]. This contamination can also happen in fishes and other animals dependent on such water. Polluted water may spread diseases or even cause death to farmers working in the contaminated water [3].

Uganda with a total land area of 241,550.7 km^2 has 41,743.2 km^2 as open water and swamps, and 199,807.4 km^2 as land, [4]. Fresh water lakes occupy 36280km^2 (15%) [5], with water being used for domestic consumption in rural and urban areas, in industry, agriculture, wildlife, recreation, transport, and power generation. In addition to the above, the open water bodies and wetlands are home to a diversity of organisms including fishes [5]. These surface water bodies are unfortunately under severe environmental stress due to threats posed by development pressure.

Rivers and streams are increasingly becoming sinks for wastes, yet with little or no regard of their assimilative capacities, natural purification capabilities and the organisms therein. Very rarely is there integration of ecosystem capacity into decisions about development.

While Uganda is striving to revive its industrial sector, it is doing poorly in taking care of its environment. This development is not matched with upgraded infrastructure as it requires large public sector investment [5], especially with regard to waste water treatment. The release of untreated waste water and effluents into water bodies, with either inadequacy or non-existence of surface water quality protection measures and sanitation and/or gaps in its implementation is a big challenge.

Tannery activities in Uganda

The leather industry has increasingly been recognized as an area of great economic potential [6], thereby igniting the zeal of the Ugandan government to ensure maximum exploitation of the potential inherent in the sector. This has resulted in formation of partnerships and formulation of policies to enhance the development of the leather industry. However, like many other countries in sub-Saharan Africa, Uganda is faced with the challenge of sustainable management of its tannery industries, as these have relocated to sub-Saharan countries due to strict environment protection laws in industrialized countries while demand for leather products has been increasing [7]. In Uganda, environment laws are present but are not effectively implemented or enforced.

Concerns about disposal of wastes from tannery industries have been high, with [7] reporting the need to regulate tannery industries for protection of public health and environment. Satisfactory intervention by the government or local authorities is yet to be seen [5]. These mostly use chrome tanning, leading to production of potentially environmentally dangerous wastes like sulphides, chlorides, ammonia, sodium and highly toxic substances such as trivalent chromium salts [7]. Many of these are deemed carcinogenic and need to have restricted dumping or undergo vigorous waste management processes for complete elimination. Beyond the waste chemicals, the tanneries produce excessively bad odour which becomes worse in the dry seasons. Unfortunately, these waste chemicals are mixed with water and then discharged into the lakes, rivers, and wetlands thereby aggravating the water quality of such systems [8][9][10]. The [6] asserted that the handling of the Chromium wastes involved precipitation of the Chromium salts and then burying them in plastic bags. This was also reported by [10], for Jinja district tanneries. This, however, is so disastrous and highly risky as chromium can over time seep into the deeper underground water wells causing pollution of the underground water sources. According to [7] a single tannery can cause pollution of ground water around a radius of 7-8Km and even beyond.

Jambo tannery and Solo stream.

Jambo Tannery (U) Limited, the tannery on which this study focussed, is located in Solo A village, Busia Municipal Council Industrial Area, in Busia District (Uganda) at GPS coordinates N 00.2840° and E 034.4965° [11]. The tannery was established in 2006. The tannery is within the 100m stretch of the stream valley. It is bordered by settlements to the South and East, Solo stream to the North and abattoir and settlements to the West. See figure.1 below.

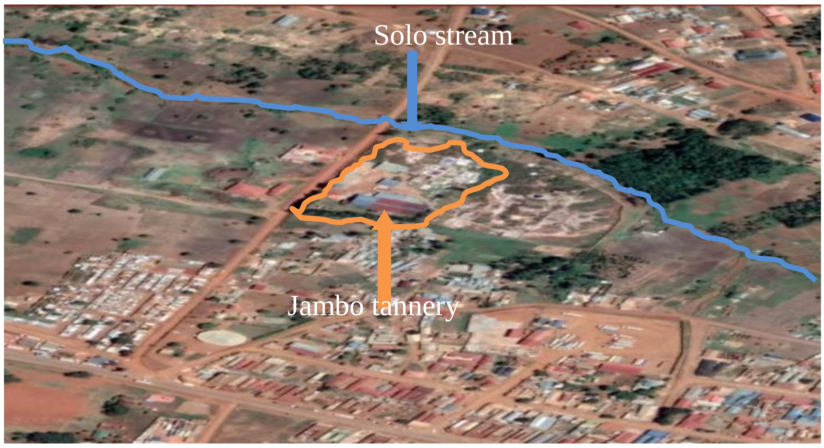


Figure 1: A satellite imagery showing the study site. Source: Google satellite images.

Just like other tanneries in Uganda, Jambo tannery uses chromium salts in the tanning process which provide an effective way of unhairing the hides. The hides and skins undergo hide and skin storage (sorting, timming, curing, storage) and beam house operations (soaked, unhaired, limed, fleshed, split), tarn yard operations (de-liming, bating, pickling, and tanning), post tanning operations and finishing operation (Summing, setting, splitting, shaving, retaining, dyeing, fat liquoring and drying) [11]. The wastes generated by the above processes undergo treatment in a series of processes among which include, sedimentation, oxidation, and clarification, sludge drying bed, second oxidation pond and maturation for the beam house and chromium lines [11] and then discharged into the Solo stream. The pattern of discharge in the past was a continuous process. This has changed to occasional discharge, which follows the occurrence of heavy rains and hence storm water discharge is not done during periods of drought.

Solo stream (over 20km long) is of great significance and any upheavals in its state has direct implications to the communities living along its banks. The lives of the people have for generations been dependent on this stream for recreation, domestic water supplies, fishing, livestock farming, small scale irrigation and general farming in its valley [12]. The stream has its mouth close to Busia central market, and here, the drainage channel of the market enters the stream. It then flows through Dabani, Sikuda, Bulumbi, and Busitema Sub-counties via West-Bugwe forest reserve. The water volume upstream is generally low, and gradually increases downstream as other water channels start to drain into the stream. The stream is devoid of its natural riparian vegetation, these being replaced by gardens, except for a few points along the stream's course. The basin of the stream is too open and exposed. The Solo flow is characterised by formation of small pools of stagnated water. The underlying sediment has a dark colour that is characteristic of the wastes discharged. The soil type of the basin alternates downstream between light and heavy clay, though heavy clay is predominant.

Fears over community health due to Jambo tannery have always been tense, as it was implicated in the deaths of hundreds of cattle and baboons in West Bugwe forest [13]. The tannery was later temporarily closed following accusations by National Environment Management Authority (NEMA) and locals that it had discharged dangerous chemicals into Solo stream. It was however later re-opened following an agreement between its management and NEMA to rectify the problem [13]. Against the backdrop of growing demand by the communities for relocation, NEMA in April, 2012 defended the tannery, asserting that it was not the major cause of pollution but just a 'contributor', citing the washing bay, sewage from the town and encroachment by residents as other sources. NEMA indicated that the tannery had taken measures to treat and separate chemical waste from the rest of the effluents before discharge into the stream [14]. Nevertheless, in August 2012,[11], reported that the effluent quality was by that time not suitable for release into the stream so that the water could be used for Agricultural and Domestic purposes, as per NEMA Standards of 1995. No follow up of the above findings has been done and yet the factory is still operational. This research therefore sought to provide clarity given the contradictions in the aforementioned publications.

Legal framework in Uganda.

A number of policies and laws that relate to tannery and chemical management are present in Uganda. [7] outlines several of them, a few of which are reviewed here.

