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Impact of Anthropogenic Activities on Water Quality: The Case ofATHI River inMACHAKOS County, Kenya

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Abstract:*This study sought to determine the effect of anthropogenic activities on the quality of water in Athi River within the Athi River locality in Kenya. The study focussed on analysing the level of hydrocarbon pollution, the relationship between industrial activities and proximity to the river and the level of coliforms in Athi River. Samples collected from selected sample points were tested in a laboratory for color, PH, total dissolved and suspended solids (TSS) dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, hardness, total dissolved solids (TDS), chloride (Cl-), and Electrical Conductivity.The findings of the research indicated that the pollution of Athi River decreases as the river flows downstream an aspect that may be attributed to the natural filtration processes as the river flows through rocks and boulders leading to a decrease in pollution. The results provided evidence in support of the null hypothesis in the case of hydrocarbon pollution where no evidence was found in favour of hydrocarbon pollution. The results provided evidence towards a strong correlation between the distance from industries to the river and the level of pollution where a decrease in distance led to an increase in pollution leading to increased pollution load. However, based on the regression analysis results, various factors had to combine to form a significant impact on the quality of the water flowing through the river. The results also showed no evidence of any coliforms or coliform counts.*

KeyWords:*Anthropogenic. Coliforms, Biochemical oxygen demand, Chemical oxygen demand, Ethylenediametetra acetic acid, Chloride, Carbon dioxide, Nephelometric Turbidity Units, Hydrogen concentration, Total dissolved solids, Total suspended solids*

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I. Introduction and Background ofthe Study

1.1. Introduction

The existence of a majority of Kenyan communities within basic minimum acceptable standards of living is highly dependent on the sustainability of rivers. As such, the quality of water flowing through the rivers is vital human survival. According to Leslie (2010), early civilizations flourished along world's famous rivers such as the Nile, Mesopotamia, Tigris and Euphrates, Indus, Huang He, Potomac, Mississippi, Niger etc. Leslie (2010) argues that the main reason behind this flourishing is the presence of water as a resource for various domestic and commercial needs.

Since water is an important resource for development, as the need for water use increases in human settlements so does the need for ensuring that the available water resources remain unpolluted asserts Mukesh (2014). Since water can be a medium of transport of disease carrying microorganisms, sufficient and adequate supply of clean, sanitized and safe fresh water is an inevitable factor to be dependent upon for human and economic development. This aspect informs the main objective of the research which is to determine the quality of water in Athi River locality of Machakos County in Kenya.

The Athi river locality is one the most important industrial zones within easy reach of Kenya's capital city and it forms part of the riparian ecosystem of Athi River which passes through it almost dividing it into two parts (Gichuki, 2009). This research paper therefore sought to determine the effect that anthropogenic activities within Athi River locality have on the quality of water flowing through the Athi River.

1.2. Background of the Study

According to the Food and Agricultural Organization (FAO 2007), the quality and safety of drinking water and water for use in other household chores has over the years hampered growth and development among African countries. This deterioration in water quality and quantity not only impacts the availability of clean and safe drinking water for populations living downstream but also affects the aquatic ecosystems along the river's path (United Nations Environmental Program 2012). This research therefore sought to determine the effect of anthropogenic activities on water quality in Athi River with a specific focus on industrial growth.

As stated in Shukla and Singh (2013), hydrocarbon pollutants have the most hazardous effect on river ecosystems. Hydrocarbon pollution can be caused by petroleum, pesticides or organic matter. However, among these causes, petroleum (otherwise referred to as oil) is the worst kind of pollutant because it is toxic to all forms of life. The fact that petroleum products are widely used makes the pollution factor even worse. The heavy nature of the petroleum products contributes significantly to their characteristic nature of hampering oxygen supply among aquatic organisms thus leading to death in organisms from oxygen deprivation (Shukla & Singh 2013). Growth in industries that makes hydrocarbons makes hydrocarbon pollution more rampant thus reducing the quality of river water with time. This research therefore studied the level of hydrocarbon pollution in Athi River in comparison with the government set standards on heavy metals contamination on water quality (Shukla & Singh 2013). In addition, this study sought to determine if the distance between the industries and the river influences the pollution levels in the river.

1.3. Problem Statement

The growth in industrialization has contributes significantly to the quality of water flowing through rivers, this indicates that an increase in industrial activities as well as other anthropogenic activities upstream would definitely affect the quality of water downstream.

Athi River whose source is the Ngong Hills meanders through the Nairobi National Park, Athi River locality and eventually becomes the Athi River as it enters the Savannah Plateau on its way to the Indian Ocean (Tibaijuka, 2007). Due to the forested nature of the river's source, the quality of water upstream or around the source is usually good and within the required standards. However, as the river flows downstream, human activities along the river's path contribute significantly towards the decrease in water quality as a result of discharge of human refuse and other harmful substances especially from the industries directly into the river.

Researchers such as Gichuki (2009) have in the past sought to determine the effect of pollution in Athi River on wildlife within Nairobi National Park as well as the effect of human activity on water quality on upstream areas of Athi River such as Ongata Rongai Township. However, the growth of downstream settlements in areas to the South East of Athi River locality has attracted low to none attention among researchers as an area in need of clean and safe water for domestic use. As such, the increase in settlements as the river progresses downstream ought to have an effect on the quality of water an aspect that previous researchers who mainly focused on upstream areas such as Gichuki (2009) overlooked. With the increasing demand for clean water fueled by the population growth in Athi River, the need to improve the quality of water available in water resources found in Athi River locality such as Athi River has become more profound.

This indicates that efforts to control pollution within Athi River Locality are essential for survival of the population living in upcoming settlements in South East Athi River as well as the larger Machakos County through which the river flows.

1.4. Purpose of the Study

The purpose of this study was todeterminethe impact of anthropogenic activities on the water quality in Athi River within Machakos County, Kenya.

1.5. The objectives of the study

The study was guided by the following specific objectives:

(a) To determine the extent of hydrocarbon pollution in Athi River.
(b) To establish the relationship between industrial activities and water pollution in Athi River.
(c) To determine the level of coliforms/coliform count in Athi River.

1.6. Research questions

The study sought to answer the following research questions;

(a) What is the level of hydrocarbon content in Athi River as compared to acceptable government and international standards?
(b) What is the relationship between industrial activities and water pollution in Athi River?
(c) What is the level of coliforms/coliform count in Athi River?

1.7. Hypothesis of the Study

The research was based on the following hypotheses

$H_{0:}$ Anthropogenic activities have no impact on the water quality in Athi River.

$H_{a:}$Anthropogenic activities have a significant impact on the water quality in Athi River.

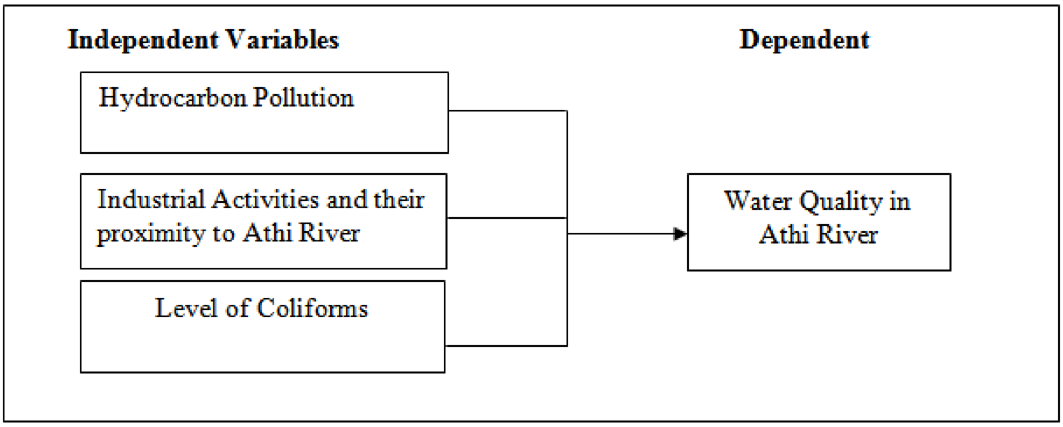
1.8. Analytical framework

The research employed an analytical framework that is based on both the scientific and observation based research methods. The scientific research framework made use of scientific tests to determine the level of pollution in Athi River while the observation based research framework made use of responses from respondents carefully selected from the research site. These respondents were guided on answering questions with the aim of gathering their views on the status of the water in Athi River as well as their views on the effect of industrial activities on the quality of river water.

The results obtained from the scientific research tests were combined with the results obtained from observation based research to determine if a relationship exists between levels of pollution and industrial growth within Athi River locality.

1.9. Conceptual framework

The conceptual framework shown below was used in the study:



1.10. Theoretical framework

Due to the uninhabited nature of the areas to the South East of Athi River in the past, no much attention has been accorded to the quality of river water in these areas. However, with the growth and expansion of the country's capital city Nairobi, the number of urban dwellers moving to neighboring metropolis such as Athi River has been increasing leading to a significant increase in residential settlements such as the Green park estate, Paradise Park estate and Pine City estate among others (Daily Nation 2015). Therefore as part of a system in the system theory approach, Athi River increased its interaction with the surrounding anthropogenic installations such as the industries located in Athi River locality and increased human settlements. This coupled with the need to increase the participation of Athi River in a system that encompasses the river, the riparian ecosystem and the dependents of the river such as the residents of Athi River formed the theoretical framework for the research. This is due to the fact that the quality of water in Athi River is determined by the environment across which the river flows and the anthropogenic activities mentioned herein forms part of that environment. As such, based on the system approach theory, Athi River is part of the interconnected elements in a characteristic manner that make up the Athi River locality as a living organism. This theoretical framework was structured around the two theories below.

1.10.1. Integrated Water Resource Management theory

In line with the Integrated Water Resource Management Theory, as part of an already existing ecosystem, Athi River plays a highly important role in the interaction as a functional unit of plants, animals and microorganism communities that co-exist within Athi River thus making up the Athi River riparian ecosystem.

In light of the above interrelationship between various components of an ecosystem, the IWRM theory can be applied in the efforts to determine and as such minimize the negative impact that anthropogenic activities have on the quality of water flowing through Athi River. This would effectively lead to maximization of the economic and social benefits that would result from the sustainable use of water from Athi River in an equitable manner among living and non-living organisms along the river's path.

1.10.2. The Ecosystem Modeling Theory

Based on the ecosystem modeling theory, reduction in pollution of Athi River would improve the status of the Athi River's riparian ecosystem where anthropogenic activities along the rivers path would effectively be made more aware of the influence they have on the quality of the water flowing through the river, an aspect that would trigger conservation efforts thus improving the livelihoods of the communities living downstream. As cited in Gikundi (2014), a useful reference point for Athi River would be the pilot project used on Nairobi River between museum hill bridge and the racecourse road bridge where anthropogenic activities along the river's path were proven to be harmful not only to the quality of river waterbut also to the communities living downstream as well as the river's ecosystem. However, as soon as conservation measures and restoration of the ecosystem strategy were implemented, the ecosystem improved as well as the livelihoods of the communities living downstream (Gikundi 2014).

II. Literature Review

2.1. Empirical review

This part of the research sought to review the research process and findings of researchers who focused on the effect of industrial activity on water pollution, the correlation between water pollution and the distance between the industrial complexes and the river, the effect of hydrocarbon pollution on the quality of water flowing through rivers and the level of such hydrocarbon pollution compared to internationally acceptable standards and finally the level of Coliforms in rivers compared to internationally acceptable standards.

According to Barbaros, Centrinkaya & Harmancioglu (2014), the management of water as a resource has been of great importance lately as a result of the ever increasing level of industrialization leading to high demand for natural resources such as water.This has led to an increase in the need to develop decision support systems that are capable of managing water resources. Based on the findings of Barbaros, Centrinkaya & Harmancioglu (2014), there is a significantly high need for an integrated water quality management solution aimed at assessing the pollution risk posed by human activities not only on rivers but also on other water bodies such as lakes, pans, dams and wells across the world.

As cited in Kuhlman et al. (2014), protection of water resources such as rivers is of paramount importance as observed in the tests carried out on River ipiranga and River Paraguina both of which are located in protected areas of Cunha and Santa Virginia yet physical, chemical, microbiological and eco-toxicological tests showed that electrical conductivity, turbidity, the level of coliforms, iron, total phosphorus and nitrate contents were increasing as the river flows downstream indicating that erosion as well as collection of debris on the rivers path as it flows downstream significantly affects the quality of water in such rivers. However, these results showed significantly lower levels of pollutants compared to the results of tests carried out in non-protected areas such as River Benin as cited in Ayobahan etal. (2014), River Donjiang as cited in Ding etal. (2015), various river basins cited in Bhuiyan et al. (2013) and Nairobi River as cited in Masese (2010) among others indicating that the importance of protecting river basins across the world is increasing with the increase in the need to preserve the quality of river water flowing and in other water bodies across the world. This need is the main reason that fueled the physical stream restoration cited in Kithiia (2010) and Verdnoschot (2008) prioritized by local, national, regional and international authorities across the world case in point Netherlands where only 4% of streams flow through their natural geo-morphology, Denmark where only 2% of rivers flow through their natural geo-morphology while in Germany only 5% of rivers flow through such natural geo paths.

2.2. River Pollution

A research carried out by Ayobahan et al. (2014) on the effects of human triggered pollution on river Benin between Ajimele and Koko town indicated that the different anthropogenic activities leads to different levels of pollution along the river's path. In their research, Ayobahan et al. (2014) found similar pollution levels between sampling stations that had similar anthropogenic activities close by. The main factors that resulted in the differences in findings between sampling stations included organic pollution, industrial effluent, soil erosion, nutrient loading and human activities. Among these factors, industrial effluent was found to have the highest level of pollution indicating that areas with high number of industries close to the river had the highest levels of pollution. This informed the recommendation derived from Ayobahan et al. (2014) which sought to have the distance between industries and rivers controlled and discharge of industrial waste into the rivers reduced or eliminated. A similar study carried out by Ding et al. (2015) sought to determine the relationship between land use and surface water quality with a specific focus on Dongjiang River Basin in China. The results of this research indicated that the different land use types led to different levels of pollution where areas with high urban domination with highly concentrated number of industries recorded significantly higher levels of pollution compared to areas with forest domination. A major proportion of land dominated by forests was found to have high dissolved oxygen concentration but water temperature and electrical conductivitywas relatively low (Ding et al. 2015). On the other hand, areas with high concentration of industries were found to have a high level of nitrogen and ammonia concentration and very high chemical oxygen demand as well as biochemical oxygen demand. This pointed towards a strong correlation between industrial growth and water pollution and a very low correlation between forestation and water pollution.

The findings of Pall et al (2013) were replicated in those of Ayobahan et al. (2014) and Ding et al. (2015) which agree with those of an earlier research by Bhuiyan et al. (2013) where he sought to determine the risk posed to the environment by water pollution in river basins around the world.

Osore (2014), added that the current increase in environmental degradation is highly attributable to pollution of water bodies leading to a significant change in eco systems that once used to be self-regulating and self-sustaining from such levels of self-regulation and self-sustenance to levels of dependence on human interference for conservation as was the case in the Nairobi river basin cleaning pilot project of 2007. In his research, Osore (2014) made use of responses from respondents living along the river's path with specific focus on Mathare slums in Nairobi and his findings indicated that the Mathare slums had a significant impact on the quality of water in Nairobi river arising from activities such as waste disposal directly into the river and encroachment into the river's riparian zone (Osore 2014).

2.3. Hydrocarbon pollution in Rivers

Wokoma (2014) sought to determine the extent of hydrocarbon pollution in the Bonny River in the Niger Delta in Nigeria and his findings indicated that hydrocarbon pollution was between 15.6 and 23.5 milligram per litre of water an aspect that showed that the level of hydrocarbon pollution was above the globally permissible levels of 10 milligrams per litre of water. This indicates that the water in Bonny River poses a significant risk to aquatic life as occasioned by the low levels of dissolved oxygen (Wokoma 2014). These findings were consistent with the findings of an earlier research by Onianwa & Essien (1999) who focused on rivers within Ibadan city and found hydrocarbon pollution levels of above 20 milligrams per litre of water.

Danquah (2010) using a structured questionnaire model studied the effect of human activities on the quality of water in River Aboabo in Nigeria and found that among other types of pollutants, industrial waste mainly comprised of hydro carbons was the leading cause of pollution in River Aboabo occasioned by rapid industrial growth and failure of conservation institution. Mukesh (2014) in his study on the Anjan River in India found a significantly low level of hydrocarbon pollutants in his sample tests while the COD and BOD parameters were found to be significantly low indicating that the quality of water in Anjan River was within acceptable minimum global standards thus making the river a good habitat for aquatic animals unlike River Aboabo cited by Danquah (2010) which was found to be unfit as a habitat for aquatic life. However, upon studying Narmada River in India, Mukesh (2016), found a significantly high level of pollutants with very low levels of dissolved oxygen and significantly high levels of BOD and COD, turbidity, carbon dioxide, hardness as well as TDS and TSS among others. All these parameters exceeded the allowable limits of water quality thus making the quality of water in Narmada River unfit for domestic consumption. The findings of Mukesh (2014) and Mukesh (2016) indicated that different human activities lead to different effects on river water quality where river Anjan cited in Mukesh (2014) had significantly low levels of pollutant thus making it suitable for aquatic life and human consumption while river Narmada cited in Mukesh (2016) had significantly high level of pollutants thus making it unsuitable for human consumption or aquatic life support.

Bae (2013) studied the changes in water quality of Hwang River in South Korea with a specific focus on rainfall events with an aim of determining the contents of surface runoffs as a source of pollutants. His findings indicated that rainfall events that occur after a long term dry season led to a significant increase in the acceleration of water quality degradation as a result of the high levels of hydrocarbon pollutants in surface runoffs washed into the Hwang River mainly from highly industrialized areas along the river's path. In addition, Bae (2013) observed that areas that had a lower concentration of industries along the river's path had significantly lower levels of pollutants indicating that proximity of industries to the river had a significant impact on the quality of water in the Hwang River.

2.4. Relationship between industrial activities and water pollution

In his empirical study on water pollution in India, Ramphal (2013) observed that over 70% of the surface water resources and a significantly high proportion of the groundwater resources in India are contaminated by biological, toxic and organic pollutants. More importantly, his research observed the quality of water based on biochemical oxygen demand (BOD) was decreasing year after year between 1995 and 2009. This indicates that the growing BOD levels beyond acceptable levels have significantly contributed to a majority of surface water resources in India being rendered unsafe for domestic use (Ramphal 2013). Kuhlman et al. (2014), found similar results on their study on the effect of anthropogentic activities upstream of conservation areas on the Parabuina River in Santa Virginia in the Atlantic forest where waters in the Parabuina River were found to have significantly high levels of BOD, COD, TSS and TDS in areas around industrial zones while turbidity, coli forms, nitrates and phosphorus were significantly lower upstream compared to downstream. In addition, Kuhlman et al. (2014)'s research findings showed a decreasing trend in pollution parameters as the river progresses from upstream areas to downstream.

Based on the World Health Organization (WHO) (2014), over 90% of wastewater from industries and domestic settlements in developing countries is discharged directly into rivers, lakes and the ocean untreated, an aspect that significantly contributes towards the deterioration of the quality of water especially for populations living downstream in the case of rivers (WHO 2014). These estimates explain the increasing deterioration in water quality observed on Ramphal's (2013) research.

According to the findings of a research by Gichuki (2009), the pollution profile of River Mbagathi around Ongata Rongai area showed a low pollution profile indicating that quality of water in the river is still sufficient for human consumption. Sample sites located closer to the source (Ngong Forest) Indicated an even higher quality based on low TSS, BOD and total Coliform counts an aspect that was associated with the proximity of this research site to the source of River Mbagathi.

Islam, Tusher & Mahmud (2012) studies focused on the both upstream and downstream sections of Turag River in Bangladesh and their findings were in tandem with the findings of Gichuki (2009) indicating that the river ecosystems were more diverse upstream compared to downstream thus agreeing with the findings of Gichuki (2009).

Raburu & Oduor (2011), carried out a research in River Nyando within the Lake Victoria Basin in Kenya focusing on the effects of agro-industrial activities on the quality of water using statistical methodology and their findings indicated that agricultural products such as fertilizers had a significant impact on water quality with pH and alkalinity being the highest recorded parameters as the river progressed downstream. In addition, the findings indicated that dissolved oxygen and total dissolved solids increased in less sloppy downstream areas of river Nyando compared to upstream forested areas (Raburu & Oduor 2011).

In Susheela, Kumar, Gowda & Jagadish (2014), an assessment of the effects of agricultural chemicals as well as industrial effluent on the quality of water in Cauvery River around Krishnar Raja Sagar Dam revealed a high concentration of heavy metals attributed to the pollution load associated with fertilizers as well as high hydrocarbon content associated with the industrial waste discharged into the rivers from industries located along the river's path. This revealed a rather severe impact of human activities on the quality of water in Cauvery River and such quality deteriorates as the river progresses downstream (Susheela, Kumar, Gowda & Jagadish (2014).

2.5. Level of coliforms and coliform counts in rivers

According to Danquah (2010), dumping of refuse, channeling of raw sewage, open defecation, discharge of untreated effluents and dumping of industrial waste directly into Aboabo River were cited as the main causes of the high coliform counts observed from the scientific tests carried out which recorded coliform counts of 300×10^4 per 100ml of water. This exceeded the allowable standard of quality in drinking water which is zero per 100ml in coliform counts. As such, the pollution of Aboabo River led to a significant decrease in the productivity of populations living in the river basin as a result of poor health which was found to be in significantly high correlation with the quality of flowing in River Aboabo (Danquah 2010). In their Study on Indian Rivers, Do, Joshi & Stolper (2014), found a statistically significant correlation between infant mortality deaths plus water diseases and the quality of water in rivers in respect to the level of fecal coliforms recorded from their test samples. They further observed that with every 1% increase in fecal coliforms in Indian rivers, additional 3 to 5 deaths per 100,000 births occur in India in any given month. This indicates that there is a strong correlation between human activities on the rivers path in respect to disposal of fecal waste into the river and the quality of water flowing in such rivers (Do, Joshi & Stolper 2014).

With Bacteriological water quality as his focal point; Rop (2010) studied the effect of anthropogenic activities on water quality in the Mara River basin covering the Bomet area part of the Mara River's main tributary Nyangores River. His findings pointed towards a significantly high rate of degradation of the water quality in Nyangores River and eventually the Mara River as a result of the poor sanitation policy framework observed in the Bomet Township where fecal waste matter is discharged directly into the river. Rop (2010) further observed that the Tenwek Mission Hospital has its waste lagoons in close proximity to the banks of River Nyangores thus the hospital's waste effluent is disposed directly into the river untreated an aspect that possess a significantly high health risk to the population living downstream. Via the use of Membrane Filtration Technique (MFT) Rop (2010)'s research tests found significantly high levels of Salmonella spp as well low levels of BOD and COD. These parameters pointed towards a significant negative effect of anthropogenic activities on the quality of water in River Nyangores a tributary of the Mara River thus reducing the ecological integrity of the Mara River as a water resource for domestic and zoological use.

In her research on the Anti-microbial Susceptibility Profiles in Athi River, Wambugu (2015) studied the Athi River as a reservoir for highly resistant strains of microbial organisms. From a total of 318 samples collected from six sampling locations in Athi River, antimicrobial susceptibility testing was carried out using the Kirby Bauer diffusion method and the results indicated that the samples contained a total mean coliform count of 2.7×10^4 coliform units per milliliter of water. The Escherichia coli isolates collected were found to be 63.8%

resistant to ampicillin and 99.4% resistant to gentamicin while 65.4% of all isolates were found to be resistant to ≥3 classes of antibiotics. Wambugu et al. (2015) further observed that more resistant strains of coliforms were found in areas closest to industrial complexes compared to the sections of the river that were mainly dominated by virgin unexploited land. As such, the growth in industries within the Athi River Locality was found to be a significant contributor towards the high levels of coliform counts in Athi River thus leading to a high potential risk to human and animal health. Matano et al (2013) studied the Mara River with an aim to determine the effects land use on the levels of Microbial Contamination in Mara River ecosystem in Kenya and Tanzania using the same parameters as used in Wambugu, et al. (2015). They used samples from five sampling sites with different land use along Mara River's path and their findings indicated that the lowest concentration of Escherischia coli was recorded at Silibwet Bridge which was also the location with the lowest concentration of human settlement while Kirumi Bridge recorded the highest concentration of Escherischia Coli and it also had the highest concentration of human settlements.