According to the constitution of Uganda,1995, the government of Uganda is tasked to take all measures to prevent damage to land, air and water resources due to pollution or any other form of natural resource degradation, and to ensure good water management systems at all levels. As embraced in article 39, every person has a right to a clean and healthy environment, and article 245, demands that parliament provides measures to protect and preserve environment from abuse, pollution and degradation, manage the environment for sustainable development and promote environment awareness. Some of the prominent and notable laws include;

The National Environment Management Policy, 1994 which emphasizes clean economic development, providing protection to the environment and other forms of natural resources from any forms of degradation.

The National Environment Act, Cap 153: This act bars unauthorised discharge of any form of wastes into the environment, except for that inspected and seen to meet the established National standards. The act is supposed to charge those who deal in or produce any form of environmentally dangerous wastes to treat them, so as to ensure environment security. NEMA is charged with issuance of the standards and guidelines to protect the environment.

Other laws include, the Agricultural Chemicals Act, No. 1 of 2006; which controls and regulates the manufacture, storage, distribution and trade in, use, importation and exportation of agricultural chemicals and other related matter; Investment Code Act Cap 92, which demands that all possible measures are taken to ensure that the activities of the enterprises do not harm the environment.

It is apparent that there are many Ministries and a plausible legal framework in Uganda, enough to curb environmental pollution for healthier living of citizens, yet pollution seems to be unstoppable. This is thus suggestive of poor implementation. This has made the case of Jambo tannery dire, hence need for this study.

The **specific objectives** were to:

1. determine the physical and chemical parameters of Solo stream water before, at and after the Jambo tannery
2. relate the physical and chemical parameters obtained to the suitability of the Solo stream water for use.

MATERIALS AND METHODS

Study area:

The study was based on the upper stream, an area 1.5km long from point of co-ordinate N0°28'28.926"E34°4'58.716" to N0°28'49.008"E34°4'23.886". The stream lies in a wide and deep valley though with a gentle slope. The tannery is just adjacent to the stream with a separation of approximately 30m, at a point where it discharges its waste water into the stream. The surroundings to the stream are farmlands and settlements on either sides of the valley, and the stream basin is open, with little or no riparian vegetation as reflected in figure 1.

Sample collection and analysis.

Two sets of samples were collected, one during the dry and the other during wet/rainy seasons between the month of December and January, in order to establish seasonal variations. Caution was taken, ensuring that the samples were collected at a depth of not more than 15 cm, to target the surface waters specifically. A total of 15 sampling sites were chosen along the 1.5km stretch of the stream. These were taken systematically at 100m intervals after the tannery to allow for the possible occurrence of natural purification of the water and hence examine the pattern of changes in the water quality parameters downstream. However, the first sampling point was approximately 150m before the tannery's discharge point (the control), while the second sampling point was at the point of discharge.

The water samples collected in clean plastic bottles were wrapped in black polythene, to prevent any effect of light on the water parameters to be analysed and taken to Uganda Industrial Research Institute laboratories (UIRI - Kampala) in a cool box for analysis. Temperature and dissolved oxygen were determined onsite using hydro lab.

Turbidity was determined using the turbidity meter; TDS by the gravimetric method while pH was determined using the pH meter. Total Hardness (TH) and Chloride by titration method; Magnesium by subtracting calcium hardness values from total hardness values; Calcium and Chromium were determined using the Atomic Spectrophotometer; Conductivity using the conductivity meter.

Bio chemical Oxygen Demand (BOD)

50ml of the water samples were taken into 1 litre flasks and diluted. Three bottles were rinsed with the diluted samples and then filled with the diluted sample. The bottles were stoppered immediately. The initial dissolved oxygen levels were determined for one bottle and the others incubated at 20°c for 5 days. After the 5 days, the final dissolved oxygen levels for the water samples were determined

$$\text{BOD, mg/l} = \frac{(\text{Initial dissolved oxygen} - \text{final dissolved oxygen})}{\text{Volume of sample diluted.}} \times 1000;$$

Chemical Oxygen Demand (COD)

To 50ml of the water sample were added 10ml of 0.25N potassium dichromate followed by a pinch of silver sulphate and Mercury sulphate. The mixture was acidified with 1M sulphuric acid. These were then refluxed in the COD digester. 50ml of distilled water together with the above reagents were also refluxed in the same way. After reflux, the contents were cooled to room temperature (26°c) and then titrated against 0.1N ferrous ammonium sulphate solution. The volume of ferrous ammonium sulphate used was recorded and COD calculated as below.

$$\text{COD, mg/l} = \frac{(\text{volume of FAS for blank} - \text{volume of FAS for sample})}{\text{50ml of sample.}} \times 0.1 \times 8 \times 1000$$

Water quality index (WQI) for categorizing water.

There are different methods used for calculating the water quality index. The method adopted here is the Weighted Arithmetic Water Quality Index method (WAWQI), and its ratings. This study considered; total dissolved solids, magnesium, calcium, chloride, biological oxygen demand, dissolved oxygen, pH, total hardness, conductivity and turbidity.

WQI was calculated as follows:

$$WQI = \frac{QnWn}{Wn}$$

Qn being quality rating of n the water quality parameter,

Wn being unit weight of n the water quality parameter

Quality rating (Qn) was calculated as follows:

$$Qn = \frac{(Vn - Vid)}{(Sn - Vid)} \times 100$$

Where:

Vn is estimated value of n^{th} water quality parameter for a given sample.

Vid is the ideal value of n^{th} parameter in pure water, that's, 0 for all other parameters apart from pH (7.0) and Dissolved oxygen (14.6 mg/l); and

Sn as the standard permissible value of n the water quality parameter.

The unit weight (Wn) was calculated as follows:

$$Wn = \frac{K}{Sn}$$

Sn being the standard permissible value of n the water quality parameter.

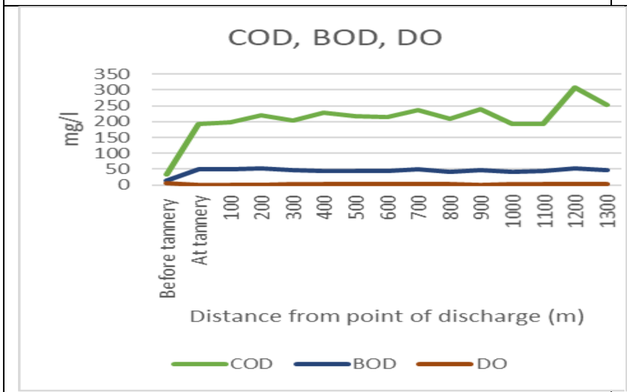
K being the constant of proportionality calculated as follows:

$$K = \frac{1}{(1/Sn)}$$

RESULTS

Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO).

Wet Season	Dry Season



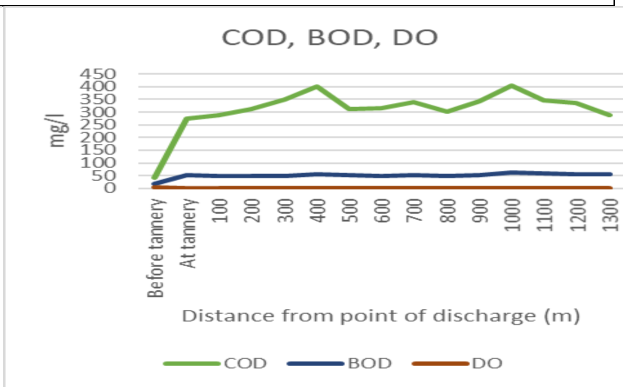


Figure 2: Graphs showing variations in COD, BOD and DO for the dry and wet seasons.