2.6. Research Gaps

As shown in the review of previous literature, various researchers have over the past focused on the quality of water in various parts of the world. Do, Joshi & Stolper (2014), Danquah (2010), Islam, Tusher & Mahmud (2012) all found a significantly high correlation between human activities and the quality of water flowing in rivers while only one researcher among the reviewed research papers i.e. Mukesh (2014) found a low level of pollution in river Anjan which was mainly occasioned by less industrialized nature of the region along the river's path thus minimizing pollutants. In addition, Ayobahan et al. (2014), Bhuiyan et al. (2013), Gikundi (2014), Osore (2014) and Masese (2010) among others observed that pollution of rivers posed a significant risk to sustainable development especially in developing economies due to the reliance of its population on river water as a resource for domestic, industrial and agricultural use.

Researchers explored various categories of human activities where Wang et al. (2012) and Wokoma (2014) found a significant negative impact on the quality of water in rivers occasioned by economic activities carried out by populations living along the rivers path. On the other hand, Onianwa & Essien (1999) focused on agricultural activities, Eruola et al. (2011), Ramphal 2013), Islam, Tusher & Mahmud (2012), and Susheela, Kumar, Gowda & Jagadish (2014) explored industrial activities while Bhat, Andrabi & Shukla (2011) explored cultural activities. All these activities were found to have a negative impact on the quality of water flowing through rivers.As such, previous research across the world seemsto draw a uniform conclusion where anthropogenic activities have a significant negative impact on quality of water in rivers and such impact seem to decrease as the rivers progresses downstream.

For Kenya in particular, researchers such as Raburu & Oduor (2011) and Ngila (2012) studied the effect of human activities on the quality of water in various rivers in Western Kenya and their findings agree with those of researchers in other parts of the world where a significant negative relationship was found between human activities and water quality. Other researchers such as Gichuki (2009) studied the pollution profile of River Mbagathi on the upstream sections around Ongata Rongai while Wambugu et al. (2015) focused on coliforms as a pollutant within the Athi River area findings of which pointed towards a negative relationship between human activities and water quality. Various researchers both locally and internationally have focused on the coliforms and coliform counts as a pollutant in various rivers across the world. Their findings seem to reverberate across the board where in all the research explored, significantly high levels of coliforms were recorded all of which were beyond acceptable standards set by the World Health Organization as well as other governmental and non-governmental agencies across the world.

Although most of the above mentioned researchers have carried extensive researches on various locations in various rivers across the world and their findings are indicative of a deteriorating quality of water as rivers flow downstream, not enough interest has been accorded to the downstream sections of Athi River especially around Athi River locality which is home to numerous factories that use the river for their day to day production needs as well as a medium for waste disposal.Apart from Wambugu et al. (2015) who studied coliforms in Athi River and Gichuki (2009) who studied the pollution profile of the upstream sections of River Mbagathi, very low research interest has been accorded to Athi River as a locality. In addition, the Athi River area has been growing significantly as a residential destination fueled by the expansion of Nairobi City an aspect that raises its profile as a research destination with an aim of finding solutions to water quality issues.

These are the main reasons behind selection of Athi River locality as the research site for purposes of this study. This study therefore sought to close this gap by investigating the hydrocarbon pollution in Athi River, industrial activities and their proximity to the river as well as their significance in water pollution and the level of Coliforms/ coliform counts in Athi River.

III. Data And Methodology

2.7. Research Design

A stratified survey coupled with scientific observation research designs were used for this study in which a descriptive methodology aided in collecting and analyzing quantitative and qualitative data from the respondents while scientific tests were used to test various parameters of the samples collected from the research site. The research design borrowed from two research methods that sought to make use of existing data mainly obtained from respondents via use of questionnaire method of data collection while collecting new information from the research site by collecting samples from the river and testing them scientifically in the laboratory.

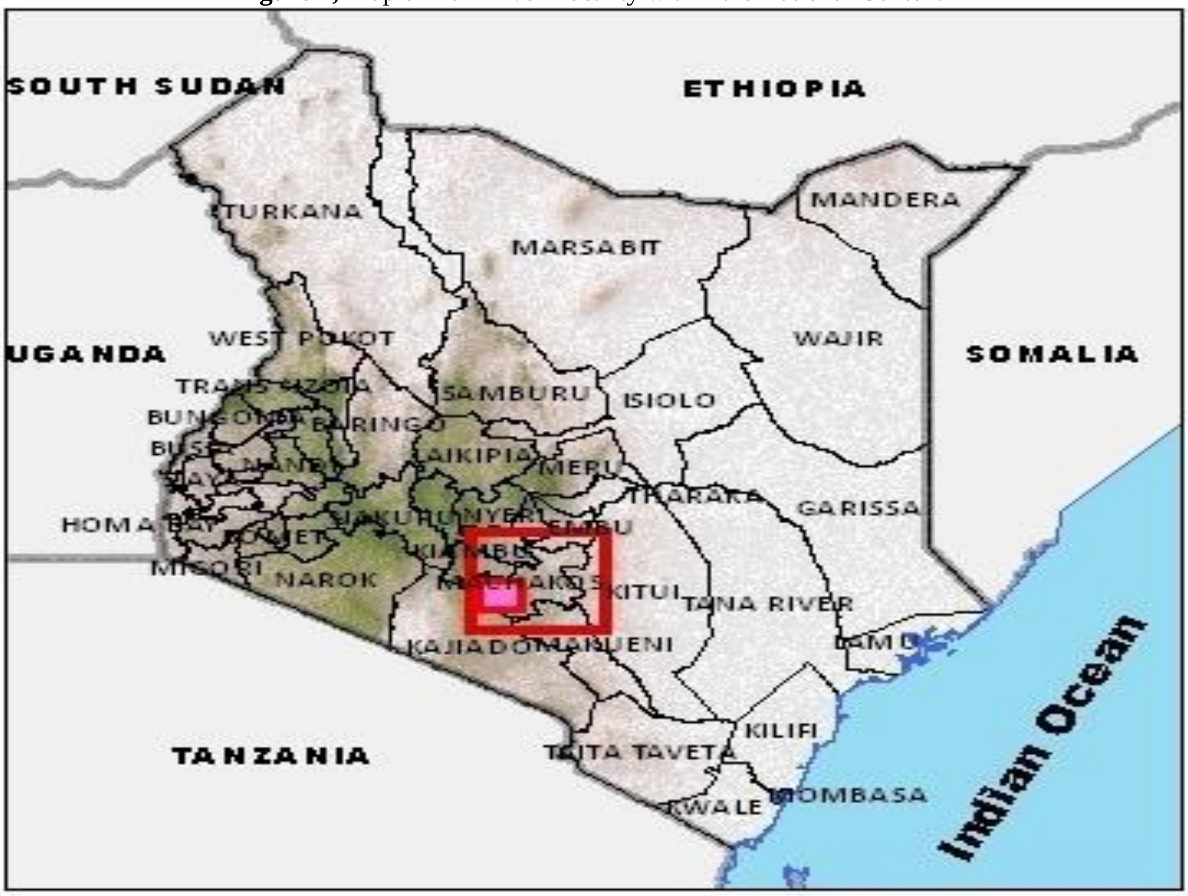
2.8. Research Site

The research was carried out along Athi River which flows through the Athi River locality/township that is located in Machakos County, Kenya. Athi River holds the second position in length and volume among the largest rivers in Kenya after Tana River and it flows from the Ngong Hills along the southern border of the Nairobi National Park as Mbagathi River, joins the Nairobi River and River Ruiru at Oldonyo Sabuk to become Athi River, joins the Galana river in the Kapiti and Athi Plains to become Athi-Galana River and finally joins Sabaki river to drain into the Indian Ocean as Athi-Galana-Sabaki River. It travels a total of 400 kilometers and covers a basin area of 70,000 km^2 (Wambugu et al. 2015).

The research site is located between GPS Positions -1.426634°, 36.9964° and -1.467398°, 26.961971° and -1.426743°, 36.964021° and -1.383658°, 36.771805°. The GPS position -1.383658°; 36.771805° was used to map the upstream sample point that was used for comparative purposes between the main research site and the upstream areas of Athi River. On the other hand, the GPS Position -1.426634°, 36.9964° was used to map the downstream sample point for comparative purposes between the main research site and downstream sections of Athi River. Industries used for the research are all located within the research site which falls on the rivers path between GPS Coordinates -1.467398°, 26.961971° and -1.426743°, 36.964021°.

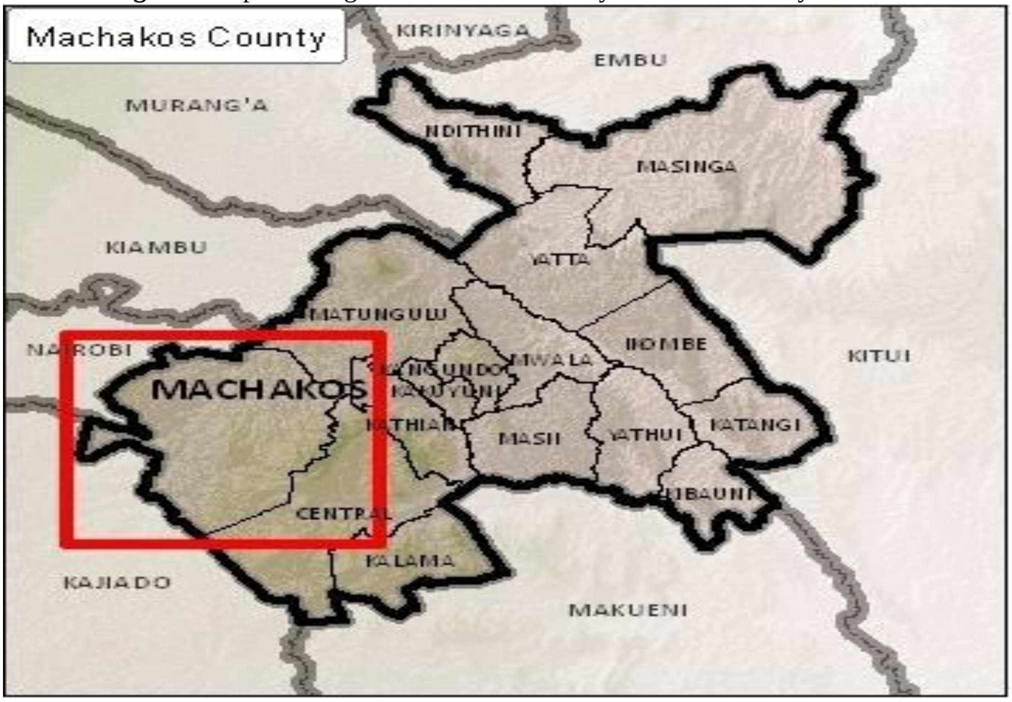
Athi River is located on 1.45^0 South latitude and 36.98^0 East longitude, at an altitude of 1,532 meters above sea level.

Figure 1; Map of Athi River Locality within the National Context



Source; CETRAD, (2017)

Figure2: Map Showing the Athi River Locality within the County Context.



Source; CETRAD (2017)

The Athi River locality is located on a relatively flat landscape that makes the flow of the Athi River slow and steady across the research site. However, the upstream section of Athi River is characterized by hills and valleys rolling gently into the Nairobi National Park where low gradient plains take over across the Athi River Locality (Statoids 2010).

2.9. Target Population and sample size

The target population for the qualitative part of the research was the professionals working within the technical departments of industries operating within the research site carefully selected based on their knowledge on the waste management procedures and standards not only within their organizations but also acceptable standards stipulated by the government and other governmental and non-governmental environmental management agencies. To ensure that the information derived from the research was wide enough to cover a reliable proportion of the target population, a sample size of 20 respondents was selected to be interviewed and their responses were recorded in questionnaires. This sample size was spread across the research site but mainly along the path of Athi River to ensure that the respondents have sufficient knowledge about the topic at hand to assist in achieving the objectives of the study. In addition, quantitative samples were collected from the river at 10 distinct sampling locations and tested in the laboratory to determine the level of pollution based on different pollution parameters as well as the relationship between such pollution parameters and the surrounding human activities along the rivers path.

2.10. Data Collection

Data was collected using structured questionnaires targeting individuals working within the technical departments of industries operating within the research site. The questionnaires were based on both closed ended questions and open ended question structure to which the respondents had five options from which to choose a response and these are: strongly agree, agree, neutral, disagree and strongly disagree or state in their own words what they think of the parameter being queried. These responses were then assigned variables that helped in manipulating data into useful information for purposes of achieving the research objectives as explained in the methodology section. In addition, water samples were collected from different sampling locations within the research site and the date, the exact location and the size of samples recorded on each sample on site for ease of identification before being taken to the laboratory for testing. The sample test results were then compared with data and information obtained from government and non-governmental agencies such as NEMA, WHO and UNEP among others to determine if the quality of the samples falls within the acceptable standards set out by the said agencies.

2.11. Data Analysis and Processing

The water sample data was analyzed in a scientific laboratory to determine the levels of various pollution parameters as outlined below;

2.11.1. Hydrogen Ion Concentration (PH)

This parameter was used to determine the level of alkalinity of the samples. This parameter mainly informs the level of acid based neutralization, softening, precipitation, coagulation, disinfection and corrosion control that is required to bring the water to quality that is suitable enough for drinking.

2.11.1.1. Determining principle on pH test

The method used to measure the PH is the electrometric method which is by guided the principle of determining the activity of the hydrogen ions within the test sample by taking potentiometric measurement of the sample using a standard hydrogen electrode and a reference electrode. To minimize interference of the pH test, a glass electrode was used due to its characteristic as an electrode that is relatively free from interference from parameters such as color, turbidity, colloidal matter, high salinity and oxidants. To minimize the effect of sodium error at PH levels of more than 10, low sodium error electrodes were used and standard buffers were used to minimize the chemical effects caused by the changes in equilibrium.

2.11.1.2. Testing procedure

A pH meter with a temperature measuring device, small beakers and stirrers were used as the main apparatus while buffer solutions 4 and 7 and distilled water were used as the reagents.

- The meter was calibrated using the buffer solutions,
- The electrode was removed from the storage solution, rinsed and blot dried with a soft tissue.
- The electrode was then placed in initial buffer solution and adjusted such that the meter reads the pH of that buffer.
- The electrode was then rinsed with distilled water and placed in the second buffer and adjusted to read to the pH of that second buffer at the same temperature.
- A sample was placed in the beaker and equilibrium between sample and the electrodes was established by stirring the sample to ensure homogeneity, the sample was then stirred gently to minimize carbon dioxide entrainment.
- The temperature of the sample was then adjusted to match the temperature of the buffer solution and then allowed to stabilize and the pH value (A) was read and recorded on a datasheet. The electrode was then removed from the sample rinsed and then a fresh sample was poured into a beaker, the procedure repeated and the pH value (B) was read and recorded on a datasheet.
- The pH of the sample was then calculated by taking the average between pH value A and pH value B as follows $pH = \frac{pHValueA\ + pHValueB}{2}$

2.11.2. Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand parameter was used to measure the amount of oxygen that would be required to break down the decomposable organic matter under aerobic conditions (Gichuki 2009 and Joshua and Nazrul 2015). This parameter was used to measure the amount of oxygen that waste matter discharged into River Mbagathi would require to break down the biodegradable matter and the results would help to determine if the waste is biodegradable under the natural conditions in the river or not. It results from the respiratory processes of micro-organisms living in the water.

2.11.2.1. Determining principle on BOD test

The main principle behind BOD Measurement is the level of oxygen microorganisms would require to break down organic substances dissolved in water. BOD's main application lies within the waste water treatment plants and it is among the main parameters that determine if a water sample can be purified or not. BOD can be determined directly by measuring oxygen or indirectly by measuring carbon dioxide as a molecule of oxygen is converted into a molecule of carbon dioxide since organisms such as bacteria inhale oxygen and exhale carbon dioxide.

A Respirometric method was used where a molecule of oxygen was converted into a molecule of carbon dioxide and the change in pressure measured. However, since there is no direct change in pressure when a molecule of oxygen is converted into a molecule of carbon dioxide via respiration, sodium hydroxide was used in a chemical reaction with carbon dioxide to form sodium carbonate thus removing carbon dioxide from the gas phase resulting in a measurable change in pressure occasioned by respiration of oxygen. This negative pressure measurement is then converted into BOD Value using the formula below.

$$BOD = \left(\frac{M(O_2)}{R.T_M}\right)\frac{\left((V_{tot} - V_1)\right)}{V_1} + \frac{T_M}{T_O} .P(O_2)$$

Where;

- $M(O_2)$ represents the molecular weight of oxygen which is equivalent to 32000mg/mol
- R represents a gas constant (83,144 LOhPa/(molOK))
- T_O represents temperature (273.15K)
- T_M represents the measuring temperature (293.15K) for BOD5
- V_{tot} represents the volume of the bottle in mL
- V_1 represents the volume of the sample in mL
- α represents the Bunsen absorption coefficient
- $.P(O_2)$ represents the difference in partial oxygen pressure (hPa)

2.11.2.2. Testing procedure

- The measuring range of the sample to be analyzed was estimated and all the additional solutions for homogenization added before the sample was filled in the overflow measuring flask.
- The homogenized sample was then transferred by means of a funnel into a graduated measuring flask, a magnetic stirrer bar inserted into the bottle and two sodium hydroxide pellets placed into the rubber sleeve which is then inserted onto the bottle.
- The OxiTop measuring head was then screwed tightly on the bottle where the rubber sleeve ensures that the bottle is tightly sealed.
- The measurement was then taken starting from the OxiTop head, on the controller and the OxiTop C by pressing S and M together until the display on the controller read zero.
- The graduated measuring flask was then placed in an incubator for five days at 20 °C
- The results were read and recorded on a data sheet after the five days.

2.11.3. Chemical Oxygen Demand (COD)

The chemical oxygen demand parameter is used to measure the quantity of oxygen that would be required to oxidize the organic matter in a waste water sample, based on specific conditions of oxidizing agents, temperature and time (Joshua and Nazrul 2015). As a general rule, BOD is 50 to 70% of the COD. As such, COD value is determined faster than BOD and is highly useful in the industrial waste treatment and control of waste treatment plants due to the fact that majority of organic compounds are oxidized completely in the COD test (Joshua and Nazrul 2015).

This test was therefore used to measure the extent of pollution in River Mbagathi as a result of industrial waste discharged into the river.

Determining principle on COD Test

Since COD is approximately half the BOD value, the determining principles under BOD applies on the COD.

2.11.3.1. Testing procedure

- 0.4 grams of mercuric sulfate crystals were placed in a refluxing flask and few granules of anti-bumping added
- 10 ml of standard potassium dichromate solution was then added and the flask connected to the condenser
- 20 ml of the sample was then added into the refluxing flask
- 30 ml of concentrated sulfuric acid containing silver sulfate was then added through the open end of the condenser while mixing the solution thoroughly by swirling while adding the sulfuric acid
- The mixture was then refluxed for two hours, cooled and then added to 90 ml of distilled water through the condenser and record it as sample B
- A blank sample containing 20 ml distilled water was then refluxed together with the reagents and recorded as sample A
- The excess dichromate was then titrated with standard ferrous ammonia sulfate using 2 to 3 drops of ferroin indicator. The end point reading was then taken as the color changed from blue-green to reddish brown.
- The COD in mg per litre (mg/l) was then calculated using the equation below and recorded on a data sheet.

$$COD\left(\frac{mg}{l}\right) = \frac{(A-B)Mx\ 8000}{MISample}$$

Where;

- A represents the volume in ml of the ferrous ammonium sulfate used in the blank
- B represents the volume in ml of the ferrous ammonium sulfate used in the sample

- M represents the molarity of the ferrous ammonium sulfate

2.11.4. Dissolved Oxygen (DO)

Dissolved oxygen parameter was used to measure the quantity of oxygen dissolved in water and it is necessary to determine if the water under scrutiny can support aquatic life (Gichuki 2009 and Joshua and Nazrul 2015). This test was therefore used to determine the level of pollution in River Mbagathi as a result of hydrocarbons such as oil discharged into the River. Hydrocarbon reduce the amount of oxygen dissolved in water therefore making this test the ideal test for measuring the suitability of water in River Mbagathi to support aquatic life.

To test this parameter,

- 300 ml of the sample was placed in a BOD bottle
- 2 ml of manganese sulfate $MnSO_4$ was added to the sample in the BOD bottle
- 2ml of sodium azide was added
- The mixture was then shaken well and 2 ml of concentrated sulfuric acid (H_2SO_4) was then added into the mixture
- 200 ml of the mixture was titrated against 0.002 molecules of sodium thiosulphate (($Na_2S_2O_3$) in 0.002 molecules of iodine and 2ml of starch indicator was added near the end point

The reading of the sodium thiosulphate was thentaken and recorded on a data sheet where each milliliter of sodium thiosulphate is equivalent to 1 milligram of Dissolved oxygen per litre (1ml Na2S2O3 = 1mg D.O/L)

2.11.5. Total Suspended Solids (TSS)

This test was used to measure the amount and composition of solids that cannot dissolve in water and are not heavy enough to sink. The composition of these solids was used to determine the composition of solids that are suspended in the water at various points on the river's path.

2.11.5.1. The determining principle on the TSS test

The rationale behind this test is to determine the increase in weight of the weighed standard glass fibre filter through which a well-mixed sample is filtered and the residue retained on the filter dried to a constant weight at 103 to 105 °C. This increase in weight represents the total suspended solids. In the event that the suspended material clogs the filter and prolongs the filtration process, then the total suspended solids is determined by the difference between total solids and the total dissolved solids.

2.11.5.2. Testing procedure

- A 50 ml well mixed sample was filtered through a sintered glass with a crucible porosity of number 4.
- The residue that remained on the filter was then dried ay 105 °C for 1 hour and then cooled in a dessicator after which it was weighed.
- The drying and cooling process was then repeated until constant weight was obtained.
- The total suspended solids value was then obtained using the formula shown below.

$$TSSinmgperliter = \frac{(A - B)x\ 1000}{SampleVolume}$$

Where;

- A represents the weight of crucible plus residue in milligram (mg)
- B represents the weight of the empty crucible in milligrams (mg)
- Alternative the total suspended solids can be obtained by getting the difference between the total solids and the total dissolved solids.

The results obtained from the above process were recorded on the data sheet.

2.11.6. Color

2.11.6.1. The determining principle on the color test

This test was used to determine the color of the water sample where clean water is expected to be clear while various ranges in color would determine the extent of pollution in the water. The difference in color in the water is mainly occasioned by the presence of different metallic ions, humus weed and industrial as well as human waste. The measuring unit for color in the water is hazen units. Hazen Units basically refers to the color produced by 1 mg/l of platinum in the form of chloroplatinic acid.

2.11.6.2. Testing procedure

To test for the color parameter in water the following procedure was followed.

- 50 ml of supernatant sample was placed in a 50 ml nesslar tubes and the tubes placed into the right hand compartment of the lovibond apparatus.
- 50 ml of distilled water was then poured into the left hand compartment of the lovibond apparatus and the color matched using the color disc.
- Where the color range was outside the highest range of 90 hazen units dilutions were made to bring back the color of the water within the allowable range.
- The color parameter was then recorded into the data sheet as the equivalent of the color of the sample multiplied by the dilution factor.
-

2.11.7. Turbidity

This test was used to determine the cloudiness or haziness of the water as a result of the large number of individual particles that are suspended in the water and cannot be visible to the naked eye.

2.11.7.1. The determining principle on turbidity test

Turbidity is caused by the scattering of light in different directions by the un-dissolved substances in the water that prevent the light to travel in a straight line. This parameter should be determined on the day the sample is taken. However, if storage is unavoidable, it is advisable to store the sample in the dark for a maximum of 24 hours. Turbidity is measured in nephelometric turbidity units (NTU). The apparatus used measure this parameter include the nephelometer that has a light source for illuminating the sample and a light detector for reading out the intensity of the light scattered.