Generally, the upper stream waters before point of discharge had higher DO levels of 4.9mg/l and 5mg/l for dry and wet seasons respectively compared to the DO levels after the point of discharge.

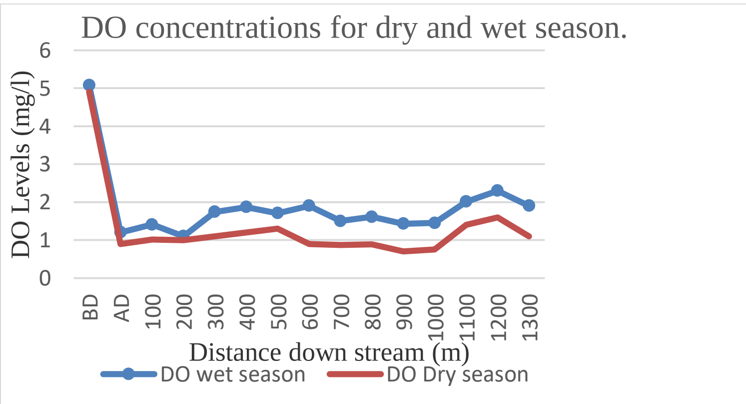


Figure 3: A graph showing variations in dissolved oxygen concentration of the Solo stream water for dry and wet seasons.

The t value of p = 0.011 indicated a significant difference between the mean values of DO during dry and wet season at 95% confidence level before the tannery

The BOD values obtained by this study don't have a regular pattern downstream. However, there is a marked increase of BOD and COD values at the point of discharge. The values for COD ranged from 32mg/l to 308mg/l for wet season and from 41 mg/l to 406mg/l for dry season while the BOD values ranged from 15mg/l to 53.4mg/l for rain season and 17mg/l to 63.7mg/l. There is a significant difference in BOD means for dry and wet seasons at 95% confidence level using t distribution values before tannery (p = 0.040), at tannery (p = 0.009) and after tannery (p =0.037). The t values also show a significant difference in means of COD and BOD at and after the tannery at 95% confidence level. These were p = 0.045 for COD and p = 0.019 for BOD.

Total Dissolved Solids (TDS) and Total Hardness (TH).

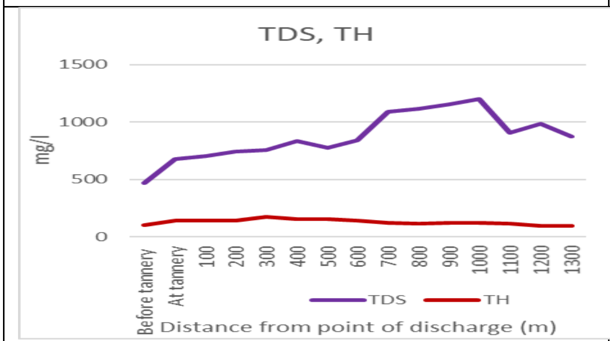
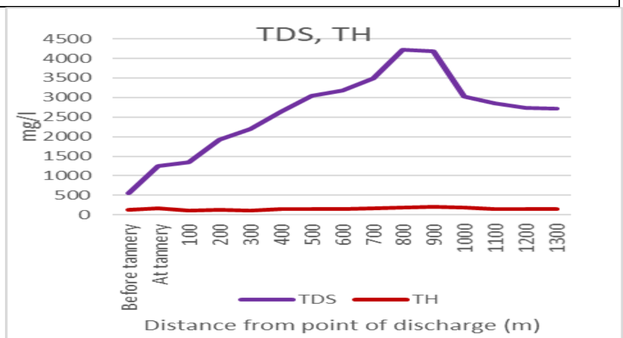
Wet Season	Dry Season
	

Figure 4: Graphs showing variations in TDS and total hardness (TH) levels of Solo stream waters for dry and wet season.

Figure 4 shows that the TDS values ranged from 466 mg/l to 1202 mg/l for wet season and from 551 mg/l to 4228 mg/l for the dry season. There is a marked increase in the TDS from the point of discharge. The TDS values generally increase from the point before discharge continually further downstream before it starts to decline at the 800m point.

The total hardness levels (figure 4) ranged from 95mg/l to 175mg/l in the wet season and 105mg/l to 205mg/l during the dry season. The t values show a significant difference in total hardness for the dry and wet seasons before tannery (p = 0.049), at tannery (p = 0.05) and after tannery (p = 0.049). There is also significant difference in total hardness using a comparison of means at and after the tannery at 95% confidence level where p = 0.019.

Calcium (Ca), Chloride (Cl) and Magnesium (Mg).

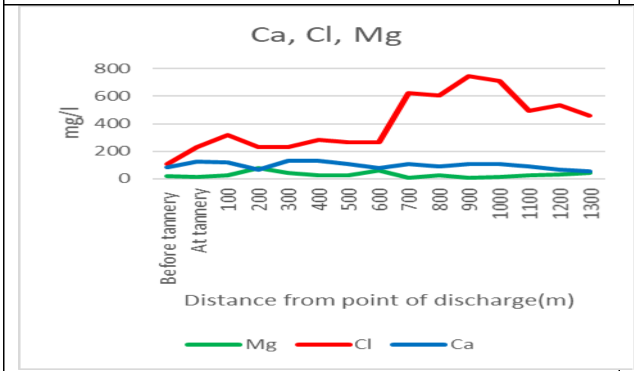
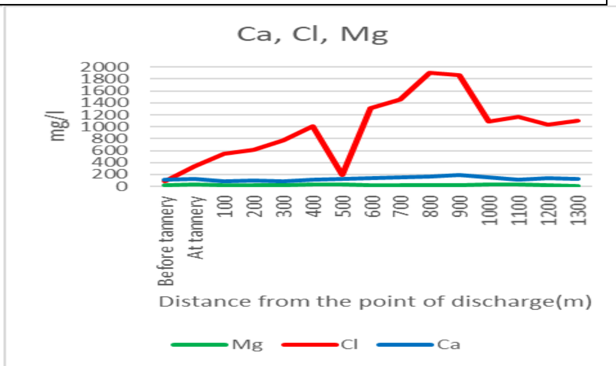
Wet Season	Dry Season
	

Figure 5: Graphs showing variations in Calcium, Magnesium and Chloride concentrations of Solo stream water for dry and wet seasons.

Figure 5 shows that Calcium values ranged from 55mg/l to 130mg/l during wet season and from 82.5mg/l to 190 mg/l during the dry season with an irregular pattern downstream. Calcium attained the highest concentration of 190mg/l at the 900m after the tannery. The t value shows a significant difference in Calcium means before and after the tannery at 95% confidence level (p = 0.049).

The magnesium values showed erratic pattern during both dry and wet season of study downstream and neither do they show significant difference for the two seasons.

The chloride values as shown in figure 5 ranged from 106.5mg/l to 765.5mg/l during the wet season and from 88.75mg/l to 1899.25mg/l during the dry season. Chloride ions had generally higher values in the dry season than in the wet season. The chloride levels in the water however, start to decline after 900m further downstream as depicted in graph.

Chromium levels

Wet Season	Dry Season

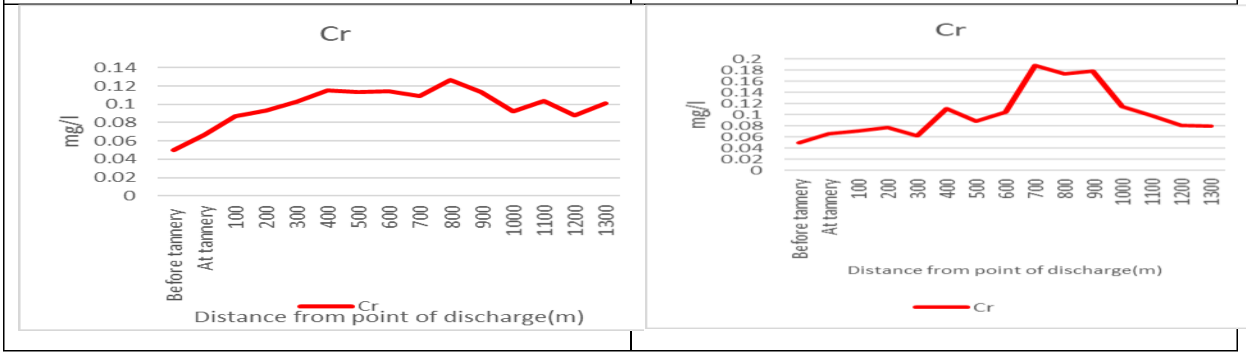


Figure 6: Graphs showing variations in Chromium concentrations of Solo stream waters for dry and wet seasons.

The chromium levels generally increased downstream, and they were higher during the dry season than the wet season (Figure 6). The chromium value was highest at the 700m spot (with a value of 0.188 mg/l). The values showed an erratic pattern, more especially for the wet season. Chromium was almost not detected before the point of discharge (<0.05mg/l). Chromium levels are significantly different during the dry and wet seasons at the tannery ($p = 0.005$) and after tannery ($p = 0.015$) from comparison of the means using t distribution at 95% level.

Turbidity levels

Wet Season	Dry Season

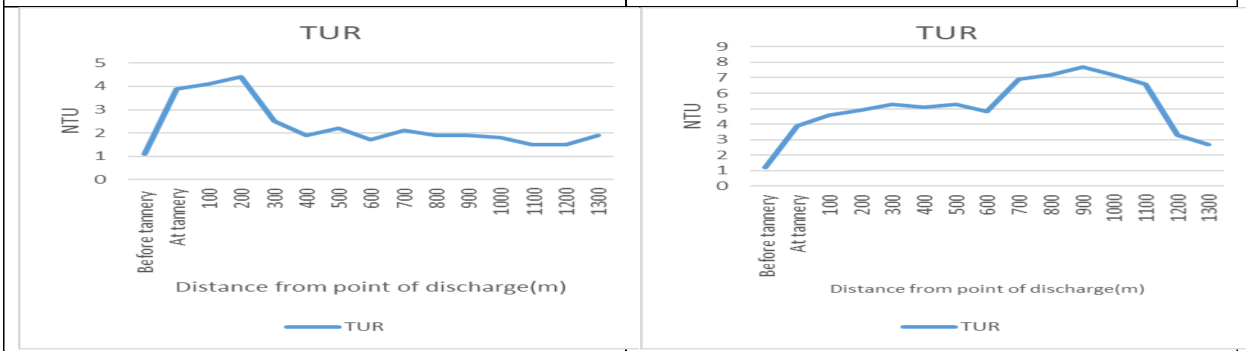


Figure 7: Graphs showing variations in turbidity levels of Solo stream waters for dry and wet season.

Turbidity after tannery discharge were generally higher than before discharge point, and at some points higher than the acceptable limits of 5NTU [15], more so during the dry season (figure 7). The t values show a significant difference between the means (averages) during dry and wet seasons before the tannery ($p = 0.028$).

Conductivity levels

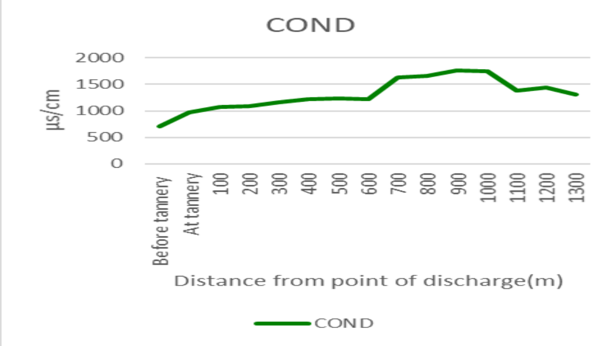
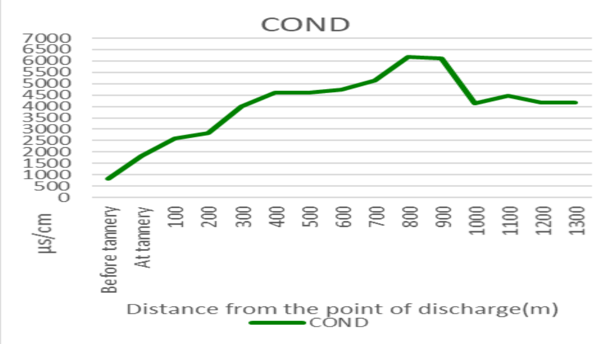
Wet Season	Dry Season
	

Figure 8: Graphs showing variation in conductivity values of Solo stream waters for dry and wet seasons.

The conductivity values (figure 8) for the dry season were generally higher than the values for the wet season. The conductivity values generally increased for both seasons downstream up to the 900m spot, after which they started decreasing. The highest conductivity values were obtained at 800m.

Solo stream Water Quality Index.

The water quality index was based on the conductivity, pH, total hardness, calcium, chloride, magnesium, total dissolved solids, BOD, COD, dissolved Oxygen, chromium, and turbidity.

Table 1: Table showing Water quality Indices at different locations on Solo stream.

Location	WQI (wet season)	WQI (dry season)
Before tannery	134.043	151.1246
At tannery	154.5869	156.4016
100m	192.1868	167.178
200m	196.6919	180.6241
300m	218.2891	155.0471
400m	240.409	249.7707
500m	235.9556	204.2135
600m	237.6609	233.0599
700m	231.0706	394.4578
800m	261.1648	367.2368
900m	237.5793	376.6389
1000m	194.8251	263.7339
1100m	217.1716	228.622
1200m	194.6331	186.6884
1300m	215.7045	182.538

Table 1 shows that the upper stream water quality index, before the point of discharge, has a value of 134.043 for rainy season and 151.125 for dry season. These differed with the water quality index after the point of discharge, whose average was 216.281 for rainy season and 239.015 for dry season. The water quality indices are poor.

pH values.

The pH values of the waters show no much variations from upstream to downstream with in the area of study and at the different sampling points. The values ranged from 7.3 to 7.8. There was significant difference in the pH levels of the water for the dry and the wet seasons before the tannery ($p = 0.017$), at tannery ($p = 0.012$). Also noted is significant difference in means (averages) as shown by the t values for means before and after tannery ($p = 0.004$), before and at tannery ($p = 0.008$) and at and after tannery ($p = 0.004$) at 95% confidence level.

DISCUSSION

The water parameters:

BOD, COD and DO levels

The relatively high DO levels shown in figure 3 in the upper stream before the point of discharge can be directly linked to the low levels of inorganic and organic substances discharged from the non-point sources. The very low DO levels after point of discharge and increased BOD and COD values (figure 1) could be attributed to the organic and inorganic waste discharge from the tannery like chromium compounds as reflected in the findings of this research. The variations downstream can however be due to stream morphological characteristics such as low turbulence, low stream flows, formation of pools of water that enhance organic and inorganic substances concentration downstream, all of which lead to low oxygen dissolution rate in water. These continue to affect local DO levels at different points downstream.