2.11.7.2. Testing procedure

- The nephelometer was switched on and allowed to warm up for 15 minutes
- Turbidity standards of 20 and 40 NTU were made and the nephelometer calibrated accordingly.
- The cuvettee was then rinsed and a 50 ml sample was poured into it to read the turbidity.
- Where the turbidity was higher than the meter reading, dilutions were made until the turbidity reading is within the metre reading.
- The turbidity is then calculated by multiplying the turbidity reading with the dilution factor. These readings were then recorded on the data sheet.

2.11.8. Hardness

This test was used to determine the level of calcium and magnesium dissolved in water in milligrams per liter. Hardness may be as a result of natural geological processes or pollution from industries and commercial operations along the water bodies’ path.

2.11.8.1. Determining principle on the hardness test

When Ethylenediaminetetra acetic acid and its sodium salt (EDTA) are added into a solution of certain metal cations, they form a chelated soluble complex. When a small amount of dye of erichrome black T indicator is added to an aqueous solution containing calcium and magnesium ions at a pH of 10.0 the solutions turn in color into wine red. When EDTA is then added as a titrant, the calcium and magnesium is complexed and when all calcium and magnesium have been complexed, the solution turns from wine red to blue marking the end point of the titration process. Reagents used include buffer solution, standard EDTA titrant of 0.01 M and Standard calcium solution.

2.11.8.2. Testing procedure

- 30 ml sample was measured and poured into a conical flask
- 1 ml of buffer solution prepared by dissolving 1.179g of disodium salt of EDTA dehydrate and 780 mg magnesium sulfate ($MgSO_4.7H_2O$) and then adding 16.9 g NH_4Cl and 143 ml concentrated NH_4OH mixing them and then diluting the solution with distilled water is added.
- An appropriate amount of dye indicator was then added and the solution titrated with 0.01 M of EDTA until the color changed from red to blue.
- The results of hardness parameter were then obtained using the equation below and recorded on the data sheet.

$$TotalHardness = \frac{(mlofEDTA)x\ 1000}{VolumeofSampleUsed}$$

2.11.9. Total Dissolved Solids (TDS*)*

2.11.9.1. Determining principle on the TDS test

This test was used to determine the type and composition of the solids that can dissolve in water. The composition of these solids was used to determine which solutions are occasioned by the natural flow of the river and which ones are as a result of the anthropogenic activities along the rivers path. The basic determining principle for this test is that the increase in the weight of the weighed dish after a well-mixed sample is filtered and evaporated to dryness to a constant weight at 180 °C represents the total dissolved solids.

2.11.9.2. Testing procedure

- A clean dish was heated to 180 °C for about one hour and then cooled to room temperature in a desiccator.
- 50 ml of a well-mixed sample was filtered and the filtrate put into a pre-weighed dish.
- The sample was then evaporated to dryness and then the evaporated sample was then dried for one hour in an oven at 180 °C.
- The dish was then cooled to room temperature and weighed.
- The process was repeated again until a constant weight was obtained.
- This weight was used to calculate the total dissolved solids using the equation below and the findings recorded on a data sheet.

$$TDS(mgperlitre) = \frac{(A - B)x\ 1000}{SampleVolume, ml}$$

Where;

- A represents the weight of the dried sample plus the dish in mg
- B represents the weight of the dish in mg.

2.11.10. Chloride (Cl^-)

2.11.10.1. The determining principle on the Chloride test

This test was used to determine the level of chloride ions in the water in comparison with the accepted regulations on the level of chloride ions in secondary drinking water. Based on EPA Secondary Drinking Water Regulations, the recommended maximum concentration of chloride ions in drinking water is 250 mg/l while that of sulfate ions is also 250 mg/l (World Health Organization 2011).

As a guiding principle, a neutral solution or a slightly alkaline solution can be used on potassium chromate to indicate the end point of the silver nitrate titration of chloride. Silver chloride is then precipitated quantitatively before red silver chromate is formed.

2.11.10.2. Testing procedure

- A 100 ml sample was taken and 3ml of Aluminium hydroxide ($AL(OH)_3$ suspension was added to it, mixed, left to settle and then filtered.
- Where sulfite, sulfide or thiosulfate was present, 1ml hydrogen peroxide (H_2O_2) was added and stirred for 1 minute.
- The sample was then titrated in pH range of 7.0 to 10.0 and where the pH was not in the range of 7.0 to 10.0, the pH sample was adjusted using sulfuric acid (H_2SO_4).
- 1 ml of potassium chromate (K_2CRO_4) indicator solution was then added and titrated with standard silver nitrate ($AgNO_3$) titrant until the pinkish yellow color was achieved marking the titration end point. The readings were taken and recorded on a data sheet.
- Silver nitrate ($AgNO_3$) titrant was then standardized and reagent blank value established where a value of 0.2 to 0.3 ml was deemed normal.
- The value of this parameter was then obtained by using the equation below and was then recorded on the data sheet.

$$ChlorideinmgperLiter = \frac{(A - B)xNx35450}{Sampleml}$$

Where;

- A represents volume of the titrated sample in ml
- B represents the volume of the titrated blank in ml
- N represents the normality of the silver nitrate ($AgNO_3$)

2.11.11. Electrical conductivity

2.11.11.1. Determining principle on electrical conductivity

This test was used to determine the ability of the water samples as an aqueous solution to transmit an electric current from one end to the other. The level of cations and anions in the water sample, the total concentration of such cations and anions, their mobility, valence as well as the temperature of the water sample determines the sample's ability to conduct electricity (Fianko 2013). The conductivity is measured using a conductivity meter.

2.11.11.2. Testing procedure

- The electrical conductivity meter was switched on the electrode rinsed to remove impurities
- Distilled Water was poured into a beaker to a level enough to cover the sensitive part of the electrode.
- The meter button was then pressed to read the conductivity readings in micro Siemens (ms)
- The electrode was then rinsed and dipped into the sample and recorded the reading on the data sheet.

2.12. Pearson correlation analysis

Pearson correlation analysis was used to determine the correlation between distance between the industries and the river in meters and the level of pollution in Athi River. Each of the parameters tested in the laboratory was used as the dependent variable to determine if industries' proximity to the river has an influence on the level of pollutant variable observed.

2.13. Regression analysis

Singular Regression analysis was used to determine the individual relationship between water pollution in Athi River and the distance between a specific industry and the river. The distance between the industries and the river was the independent variable in equation 2 below while the parameter measured in section 4.8 above was used as the dependent variable based on an average basis across the sample test points to determine if distance between the industry and the river influences the level of pollution parameter observed.

$PPi = \propto + \beta Dppi1 + \varepsilon$......................**Equation 2**

Where;

- PPi represents the average pollution parameter i across the sample points on the river's path
- $\propto$ represents the regression alpha coefficient
- D represents the distance between the industry and the river
- $\beta Dpp1$Represents the beta coefficient of the distance between industry 1 and Athi River and the pollution parameter i.
- ε Represents the regression error term.

On the other hand, multiple regression analysis was used to determine the combined relationship between factors affecting water quality in Athi River such as the distance between the selected industries and the river. The distances between the industries and the river was the independent variables in equation 3 while the pollution parameters measured in section 4.8 above was used as the dependent variable based on an average basis across the sample test points to determine if the distance between the industries and the river has an influence on the level of pollution parameter observed.

$PPi = \propto + \beta Dpp1 + \beta Dpp2 + \beta Dpp3 + \beta Dpp4 + \beta Dpp5 + \varepsilon$.............**Equation 3**

Where;

- PPi represents the average pollution parameter i across the sample points on the rivers path
- $\propto$ represents the regression alpha coefficient
- $\beta Dpp1, \beta Dpp2, \beta Dpp3, \beta Dpp4, \beta Dpp5$ represents the beta coefficient of the distance from industry to the river and pollution parameter 1, Industry to the river and pollution parameter 2, Industry to the river and pollution parameter 3, Industry to the river and pollution parameter 4 and Industry to the river and pollution parameter 5.
- ε Represents the regression error term.

2.14. Test of statistical significance

To test the statistical significance of the results obtained from the regression analysis section, the t-test statistic was used. This test is obtained from the regression output indicating that the regression analysis will yield the results for equation 2 and equation 3 as well as the results of the t-test statistic.

2.15. Issues of reliability and instrument validity

To enhance the reliability and the validity of the data, the samples were tested in government accredited laboratory and an official stamp of approval sought from the professionals involved in the laboratory tests. The research carried out scientific tests on samples collected from various distinctsampling locations on Athi River's path with an aim of eliminating location bias that may compromise the reliability and validity of the results if such samples were collected from one or a few sampling locations. The respondents were also selected from various industries operating along Athi River's path to ensure that information and data collected is widespread across the research site. In addition, the combination of qualitative data and information collected from respondents working within the research site and the quantitative results of scientific tests carried out enhanced the reliability and validity of the research findings.

2.16. Legal and Ethical Considerations

Legal and Ethical considerations were upheld in this study as the researcher did not compel respondents to participate in the study but rather let respondents participate on their own volition (Gall et al., 2007). Another very important ethical and legal consideration was for the research to secure appropriate authorization from all authorities concerned (the university (ANU) and the National Commission for Science, Technology and Innovation (NACOSTI), as well as from the respondents. To ensure adherence to ethical standards, the research accorded appropriate credit to all ideas, premises, processes, results and information obtained from other people or institutions. An objective approach was used in all phases of the research to ensure an accurate account of the research topic is reflected in the results. In particular, consent was obtained from each respondent before involving them in the intended research and confidentiality in the treatment of non-public information obtained from the respondents in the information and data gathering process was guaranteed.

III. Results And Findings

2.17. Preliminary findings based on observation

Among the ten sampling locations, none of them except sampling site 10 showed a sign of aquatic life as shown in the pictorial representation on plate 1 below.

Plate 1; Sign of aquatic life on sampling location 10

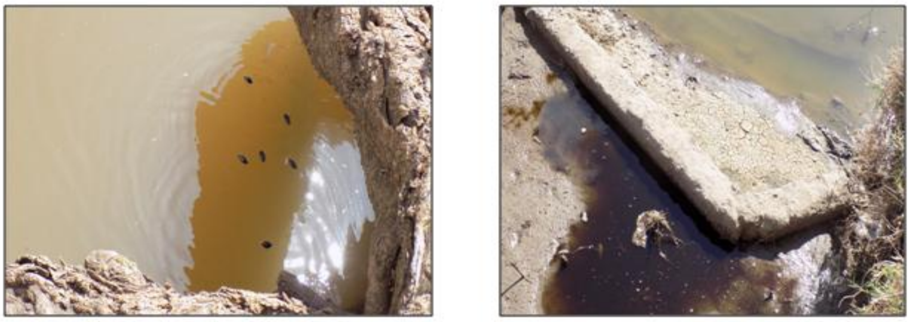


Plate 11: Signs of aquatic life on sampling location 10 compared to waste disposal at sampling location 4

Plate 1 above provides preliminary evidence that shows the effect of pollution as the river flows downstream where left hand portion of the plate shows evidence of life at sampling location 10 which is located closer to the source of the river in the Ngong Forest. On the other hand, the right hand portion of the plate shows the filth discharge into the river at sampling location 4 an aspect that completely changes the ability of the river to support aquatic life as is evident in all the sampling locations located within the research site as well as downstream none of which showed any signs of aquatic life.

2.17.1. Results of physical and chemical pollution parameters tested

The physical and chemical parameters that were tested in the laboratory are represented in table 1 below.

Table 1:Laboratory results for parameters at different sampling locations

Lab No.	670/16/17	671/16/17	672/16/17	673/16/17	674/16/17	675/16/17	676/16/17	677/16/17	678/16/17	679/16/17	Standard
Sampling Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Parameters											
Ph @ 23 °C	6.67	6.78	6.81	6.83	6.84	6.58	6.50	6.90	7.05	6.86	6.5 - 8.5
BOD (mg/L)	13.00	15.00	20.00	25.00	2.00	32.00	3.00	11.00	26.00	19.00	30.00
COD (mg/L)	90.00	100.00	80.00	90.00	70.00	160.00	90.00	150.00	70.00	110.00	50.00
Dissolved Oxygen (mg/L)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.05	0.10	-
Colour (Hazen)	40.00	30.00	800.00	800.00	800.00	300.00	600.00	30.00	30.00	20.00	-
Turbidity (NTU)	12.10	5.45	12.20	37.95	2,225.00	1,850.00	2,900.00	19.70	5.55	18.30	
TDS (mg/L)			1,336.67	1,536.50	1,436.67	1,261.50	1,695.00	ND	420.00	ND	600.00
TSS (mg/L)			1,763.50	2,108.33	1,901.67	1,675.00	2,146.67	391.50	1,026.50	ND	600.00
Total Hardness (mg/L)		100.00	96.00	76.00	72.00	84.00	144.00	180.00	140.00	220.00	60.00
Chlorides (mg/L)		59.56	14.18	17.02	8.51	5.15	14.18	184.34	184.34	290.00	250.00
Conductivity (μs)	555.00	532.00	213.00	231.00	194.00	207.00	226.00	12.01	1,419.00	1,580.00	-

2.17.1.1.pH tested at a temperature of 23 °C

Based on the results presented in table 1, the pH values range from 6.5 to 7.05, where the highest pH value being recorded at sampling location 9 while the lowest pH value was recorded at sampling location 7. This indicates that sampled water was within the acceptable standards according to theNational Environmental Management Authority (NEMA) which requires pH values to be within the range of 6.5 and 8.5. The results shows that the sampled water was within the allowable pH values provided by the WHO which requires pH values to be within 1 point of the neutral value of 7 (World Health Organization 2011). The highest pH values were recorded on sampling location 8, 9 and 10 all of which are located on the upstream section of the research site. Sampling location 8 and 9 hadpH values that are closest to the neutral pH value of 7 (Kenya Bureau of Standards2011).The pH values decreases as the river flows downstream indicating an increase in acidity with sampling point 6 and 7 having the highest levels of acidity at pH values of 6.58 and 6.50 respectively. This indicates that since these sampling locations have a relatively higher concentration of industries in close proximity compared to the other sampling locations, the industries have an impact on the pH levels of the river water. Sampling location 1 which is the farthest downstream sampling location has the third lowest pH value indicating that the acidity level of the water may be attributed to the industries located before this location on the rivers path.

2.17.1.2.BOD Presented in milligrams per Litre (mg/l)

As shown in table 1, the BOD levels among the ten sampling locations range from 2 mg/l to 32 mg/l litre. Among the ten sampling locations only sampling location 6 recorded a higher than recommended BOD of 32 mg/l indicating that on average the level of oxygen required by microorganisms to break down biodegradable matter in the water is lower than the required maximum standard of 30 mg/l. The results showed no distinct difference between upstream sampling locations and downstream ones indicating that the BOD parameter does not provide any evidence that industries or settlements within the research site have any significant impact on the quality of water in Athi River.

2.17.1.3.COD presented in Milligrams per litre (mg/l)

As shown in table 1, COD levels range from 70 mg/l to 160 mg/l. This indicates that all the sampling locations recorded COD levels that are higher than the recommended maximum standard of 50 mg/l according to the Kenya Bureau of Standards (2011). Just like in the case of BOD, the highest COD level was recorded at sampling location 6. The COD levels also show no significant change in pollution levels as the river flows downstream as is evident from the COD figures that have relatively no different between upstream locations and downstream ones.

2.17.1.4.Dissolved Oxygen (DO) presented in milligram per litre (mg/l)

Table 1 shows that the ten sampling locations recorded dissolved oxygen values of 0.1 with only sampling location 8 and 9 recording values of 0.05. This indicates that sampling location 8 and 9 are less suitable to support aquatic compared to the other eight sampling locations. In addition, since there is no required standard on the level of dissolved oxygen needed, the suitability of the water flowing through Athi River to support aquatic life would highly dependent on the specific organisms' oxygen needs (World Health Organization 2011).

2.17.1.5.Color presented in hazen units

Table 1 shows a significantly wide variation in color ranging from 20 hazen units to 800 hazen units. Upstream sampling locations such as location 8, 9 and 10 recorded the lowest hazen units indicating that the water color deteriorates as the river flows downstream. However, sampling location 1 and 2 recorded significantly low values of color compared to the central section of the research site. The low color measure of the upstream sampling locations may be attributed to the closeness of these sampling sites to the source of the river thus minimal pollution while the lower color parameter in the downstream areas may be attributed to the River's path where rocks and boulders tend to filter the water trapping a majority of the debris that cause the haziness.

Sampling locations 3, 4 and 5 recorded the highest values of hazen units an aspect that was attributed to their close proximity to the Nairobi Namanga road as well as their close proximity to the Nairobi Mombasa standard railway therefore increasing human activities that may lead to increased debris on the river's path.

2.17.1.6.Turbidity presented in nephelometric Turbidity Units (NTU)

As a measure of how much light is deflected by un-dissolved substances present in the water samples, turbidity gives an insight on how much Total Suspended Solids are present in the sample. As shown in table 1, the sampling locations recorded a wide range of NTU between 5.45 and 2,900. This indicates that in the upstream and downstream sampling locations, turbidity is very low and as such there are no much light obstructions in the water. However within the central part of the research site between sampling location 5 and 7, the turbidity levels were very high between 1,850 and 2,900 units. This was mainly attributed to human activities such as the mini dam constructed on sampling location 6 therefore increasing the trapping of dirt and debris leading to very high turbidity levels.

2.17.1.7. Total dissolved solids (TDS) presented in milligram per litre (mg/l)

In some sampling locations such as location 8 and 10, no TDS were observed, however in the remaining sampling locations, the TDS recorded range from 420 mg/l to 1,695 mg/l where sampling location 9 recorded the lowest TDS while location 7 recorded the highest TDS. This is in line with the findings of BOD, COD and pH where high values of such parameters were recorded in these sampling locations. This could be attributed to the two large industries located in close proximity to the river namely the East Africa Portland Cement and the Savannah Cement factories as well as the high rate of surface runoff occasioned by the just started long rains within the research site.

Sampling locations 3, 4, 5, 6 and 7, all of which are within the research site recorded TDS values of more 1,000 mg/l as shown in table 1;this level of TDS is much higher than the maximum allowable limit of 600 mg/l according to the WHO guidelines (2011).

2.17.1.8. Total Suspended Solids (TSS) presented in milligrams per litre (mg/l)

As shown in table 1, the TSS values recorded across the ten sampling sites range from 391.5 mg/l to 2,146.67 mg/l while in some sampling locations no TSS were recorded. Among the ten sampling locations, only two locations i.e. sampling location 8 and 10 recorded TSS values of less than 600 mg/l as required by the World Health Organization (2011). Sampling location 7 recorded the highest TSS which is consistent with the high values recorded on the other parameters thus making it the highest ranking sampling location in terms of pollution.

2.17.1.9. Total Hardness presented in milligrams per litre (mg/l)

As presented in table 1, the total hardness values range from 72 mg/l to 220 mg/l where sampling location 5 recorded the lowest value while location 10 recorded the highest value of total hardness. The values of total hardness decrease as the river flows downstream indicating that the level of calcium and magnesium as well as other polyvalent metallic ions in the water is higher upstream compared to downstream. This may be attributed to natural geological processes since the hardness parameter decreases significantly as it enters the research site at sampling location 8 and continues decreasing to the minimum value recorded at sampling location 5 before increasing to 100 mg/l recorded at sampling location 2. In addition, all the ten sampling locations are beyond the allowable limit of 60 mg/l provided by the World Health Organization (2011).

2.17.1.10. Chlorides (Cl^-) presented in milligrams per litre (mg/l)

From the chloride values recorded in table 1, among the ten sampling locations, only location 10 recorded chloride ion values that are higher than the recommended limit of 250 mg/l. The chloride levels decrease as the river flows downstream indicating that chloride ions concentrates are mainly located in the upstream sections of the river an aspect that may be attributed to natural geological processes.

2.17.1.11. Electrical conductivity presented in Micro Siemens (μs)

Table 1 presents the electrical conductivity units recorded between the ten sampling locations ranging from a low of 12.01 units recorded at sampling location 8 to a high of 1,580 recorded at sampling location 10. The electrical conductivity decreases as the river flows downstream indicating that the increase in the level of pollutants downstream leads to a decrease in the number of cations and anions in the water thus making such water less valent in its ability to conduct electricity (World Health Organization 2011).

2.17.1.12. Summary on laboratory test results

The results showed that sampling locations within the research recorded a higher level of pollution compared to locations in the upstream section of the river. However, despite the fact that most parameters failed to show consistent increase in pollution as the river advances downstream, it is evident that the river is more polluted within the research site compared to upstream areas. Human activities such as construction of small mini-dams across some parts of the river's path leading to obstruction of the river's natural flow could have contributed to the failure of the pollution parameters to increase as the river advances downstream. In addition, the BOD values indicates that among the sampling locations tested, only one sampling location had a BOD level that was higher than the recommended standard of 32mg/l according the Kenya Bureau of Standards (2011) and the World Health Organization (2011). This indicates that the hydro carbon pollution targeted by the first objective of this research was not significant because it is mainly associated with high BOD values as well as high COD values (Halder & Islam 2015).

2.17.2. Pollution status results based on the interviewed respondents

The results obtained from the respondents' questionnaires on the main sources of pollution and the type of waste industries dump into Athi River were presented in table 2 below.

Table 2:Main pollution sources in Athi River based on respondents' responses

Questionnaire Responses		
Respondent No.	**Type of waste industries dispose into Athi River**	**Athi River's Main Pollutant**
1	Human Waste	Human Waste
2	Industrial Waste	Human Waste
3	Industrial Waste	Human Waste
4	Industrial Waste	Industrial Waste
5	Industrial Waste	Industrial Waste
6	Most Industries Recycle	Industrial Waste
7	Clinker and Gypsum	Industrial Waste
8	Human Waste	Industrial Waste
9	Heavy polymers	heavy polymers
10	Human and industrial waste	Human fecal waste
11	human waste	Human waste
12	Industrial Waste	Industrial Waste
13	Industrial Waste	Industrial Waste
14	Industrial Waste	Human Waste
15	Industrial residue	Human Waste
16	Human Waste	Industrial Waste
17	Industrial Waste	Industrial Waste
18	Industrial Waste	Industrial Waste
Industrial Waste	12 = 67%	11 - 61%
Human Waste	4 = 22%	7 = 39%
None	1 = 6%	0%
Both	1 = 6%	0%

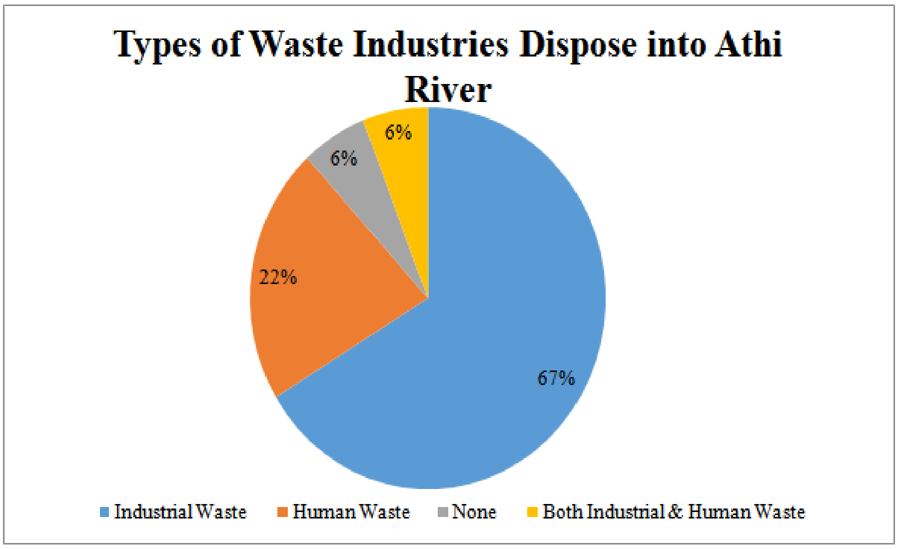


Figure 3;Pie chart showing proportion of types of waste disposed by industries into Athi River

As shown in table 2 and figure 3, responses provided with regards to the sources of pollution and the type of waste matter disposed into the river indicated that 67% of the respondents cited industrial refuse as the main type of polluting matter. Clinker and gypsum mainly occurring as a waste product from cement production was cited as the main waste product disposed by cement manufacturing companies which are mainly pre-dominant in the research site. On the other hand, 22% of the respondents cited human refuse as the main waste matter disposed into the river while 6% cited none and another 6% cited both industrial refuse as well as human refuse as the main type of waste matter disposed into the river.