The seasonal variations of DO, BOD and COD could be attributed to temperature variations, thereby influencing biochemical reactions, for example decomposition in the water (being higher in dry and lower in wet season), and increased chemical reactions of mineral ions in the water (oxidation reactions) affecting Oxygen consumption rates accordingly. This subsequently resulted in high BOD and COD values in the dry season.

Total Dissolved Solids and Total Hardness

The high TDS values (figure 4) for the dry season could be attributed to the excessive decrease in the water volumes that probably leads to increase in concentration of the mineral ions contributing to the high TDS. The marked shoot up in the TDS values at the point of discharge could be directly attributed to the tannery waste waters that contain elements like calcium, magnesium, chromium and chlorides whose trend seems to significantly correlate with that of TDS. The consistent initial increase in TDS values could be attributed to the morphological characteristics of the stream flow, for example the many small pools of water downstream that may potentially act as concentration points for some ions. In addition, there could be erosions from the agricultural fields and slow release from the sediments that have even changed in colour, an indication of mineral ion enrichment as a result of exposure to enriched waste waters. Changes in soil chemical composition of the stream banks leading to difference in mineral ion removal from or release into water could also be another possible explanation.

The higher levels of total hardness are traced back to the high calcium levels during the dry season as compared to those of the wet season, which all may be attributed to the declines in water volumes. Total hardness simply reflects the summative value of calcium and magnesium since these are the major contributors. Therefore, any factor affecting calcium and magnesium levels directly affects total hardness levels.

All the values obtained for total hardness lay within the permissible range of 300mg/l as according to the WHO guidelines and standards.

Calcium, Chloride and Magnesium

The irregular patterns of Calcium (figure 5) could be attributed majorly to the anthropogenic activities in the surrounding areas that possibly contribute to the calcium levels in the stream through the surface run offs. These included grazing activities in the nearby open grasslands and poor disposal of the domestic wastes. The other cause could be the change in the soil composition of the stream bank downstream especially around 900m point. The soil is so distinct with a characteristic yellowish colour. The sediments could also be contributing to this. The high calcium levels during dry season could be attributed to reduced water volume.

The magnesium values showed erratic pattern during both dry and wet season of study downstream and neither do they show significant difference for the two seasons.

Magnesium is mostly contributed to by natural sources like the soils and these may include the soils of the stream banks, or even far off through the surface runoff into the water. This possibly explains the higher average levels of magnesium during the wet season. Artificially, the magnesium levels may be increased by poor waste disposal and other anthropogenic activities in areas near the stream valleys where surface runoff can easily deposit these into the stream.

The results on chlorides (figure 5) show a clear increase from the point before discharge downstream. This could be suggestive of the fact that the waste water discharge from the tannery contributes greatly to the total chloride load of the stream. The lower chloride values during the wet season could be attributed to the volume of water in the stream being much; and significant dilution. This is not the scenario during the dry season, as there is low rate of dilution and also, water levels greatly subside and hence concentration of chlorides increase. The general decline in the chloride levels after 900m could be an indication of increased natural purification process further downstream.

Chromium

The low chromium levels (figure 6) during the wet season could be attributed to the dilution effected by the storm water. The water volume was also high during the season, thus generally lowering the concentration of chromium. The absence of chromium in the stream water before point of discharge could be a direct indication that chromium in the water after discharge point is a result of chromium rich waste water discharged from the tannery.

The general increase however, in chromium levels downstream could be an indication of the slow natural purification process and possible retention of chromium by the sediments and later slow release into the water, depending on the soils. Absence and/or presence of the riparian vegetation could also be playing a very important role in natural purification of the water.

Turbidity

The trend of turbidity in figure 7 could be due to the discharge pattern, as it coincides with the rains and mostly evening time. The sample collection was, however, always carried out in the morning time and hence much dilution could have been achieved by the storm waters and hence the low turbidity. The water volumes are also much during the wet season there by reducing concentration of suspended material as opposed to dry seasons. The lower turbidity values before point of discharge are generally due to the low levels of organic discharge from the non-point sources compared to that at and after the tannery.

Conductivity and pH

Conductivity is in all aspects dependent upon total dissolved solids. This probably explains why there were higher conductivity values in the dry season compared to the wet season (figure 8). Besides the trend of conductivity being affected by the trend in the total dissolved solids, conductivity is also affected by the temperatures. An increase in the temperatures translates in an increase in conductivity.

The pH values obtained could be attributed to the discharge pattern of the tannery. The tannery discharges the waste water occasionally and much dilution is achieved by the help of the storm waters making it hard to establish the exact impact of waste water from the tannery on the pH of the stream waters whereas a study conducted by [11] showed waste water pH value of 8.5. The variations at the different points downstream could be attributed to the different water channels that drain into the stream hence impacting on pH levels differently, variations in the microbiological decomposition rates and on presence or absence of riparian vegetation at different sampling points, which helps in natural purification process.

Relation of each of the physical and chemical parameters to Suitability of the Solo stream water for use:

DO levels and its implications on agriculture, fisheries and domestic use

DO is of less importance in terms of affecting the suitability of water for agricultural practices like irrigation [21]. The effects posed by water with low DO is traced back to the inorganic and organic composition of the water.

Fishes greatly need oxygen for their survival and, in water, they obtain the oxygen in terms of dissolved oxygen and hence any surge in dissolved oxygen directly translates in the inability of the aquatic system to support fish life. Low DO is usually a major contributor to fish kills. Different fish species have specific requirements for the particular DO levels below which they will not reproduce, feed or survive. Most fish do well in waters that contain at least 5mg/l [46]. At levels below 5mg/l, some game fish become stressed and hence move to areas with high DO, if they are able to do so. At levels below 3 mg/l, most fish will not feed and will show signs of distress [47], for example, fish will be always at the surface of the water and appear to be pushing their noses out of the water [47]. According to [48], even the hardy fish die at DO levels below 3 mg/l. A drop further adversely affects the fish and other aquatic organisms like the crabs, mayfly nymphs, stonefly nymphs, and beetle larvae and end up dying [48]. The DO levels in the upper stream before point of discharge of 5.08 and 4.9 for wet and dry seasons respectively (figure3) met the minimum proposed levels and can ably support fish life. The water at and after the tannery discharge point had DO levels which are lethal to fish (an average of 1.65 and 1.05 for wet and dry seasons respectively), and can not support fish life.

DO in itself has no reported dangers it poses to human life. The contributing factors, however, like organic and inorganic composition are the ones whose effect is felt.

COD and BOD values and their implications on agriculture, fisheries and domestic use.

High COD and BOD values are indicative of high organic and inorganic load of the water, yet can be high without any negative effects on the plants and hence no standard restriction is made for it in irrigation water [49]. High organic matter content may improve the water holding capacity of the soil yet it may present problems like bio-filming and bio fouling in the distribution systems especially in drip irrigation [49]. High values of BOD and COD may also cause a shift in the nutritional balance of the soil and soil properties like pH depending on the levels of the individual mineral ions present. Nitrates and phosphates, may increase productivity while some ions may cause water stress to the plants [49]. Water with high COD may as well increase the COD of the soil hence creating oxygen deficient soils and thus offsetting reactions like denitrification [49]. There are generally no universal recommended/ permissible levels of BOD and COD for irrigation water.

Generally, high BOD and COD levels lead to a decline in water DO levels due to high oxygen consumption in decomposition of organic matter by bacteria [50] and in oxidation of the inorganic ions in the water. This may then lead to suffocation of fish and other animals that play important ecological roles, and release of other pollutants (including nutrients and toxicants) that may be stored in the sediments, due to changing chemical conditions associated with anoxia. Chronic BOD may lead to biodiversity loss, [50]. It is important to note that the effects of high BOD and COD values on fisheries are all traced back to lower DO levels that results. According to [51] the recommended BOD levels for aquaculture are 10-20 mg/l. The Solo stream water had far much higher BOD levels (figure 2) than those recommended above and hence does not favour fish life especially after the point of tannery discharge.

There is no standard value recommended concerning the COD levels for water consumed domestically. [52] however, considers water with BOD at a level of 1-2mg/l to be very good since organic waste is very minimal, water with a BOD level of 3-5mg/l to be moderately clean and water with a BOD level of 6-9mg/l, as somewhat polluted because organic matter is usually present and bacteria are decomposing this waste. Therefore, using the above observations, Solo stream water with BOD levels higher than 9mg/l (figure 2) can present potential health risks when consumed domestically (drinking and cooking).

TDS and its implications on agriculture, fisheries and domestic use.

Irrigation using water with high TDS levels leads to build up in the mineral ion concentration in the soil. Accumulation of such ions around the root zones causes water stress to the plants as it acts as a binding factor for clay and humus in the soil thereby blocking and reducing the air spaces and preventing water penetration [19]. Over time, irrigation using water rich in mineral ions is likely to increase the salinity of the soil which may likewise cause nutritional imbalances and shifts in soil pH thereby making soil unsuitable for growth of salinity sensitive crops [20]. In livestock, water with high salt content may cause physiological upset or even death due to depression of appetite caused by a water imbalance rather than related to any specific ion [21] and this usually leads to poor feeding. Some other symptoms like diarrhoea and general water stress may arise [21]. The high TDS values far above 1000mg/l observed in the area of study (figure 4) make the water of Solo stream unsuitable for livestock consumption and irrigation purposes.

The greater the amount of solids in the water versus the solids in the tissue of the fish the greater the fluid loss via the gills and subsequent dehydration. A level of 400ppm or less is recommended for most freshwater fish although many soft water fish demand a significantly lower level [22]. Low TDS is more desirable for breeding, (enhancing egg and larval development), though this depends on the species of fish. Increased levels of TDS are also responsible for increasing COD levels and consequently causing low DO levels in water resulting in fish kills [22]. Thus, the high TDS values recorded of up to 2000mgl^{-1} after discharge point (the tannery) in the stream as given in figure 4 are deleterious to fish life, making the water unsuitable for aquaculture

An elevated level of TDS, in itself, does not indicate that the water presents a health risk, yet elevated levels of specific ions like nitrate, arsenic, aluminium, copper, or lead, and chromium could present health risks [23]. High TDS levels increase cases of heart diseases, inflammation of the gall bladder and gall stones. At levels higher than 500mgl^{-1}, excessive scaling in water pipes, water heaters, boilers, and household appliances such as kettles is experienced [24]. Solo water with TDS higher than 500mg/l as recommended by WHO is unpalatable [15].

Total Hardness values and their Implications on agriculture, fisheries and domestic use.

The impacts of total hardness are traced back to the effect of the contributing ions and more especially according to the one dominating in the calcium/magnesium ratio. Total hardness with high calcium carbonate levels can cause formation of white encrustations that may block irrigation pipes [36] while high magnesium levels may cause water infiltration challenges [33] All in all, the impacts of total hardness are traced back to the individual impacts of calcium and magnesium as contributing ions. The water of Solo stream is suitable for agricultural use due to the fact that its hardness levels (figure 4) lie within the acceptable standards of 300mg/l as per the WHO standards. The calcium-magnesium ratio is also so good, being that the ratio is on average about 3:1.

Hard water may have general effects on the fertilization and early egg development in fresh water fishes as suggested by [31] and [32]. This is majorly through affecting the osmotic properties of water and hence sperm motility. However, there is no standard for total hardness, concerning its permissible levels for fish life yet. According to the WHO grading, the water of Solo stream falls under the category of hard water, it being above the stated 100mg/l [15]. Despite the relatively high calcium levels above permissible levels of 75mg/l, the Solo stream water (figure 5) can still support fish life save for those sites with calcium levels exceeding 150mg/l.

Generally hard water does not easily form lather with soap and hence leads to soap wasting. Both calcium and magnesium are essential minerals and beneficial to human health in several aspects. Inadequate intake of calcium has been associated with increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity [34]. Excessive intake of calcium is controlled by the excretory functions of the kidney and regulated absorption in the gut. High levels of magnesium associated with sulphates at levels higher than 250mg/l can cause laxative effects [37].

The water of the portion of Solo stream studied (figure 4), was within acceptable range of 300mg/l as according to WHO guidelines and so is good for domestic consumption when considering total hardness.

Calcium levels and their implications on agriculture, fisheries and domestic use.

Calcium in the soil plays an important role of binding soil particles. Plants need calcium for proper growth which is taken up in form of calcium ions. However, high calcium levels beyond 100mg/l can cause phosphorous and magnesium deficiency, and clogging of irrigation equipment due to scale formation (encrustations of calcium carbonate) [29].

The average calcium levels of Solo stream water as given in figure 5 exceeded the recommended 100mg/l and hence, making the water unsuitable for irrigation purposes.

Stress manifests differently in different organisms, ranging from lethargy to erratic swimming or growing more slowly than usual [30]. In extreme cases, too much calcium can kill aquarium organisms. [31], established that, calcium can have a detrimental effect at higher concentrations by increasing the osmotic concentration of the water leading to swelling of the eggs, and hence reducing larval survival. [32] showed that hard water (combination of calcium and magnesium hardness) caused low fertilization rate for freshwater fishes possibly due to its high osmolality, which is believed to inhibit sperm motility in freshwater fishes. Ca^{2+} and Mg^{2+} hardness higher than 150 mg/l CaCO3 suppressed sperm motility in perch (*Perca fluviatilis*), [32]. It is thus important to note that the effects of calcium on the fish life is majorly with the early stage of development. The calcium levels of Solo stream water at some points (those exceeding 150mg/l) therefore may not be favourable for reproduction of freshwater fishes expected to inhabit this water.

Calcium and magnesium are very important to the human health with benefits like reducing risks of death from cardiovascular diseases and to this effect, water with calcium is generally regarded as harmless to human health. The human body is however recommended to have an intake of 0.7mg to 2mg of calcium daily and excessive amounts of calcium can lead to formation of gallbladder stones [21]. By the fact that calcium levels were generally higher than those recommended by WHO, (figure 5) the water of Solo stream is unsuitable for drinking when considering calcium levels.

Magnesium levels and their implications on agriculture, fisheries and domestic use.