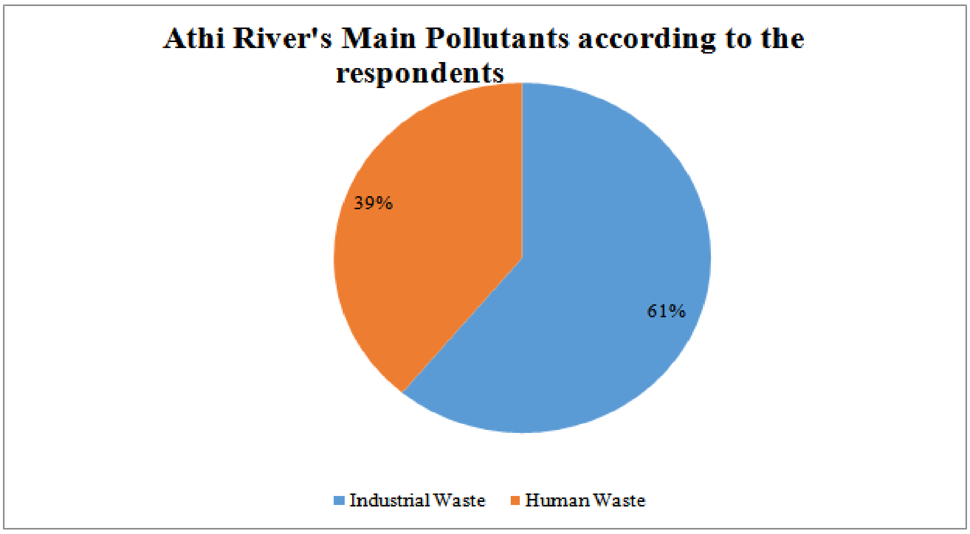


Figure 4*;* Pie chart showing the proportion of main pollutants according to the respondents

On the other hand, as shown in table 2 and figure 4, 61% of the respondents cited industrial refuse as the main pollutant of the river while 39% of the respondents cited human refuse as the main pollutant. This indicates that majority of the respondents believe that the pollution parameters obtained in table 1 were occasioned by industrial refuse as opposed to human refuse.

These findings indicate that since industries located in Athi River emit both industrial waste and human waste, they are mainly deemed to be the main sources of pollution for Athi River.

2.17.3. Level of coliforms in the water

As observed in the tests for the pollution parameters above, the levels of pH observed was within the range of 6.5 and 7.05 which is within the allowable limit of 6.5 to 8.5. On the other hand, the level of BOD was below the maximum recommended standard of 30 mg/l in all the ten sampling locations except one location indicating that the level of pollution in Athi is within the required standard of quality based on the BOD and pH parameters. As such, the level of purification required to bring the water to a safe state for human consumption is relatively low. This indicates that just like in hydro carbon pollution, the level of coliforms in the samples collected was very low an observation that was informed by the low level of BOD and the results of the pH test which all placed the pH results within the safe basic band of between 6.5 and 7.05 indicating that the water is neither acidic nor basic. It is within the neutral range required for safe human consumption while the BOD is below the maximum allowable limit of 30mg/l (World Health Organization 2011). This observation was also supported by the respondents responses on the methods used by organizations located within the research site for disposal of human waste as shown in figure 5.

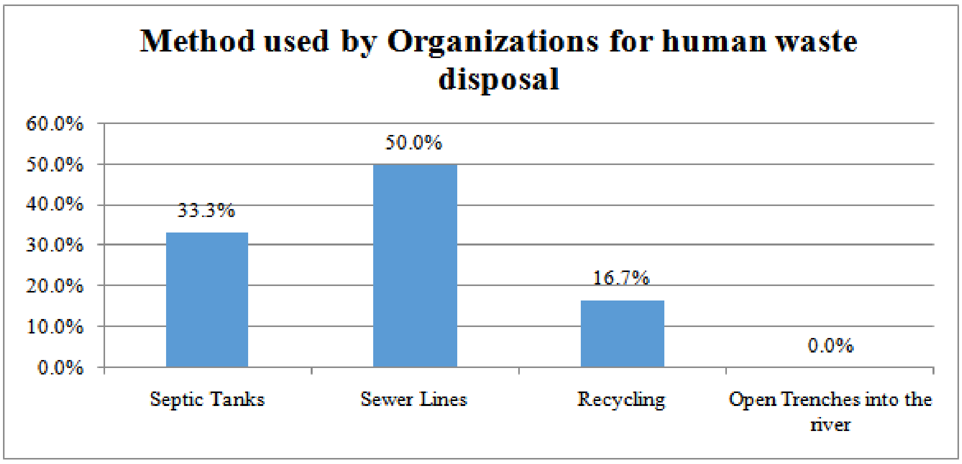


Figure 5: Respondents' responses on human waste disposal methods

As shown in figure 5, 50% of the respondents indicated that organizations located within the research site mainly use sewer lines as a human waste disposal method adding that such sewer lines are managed by the government appointed professional bodies such as the Mavoko Water and sewerage companies and as such they do not channel such sewer lines into the river. On the other hand, 33.3% of the respondents indicated that organizations within the research site use septic tanks to dispose their human refuse while 16.7% of the respondents indicated that organizations within the research site recycle their waste water and utilize such recycled water in the day to day industrial processes.

2.17.3.1. Summary on the level of coliforms in Athi River

The above analysis on the level of coliforms in Athi River indicates that the samples taken and the responses from respondents within the research site did not provide sufficient evidence to support presence of significance levels of coliforms in the river water Athi River. This is evident from the BOD tests and the pH tests that indicated that the two parameters were within the allowable standards of quality according to the Kenya Bureau of Standards, NEMA and the World Health Organization. In addition, the respondents' opinions indicated that organizations operating within the research site do not dispose their human waste which is the main source of coliforms into the Athi River.

2.17.4. Pearson correlation analysis for distance (industry to River) and water quality

The relationship between the distance from the industries/factories to the river and the quality of water flowing through the river was tested using the Pearson correlation analysis. This analysis showed whether the quality of water in Athi River was dependent on the distance between the river and the source of the pollutants or not. The results of the Pearson correlation are presented in table 3 and figure 6.

Table 3:Correlation between distance and water quality

Correlation Btw Distance and Pollution Parameters	
Parameter	**Correlation**
pH	0.242
BOD	0.344
COD	0.294
DO	- 0.774
Color	- 0.587
Turbidity	- 0.286
TDS	- 0.436
TSS	- 0.326
Total Hardness	0.684
Chlorides	0.721
Conductivity	0.478

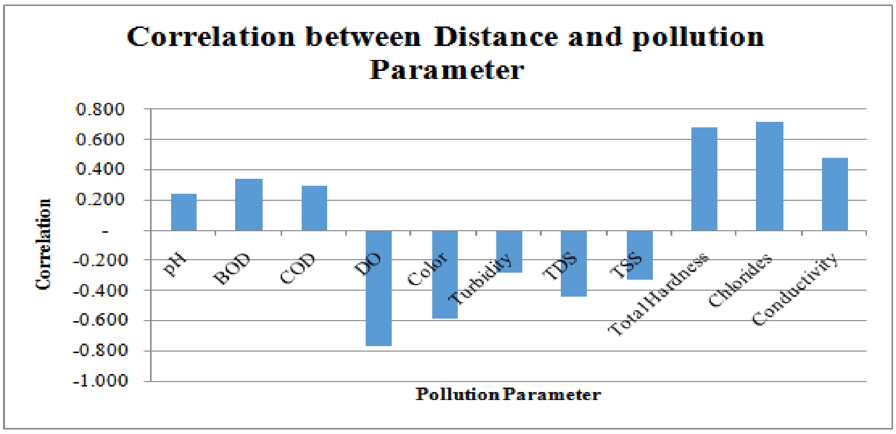


Figure 6*;* Bar graph showing correlation between distance and pollution parameters

As shown in table 3 and figure 6, six pollution parameters are positively correlated to the distance between the river and the sources of the pollutants. This indicates that for pH, BOD, COD, Total Hardness, Chlorides and Electrical Conductivity, a change in the distance between the industry and the river would lead to change in the same direction of the pollution parameter. For instance a decrease in distance which is translated into an increase in pollution potential would lead into an increase in the pollution parameter which is translated into an increase in pollution. As such, an increase in pollution potential (i.e. a decrease in distance would lead to an increase in pH, an increase in BOD, an increase in COD etc.) where chlorides will have the highest increase due to the fact that Chlorides have the highest correlation with distance/pollution potential while pH will have the lowest increase due to the fact that pH has the lowest correlation with distance/pollution potential as shown in table 3 and figure 6.

On the other hand, for Dissolved oxygen, color, Turbidity, TDS and TSS, a change in the distance between the industry and the river would lead to a change in the opposite direction of the pollution parameter. This indicates that an increase in distance between the industry and the river translated into a decrease in pollution potential would lead into a decrease in DO, color, Turbidity, TDS and TSS. The decrease in DO and color indicates that the quality of water will decrease while the decrease in Turbidity, TDS and TSS indicates that the quality of water will increase as it is subjected to a longer natural filtration process along the path between the industry and the river (Tibaijuka 2007).

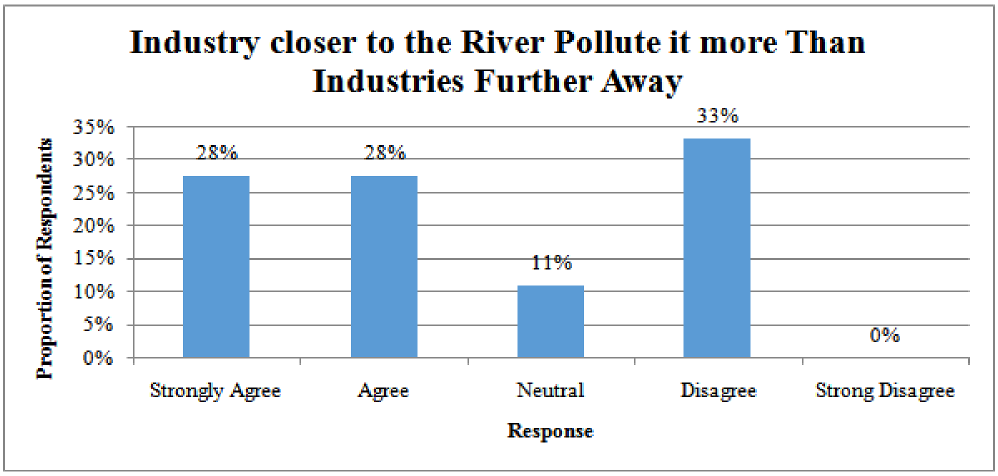


Figure 7: Respondents views on the distance between source of pollutants and the river

As shown in figure 7, 56% of respondents agreed that industries closer to the river contributes a higher level of pollution into the river compared to the industries located further away from the river, 11% of the respondents were neutral while 33% disagreed. This indicates that the distance between the river and the source of pollution i.e. the industries within the research site had a significant impact on the level of pollution observed on the river

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2.17.4.1. Summary on correlation analysis

The above correlation analysis indicates that the distance between the industry and the river determines the extent to which the river will be polluted. As such, as the distance decreases, the values of pH, BOD, COD, Turbidity, Total Hardness, electrical conductivity and Chlorides increases leading to a decrease in water quality as a result of the increased pollution potential occasioned by the close proximity of the source of pollutants. On the other hand, an increase in distance translating to a decrease in pollution potential would lead to a decrease in pH, BOD, COD, Turbidity, Total Hardness, Electrical Conductivity and Chlorides which indicates that the water quality will increase.