A research carried out by [33], showed that fodder yield of maize and grain yield of wheat were significantly decreased when irrigated with water having higher magnesium content compared to calcium. It was also seen to impair soil conditions. Soils containing high levels of exchangeable magnesium are often troubled with soil infiltration problems [19]. This is because at equal or lower magnesium concentration in the Mg/Ca ratio, magnesium behaves like calcium and if magnesium becomes more than calcium it behaves like sodium resulting in soil dispersion and decreased infiltration rate [33]. In a magnesium dominated water (ratio of $Ca/Mg < 1$) or a magnesium soil (soil-water ratio of $Ca/Mg < 1$), the potential effect of sodium may be slightly increased, that is, a given Sodium Absorption Ratio (SAR) value will show slightly more damage if the Ca/Mg ratio is less than 1. The lower the ratio, the more damaging is the SAR [19]. Magnesium is also known to cause scouring and diarrhea in livestock [21]. The Solo stream water poses no such threats to livestock, when considering the magnesium levels as they all were within the recommended standards of WHO for agricultural use (figure 5) hence suitable for use. The Ca/Mg ratio of the water also poses no threat when used in irrigation, since it is greater than one.

Chapman (1996) cited in [21] suggested that magnesium is not of much concern when considering parameters for fish life. Despite there being no set standards for magnesium levels permissible for aquaculture, [32] and [31] suggest that excessive magnesium coupled with calcium may generally affect osmotic properties of the water posing a challenge to fertilization in freshwater fish and even affect early development.

Magnesium is one of the seven major minerals that the body needs in relatively large amounts. Magnesium inadequacy is associated with pathological hypertension, cardiac arrhythmias of ventricular and atrial origin, hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome [34]. But excessive Magnesium can in turn cause a deficiency in calcium. Symptoms of toxic magnesium levels can range from upset stomach and diarrhoea, to more serious symptoms of vomiting, confusion, slowed heart rate and dangerously low blood pressure. Severe magnesium overdoses can lead to problems in breathing, irregular heartbeat and even death [35]. The water of Solo stream at some points proved to be not palatable, as according to the ICMR standards of 50mg/l of magnesium, though it was safe for domestic consumption during the dry season, with respect to magnesium.

Chloride levels and implication on agriculture, fisheries and domestic use.

According to [53], the chloride anion is very stable and does not leave the soil system unless it is leached by an excess of good quality irrigation water, or removed from the soil by exported vegetative plant parts. Chloride ions can also accumulate in the soil, causing deterioration of soil fertility, and under extreme conditions, render the soil unproductive [53]. Chloride ions in the soil are readily taken up by the plant and can accumulate in the leaves [19]. High chloride concentration can cause toxicity problems in crops, reduce the yield, cause leaf necrosis and death and leaf damage as a result of deposition of chloride on leaves during overhead irrigation [54]. Chlorides also increase the electrical conductivity of water and thus increases corrosivity of metallic pipes. Chloride concentration below 70 ppm, are generally good for plants, while beyond 70 ppm, plants start to show injury and above 350 ppm plants experience severe problems [54]. WHO recommends that water should be having not more than 250mg/l. However, the SFM, recommends that the water for irrigation needs not to exceed 150mg/l as this is favourable to all plants. The water of studied portion of Solo stream (figure 5) has chloride concentrations which do not meet any of the recommendations and therefore is not suitable for irrigation purposes.

High chloride concentrations in freshwater can harm aquatic organisms by interfering with osmoregulation, [55], resulting in poor growth and reproduction. According to [55], fish, with some exceptions are less sensitive to chloride exposure than the free-floating planktonic crustaceans, yet these are food source to fish and amphibians, and keep algae in check, thereby controlling eutrophication that causes oxygen depletion in water. Department of Environmental Management (DEM), Rhode Island, sets standard limits for freshwater organisms as 860 ppm (preventing acute immediate effects of exposure) and as 230 ppm (preventing chronic and long-term effects of exposure) [55]. Solo stream water, in the studied portion, are richer in chloride ions specifically after point of tannery discharge, (with an average of 428mg/l during rainy season and an average of 1027mg/l during dry season) compared to the 230mg/l as recommended by the DEM for their waters. The Solo stream waters are very high in Chlorides which may affect the fisheries.

Chloride is an essential nutrient for human health and obtained majorly from foods, with drinking water making up only a small portion of normal dietary intake [56]. Chloride in drinking water is not harmful, and most concerns are related to the frequent association of high chloride levels with elevated sodium levels [57]. For example, chloride toxicity is seen in individuals with impaired sodium chloride metabolism, like in congestive heart failure [56]. There is no health based drinking water guideline for chloride, though the Guidelines for Canadian Drinking Water Quality recommend an aesthetic objective for chloride levels of 250 mg/L, based on the potential for undesirable tastes at concentrations above this level, and the increased risk of corrosion of pipes [57] and EPA recommends levels not higher than 250 mg/L to avoid salty tastes and undesirable odours [58].

The water from the studied portion of Solo stream is far unsuitable for domestic consumption (drinking) since all the average values for chlorides (figure 5) are higher than the recommended levels by both the EPA and Canadian standards.

Chromium levels and the implications on agriculture, fisheries and domestic use

Chromium compounds when dumped on land, bind to soil particles [38] and total concentration of chromium in the soil has been reported to increase with increased use of chromium contaminated irrigation water [39]. Toxic effects of Cr on plant growth and development depend primarily on its valence state. Cr (VI) is highly toxic and mobile whereas Cr (III) is less toxic. Examples of effects of chromium on plants are; alterations in the germination process as well as in the growth, which may affect total dry matter production and yield. Also affected are plant physiological processes such as photosynthesis, water relations, mineral nutrition and metabolic alterations (oxidative stress). Phytotoxicity and alteration of chloroplastic pigments have been reported in *Vigna unguiculata* seedlings [40]. Chromium also shows tendencies of bioaccumulation in plant parts to toxic levels, with serious systemic health problems to human body, if plants are irrigated with chromium contaminated water, even at low concentrations of 10 $\mu g\ l^{-1}$, 20 $\mu g\ l^{-1}$, 50 $\mu g\ l^{-1}$, 100 $\mu g\ l^{-1}$ and 250 $\mu g\ l^{-1}$ [41]. The accumulation is shown to be greatest in roots, leaves, and stem and lowest in pods [39]. However, this is dynamic for different plants. It is apparent that the water in the upstream had chromium levels higher than the recommended 0.05mg/l as by the WHO standards and so it is not suitable for use in irrigation (Figure 6). This water is capable of causing bioaccumulation and even bio-magnification besides adversely affecting the growth of plants.

The natural concentration of chromium in lakes and rivers has been seen to range from 1 to 10 μg/l and EPA proposed level for protection of aquatic life and human health are 50 to 100 μg/l [42]. A number of reports have showed the occurrence of anomalies in various fish species at physiological, histological, biochemical, enzymatic, and genetic levels due to the toxic effects of Cr (VI) [38]. These include; lymphocytosis, anaemia, eosinophilia, bronchial and renal lesions. Its high concentration can harm the gills of fish that swim near the point of disposal of metal products in surface waters [38]. A study on the carp (*Cyprinus carpio*) derived immune cells that were subjected to Cr (VI), revealed a decrease in the activation of mitogen induced lymphocytes, a remarkable change in neutrophils shape and phagocyte function hence showing reduced power of resistance to certain pathogens under chronic Chromium challenges in fishes [42]. Another study on rainbow trout showed that, the sperms of Cr-exposed fish even at the lowest concentration of 5 µg/l showed relatively high sensitivity, *Cyprinus carpiovar communis* showed fluctuations in the osmoregulatory functions on exposure to chromium sulphate, while studies on Chinook salmon revealed that exposure to increasing Cr concentrations for 105 to 134 days affected both growth and survival rate with physiological modifications as well as DNA damages occurring at a concentration of 24 µg/l [42].Since chromium as seen in above studies, had great effects on fish even at lower concentrations, the chromium levels in Solo stream, after the point of discharge, with values far higher, above the recommended 0.05mg/l, are detrimental to fish life.

Beside the role of Cr (III) in metabolism of glucose, fats and proteins in animals and humans it has distinct toxicological features. Trivalent chromium is not readily absorbed by body cells as tetravalent chromium, and thus reduction of Cr (VI) to Cr (III) extracellularly, prevents its toxicity [43]. Based on way of exposure to the body (inhalation, oral, and dermal contact), chromium has a number of health effects, ranging from, systemic, immunological, neurological, reproductive, developmental, genotoxic, carcinogenic effects, and death [44]. High level of chromium (VI) in drinking water causes tumours in the stomachs of humans and animals [45] and disrupts cellular integrity and functions [45].

Dermal exposure to chromium is reported to cause irritant and allergic contact dermatitis characterized by symptoms of dryness, erythema, fissuring, papules, scaling, small vesicles, and swelling [45]. Penetration of the skin will cause painless erosive ulceration ("chrome holes") with delayed healing which commonly occur on the fingers, knuckles, and forearms [45].

Exposure to Chromium (VI) salt aerosols for example, exposure to chromium (VI) trioxide is reported to cause damage to the nasal mucosa and perforation of the nasal septum, as exposure to insoluble chromium (VI) compounds results in damage to the lower respiratory tract [43]. Solo stream at and after tannery (figure 6) had chromium levels above the permissible levels of 0.05mg/l as according to WHO guidelines and making it unsuitable for any domestic consumption or use.

Turbidity and its implications on agriculture, fisheries and domestic use.

Materials suspended in water can cause sedimentation in pipes, tanks, and other equipment; clogging of fine, spray nozzles and micro-irrigation system and reduced herbicide performance [16]. With regard to Solo stream (figure 7), the water at most points had turbidity levels within acceptable standards of 5NTU that cannot cause much clogging in water irrigation systems.

Different contributors to turbidity (organic, inorganic and living material) affect fishes differently. While phytoplankton increase DO levels through photosynthetic activity, utilize harmful compounds like ammonia and provide food for the fish, organic material leads to increased BOD and decreased DO levels. Inorganic matter like silt can clog fish gills [17]. High turbidity has also been observed to disrupt spawning, cause decreased food availability and fish feeding ability. It has also been reported to cause disruption of migrations (through avoidance) and food web dynamics (through decreased predator success and enhancement of prey survival due to poor light penetration/low visibility) [17]. Tropical fishes are resistant to high turbidity levels hence Solo stream water can support some fish life, when considering turbidity.

While turbidity is both an aesthetic and clinical parameter, highly turbid waters don't appeal to a person for use by mere sight. Turbidity, on the other hand, may be indicative of some contaminants, dangerous to human health. Increase in turbidity levels in drinking water increases the risks of gastrointestinal diseases among people who consume it [18].

The EPA recommends that turbidity of the water for drinking should not exceed 1 NTU [17], while 0.1 NTU is recommended for better disinfection proceedings [15]. Turbidity of the Solo stream water was generally beyond the acceptable limits for drinking, and hence not suitable for domestic consumption.

Conductivity values and implications on agriculture, fisheries and domestic consumption.

Conductivity is only indicative of the level of the total dissolved solids/salinity and hence its effects on different uses is dependent on the type and concentration of individual ions contributing to the conductivity values for example chlorides, sodium, sulphates, carbonates, calcium, magnesium, nitrates, ammonium ions and heavy metals like aluminium, chromium, iron and lead. Higher conductivity is indicative of higher salt concentration, which reduces uptake of water by plants [59]. The EPA however, provides permissible levels beyond which the water may not be suitable for the different uses. For example, drinking water needs to have a conductivity less than 750µS/cm at 25°C, aquatic life required between 150 to 500µS/cm at 25°C while irrigation water needs to have less than 750µS/cm at 25°C [60]. With respect to conductivity, water of Solo stream, in the studied portion, is generally not suitable for drinking, fresh water aquatic life and agricultural irrigation since the conductivity values are generally higher than those recommended for various uses according to the EPA standards.

pH and implications on agriculture, fisheries and domestic use.

All crops are specific in terms of pH ranges under which they can grow well and a rift in water pH levels therefore directly affects its suitability for agricultural uses like irrigation. Irrigation water should have pH in the range of (6.5-8.4) and beyond these limits, the water may make the soil much acidic or alkaline to the disadvantage of crops that require neutral, alkaline and/or acidic pH accordingly [21]. Water pH affects a number of aspects of plant growth like nutrient availability, chlorosis, soil microorganisms, and colour which lead to stunted growths and stress in most plants if irrigation water is not within the range of plant preferences [25]. The water will also pose corrosive challenges to the pipes, and cause soil nutritional imbalances. The pH of Solo stream waters, in this respect, poses no problem and can be used for irrigation with no risks of disturbing the nutrients balance of the soils, soil microorganisms and accelerating corrosion of metallic pipes, since they are in agreement with the ICMR standards (6.5-8.5), the Canadian standards (6.0-9.0) and the WHO standards of (6.5-9.5).

Fish cannot survive in water with pH below 4 and above 11 for long periods, though different species prefer different pH levels as in the example of koi which can thrive in water that has a pH of 7.5 while African Cichlids prefer water that is more basic with a pH of 8.5 [26]. High pH levels (>9) cause conversion of ammonium ions in water to toxic ammonia which can kill fish [27] while acidic water impedes growth of phytoplankton, zooplankton and other bacteria which are important for fish survival [21]. With regard to fisheries, Solo stream water pH poses no problem and can ably support aquaculture since its pH values both before and after discharge point lie within the acceptable limits.

pH is regarded as an aesthetic parameter as its major effects are only related to taste and odour of the water. Health effects are most pronounced in pH extremes and these may include eye and skin irritation, heavy metal effects and gastrointestinal upset resulting from leaching of heavy metals from plumbing systems [28]. Water for domestic consumption needs to be within the limits of 6.5-8.5, according to EPA standards. The Solo stream water pH lies within the acceptable limits for domestic consumption.

Solo stream Water Quality Index and its implications on the different utilities.

Water quality index is simply a reflection of the different water parameters and how they are affecting the water quality of the water system. Thus, the water quality indices are poor just because the water parameters upon which the water quality index was dependent were also very poor.

Considering the results on water quality index from the study (table 1), and comparing them with the categorizations in the table 2, the values obtained in this study showed that the water was unsuitable for domestic consumption, agriculture and fisheries use. These values according to the ICMR ratings, make the water only viable for irrigation and not any other domestic consumption. The water needs treatment before any form of consumption.

Table 2: Table showing categorization of water quality in accordance with suitability for its use [61], based on WAWQI method.

S.No.	WQI	Status	Possible uses
1	0-25	Excellent	Drinking, irrigation, industrial
2	25-50	Good	Domestic, irrigation, and industrial
3	51-75	Fair	Irrigation and industrial
4	76-100	Poor	Irrigation
5	101-150	Very poor	Restricted use for irrigation
6	Above 150	Unfit for drinking	Proper treatment required before use.

CONCLUSION

Generally, the water quality before the tannery was better than that after the tannery. This is suggestive of the tannery wastes playing a significant role in the deterioration of Solo stream water quality more so as regards chromium, turbidity, TDS, chloride, dissolved oxygen, BOD, COD, and conductivity. The values of most of the physical chemical parameters determined were above the maximum permissible limits and together with the water quality indices obtained, the water is unfit for domestic consumption, aquaculture and irrigation.

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