2.17.5. Results of the regression analysis

2.17.5.1. Singular regression analysis

The results of the singular regression analysis of the distance from the source of pollution i.e. the industries to the river and the individual pollution parameters are as shown in table 4.

Table 4: Singular Regression output between distance and the pollution parameter

Regression Output											
Parameter	**pH**	**BOD**	**COD**	**DO**	**Color**	**Turbidity**	**TDS**	**TSS**	**TH**	**Chloride**	**Conductivity**
R Square	0.059	0.118	0.086	0.600	0.345	0.082	0.190	0.107	0.468	0.521	0.228
Coefficients											
Alpha	(8,000.0)	1,335.2	989.3	5,082.6	2,421.2	1,998.7	2,337.0	2,259.0	(71.3)	1,283.2	1,339.6
Beta	1,438.77	26.99	7.56	(36,342.00)	(1.51)	(0.22)	(0.59)	(0.37)	17.93	9.87	1.19
t Staistic - Alpha	0.532	0.013	0.259	0.000	0.000	0.000	0.000	0.002	0.914	0.000	0.003
t Staistic - Beta	0.448	0.274	0.354	0.003	0.045	0.367	0.157	0.300	0.014	0.008	0.116

As shown in table 4 above, the results of the singular regression analysis between the distance from the industries to the river and the results of each specific pollution parameter in all the sampling points indicated there is a positive relationship between distance from the source of pollution i.e. the industries to the river and the specific pollution parameter in all the eleven pollution parameters used except pH and Total Hardness which showed a negative relationship. This is indicated by the positive values of the alpha coefficient which states that for instance on average where the source of pollution is zero meters from the river the average value of BOD in Athi River would be equivalent 1,335.2 mg/l. On the other hand, based on these results, where the source of pollutionis zero meters from the river, the value of total hardness would be -71.3 mg/l. This indicates that the value of BOD would decrease with the increase in the distance between the river and the source of pollution i.e. the industries.

Therefore using these findings, the formula for calculating BOD by substituting the coefficient values in equation 2 would be as shown below.

$$BOD = 1{,}335.2 + 26.99D + 0$$

Where;

- BOD represents the pollution parameter
- 1,335.2 is the alpha coefficient between distance from the river and the BOD pollution parameter
- 26.99 is the beta coefficient between distance from the river and the BOD Pollution parameter
- D represents the average distance from the river to the industries (source of pollution)
- 0 represents the regression error term which is assumed to be equal to zero.

As shown in table 4, the R-Square values represent the explanatory power of the independent variable on the dependent variable. As such, the low values of the R-Square indicates that distance from the river to the industries have may not be used to explain the individual pollution parameters. For instance, based on the findings in table 4, only 11.8% of the changes in BOD can be explained by the changes in the average distance between industries and the river. As such, the findings indicate that distance is poor predictor of the pollution parameters. The highest R-Square value was recorded on Chloride pollution parameter where 52.1% of the changes in Chloride pollution parameter could be explained by the changes in the average distance between the industries and the river. This therefore indicates that the distance between the river and the source of pollution in the form of industries located within the research site is not a determining factor on the level of pollution in the river. This is supported by the respondents' responses as shown in figure 7 where 44% of the respondents did not think distance is necessarily a factor in determining the level of pollution in the River.

However, as shown by the test statistic values for beta and alpha values of each of the eleven pollution parameters tested, the alpha and beta values are not statistically significant at 95% confidence level. This is shown by the fact that all the t-statistic figures for beta and alpha values are less 95% meaning that more than 5% of the results could have been obtained by chance. However at 90% level of confidence, the alpha value for total hardness is statistically significant because it reads 91.4% meaning that only 8.6% of the results of total hardness could have been obtained by chance.

Based on the findings of singular regression analysis, the alternative hypothesis holds. As such, the human activities within Athi River have an impact on the quality of water flowing through Athi River; however such impact is not statistically significant. As such it is negligible.

2.17.5.2. Multiple regression analysis

To improve the validity of the results obtained in the singular regression analysis a multiple regression analysis was carried to incorporate factors that may jointly affect the quality of the water in Athi River. This regression assumes that in addition to distance other factors such as the other pollution parameters would have an impact on the value of dependent variable. This indicates that for instance, in addition to changes in the distance between the river and the industries, changes in pH, Hardness, color etc may result into changes in the BOD if the BOD is the dependent variable and the other factors are the independent variables.
The results of the regression analysis are as shown in table 5.

Table 5: Multiple Regression output between distance and the pollution parameters

Multiple Regression output		
Multiple R	0.997	
R Square	0.993	
Adjusted R Square	(0.025)	
Standard Error	144.295	
	Coefficients	***t- Statistic***
Alpha	999.9	1.0
Beta - pH	-	1.0
Beta - BOD	-	1.0
Beta - COD	(622.5)	1.0
Beta - DO	-	1.0
Beta - Color	(64.7)	1.0
Beta - Turbidity	20.1	1.0
Beta - TDS	(6.3)	1.0
Beta - TSS	44.6	1.0
Beta - TH	85.4	1.0
Beta - Chlorides	(180.5)	1.0
Beta - Conductivity	(257.3)	1.0

The results in table 5 were obtained by regressing the average distance between the industries and the river on the pollution parameters combined to determine how such pollution parameters collectively influence the value of the dependent variable where such a dependent variable is the average pollution recorded on Athi River.

As shown in table 5, when the eleven pollution parameters are used together with the distance from the river to the industries to determine the average pollution parameter of Athi River, the results indicate that collectively, 99.3% of the changes in the average pollution in Athi River can be explained by the changes in distance between the river and the industries, the changes in pH, changes in BOD, COD, DO, Color, Turbidity, TDS, TSS, Chloride, Total Hardness and electrical conductivity. This indicates that to better predict the changes in one pollution parameter with a high level of accuracy, it has to be assumed that a myriad of factors combine to influence the outcome of that particular pollution parameter. In this case as presented in Table 5, changes in BOD could be occasioned by the changes in the distance combined with the all the eleven pollution parameters as a factor of the distance where the factor of the distance is represented by the beta coefficient.

This indicates that based on the findings on table 5 and substituting the coefficient values in equation 3, the average pollution parameter for Athi River is calculated as shown below.

$$PPi = 999.9 + 0pH + 0BOD - 622.5COD + 0DO - 64.7Color + 20.1Turbidity - 6.3TDS + 44.6TSS - 85.4TH - 180.5Chlorides - 257.3Conductivity + 0$$

This can be simplified as follows.

$$PPi = 999.9 - 622.5COD - 64.7Color + 20.1Turbidity - 6.3TDS + 44.6TSS - 85.4TH - 180.5Chlorides - 257.3Conductivity$$

This means that the pH, BOD and DO have no significant relationship with Distance from the river to the industries, COD, Color, TDS, Total Hardness, Chlorides and Conductivity have a negative relationship with distance while Turbidity and TDS have a positive relationship with distance.
The values of the t-statistics indicate that all the beta coefficients obtained are statistically significant at 95%, 99% and 90% confidence levels. Based on the t-statistic values 0% of the results obtained for each beta coefficient was obtained by chance.

2.17.5.3. Summary of regression analysis
Based on the regression analysis above, it is evident that the industries located within the research site have an impact on the level of pollution in Athi River. However no one factor such as distance can significantly influence the level of pollution. As such various factors combine to form the River's pollution profile leading to a statistically significant impact on the level of pollution in Athi River.

IV. Conclusion And Recommendation

a. Conclusion on Pollution parameters tested in the laboratory.

As a general observation based finding, plate 1 shows a clear distinction between sampling location 10 and 4 in terms of each of these sampling location's ability to support aquatic life an aspect that was used as an indicator of the level of pollution present at those locations. Sampling location 10 showed signs of low hydrocarbon pollution as shown by the presence of aquatic life while sampling location 4 which is located further downstream showed no signs of aquatic life. In addition no other sampling location among the ten showed signs of aquatic life apart from sampling location 10 which is located on the furthest upstream point outside the research site. Part of the reasons behind the selection of sampling location 10 was to show distinctions such as this one.

As is evident from the parameters tested and presented on table 1, pollution indications within the research site vary from parameter to parameter. However it is evident that water pollution is higher within the research site compared to locations upstream as well as downstream. The upstream locations as shown by the BOD, COD, TSS and TDS and DO values are relatively less polluted compared to the locations centrally located within the research site. Sampling locations 5, 6 and 7 which are at the central part of the research site recorded the highest levels of pollution as measured by COD, BOD, TSS, TDS and Turbidity. This indicates that since this area had the highest concentration of both human settlements and industrial footprint, it had the highest pollution as a contributed by both human settlements such as the kasorio village and industries such as Savannah cement and East African Portland Cement. However the pollution also decreases as the river advances downstream an aspect that may be attributed to the natural filtration process as the water flows through rocks and boulders on its path leading to a decrease in pollution parameters such as BOD, Color, Turbidity, TSS and TDS as indicated on table 1. Parameters such as electrical conductivity showed a consistent increase across the sampling locations as the river flows downstream an aspect that indicates that the natural filtration process has an impact on the quality of water despite the pollution levels that occurs within the research site. The decrease in electrical conductivity can be explained by the fact that as the water flows downstream, impurities such as suspended solids and dissolved solids decrease as a result of the filtration processes, as such, since these impurities usually affect the water electrical conductivity, a decrease in metallic impurities such as chlorides leads to a decrease in the ability of the water to pass anions and cations from one end of the water sample to the other. This provides evidence in support of the alternative hypothesis which holds that the anthropogenic activities within and around the research site have a significant negative impact on the quality of water flowing through Athi River.

However, the BOD values indicate that only one sampling location among the ten locations tested had a BOD of over the recommended standard of 30mg/l. As such, since the hydro carbon pollution is mainly associated with high BOD and COD values of more than 100mg/l according to most previous researches such as Halder & Islam (2015) and Wang et al. (2012), it was evident that the extent of hydrocarbon pollution targeted by objective one of this research was negligible. On the other hand, as shown in table 1,the total hardness parameter decreased with the progress of the river downstream. Just like in the case of TDS and TSS, this decrease in hardness was attributed to the natural filtration process as the river flows downstream. In addition, the source of the river which is the Ngong Forest is associated with volcanic activity as cited in Gikundi (2014) an aspect that increases the water's hardness on the upstream areas due to the high level of volcanic based minerals such as chlorides present in the water. Additional evidence in support of this fact is shown by the high level of chlorides on the upstream sampling locations and such chlorides decreases as the river progresses downstream.

Based on the results of the scientific tests, it is evident that the findings support the alternative hypothesis which states that anthropogenic activities have a significant impact on the quality of water flowing through Athi River. However, the findings showed no sufficient evidence on the presence of hydro carbon pollution which indicates that where hydro carbon pollution is concerned; the null hypothesis holds

b. Conclusion on Pollution status according to the respondents

As indicated in the results tabulatedabove, it is evident that majority of the respondents believe that industrial waste is the main pollutant of the Athi River followed closely by Human Waste. Both of these sources are attributed to the human activities otherwise referred to as anthropological activities around and within the research site. Table 2 shows that among the twenty respondents interviewed, 67% of them believe that most industries dispose industrial waste into the river while 22% dispose human waste. On the other hand, 6% of the respondents believe that industries neither dispose human waste nor do they dispose industrial waste. Instead, they use recycling efforts to minimize the impact their activities have on the environment. 6% of the respondents believe that industries dispose both industrial and human waste into the river. 61% of respondents as shown in table 2 believe that the main pollutant of Athi River is industrial waste while 39% believe that the main pollutant is human waste. This indicates that since these pollution parameters are occasioned by activities carried out by human beings along the river's path, the alternative hypothesis holds which states that the anthropogenic activities have a significant impact on the quality of water flowing through Athi River.

c. The relationship between distance and pollution

As shown in table 3 and figure 6, there is strong correlation between the distance from the river to the industries sampled and the level of pollution parameters analyzed. For instance the decrease in distance which translates into an increase in pollution potential would lead to an increase in the pH, BOD, COD, Total Hardness, Chlorides and Electrical conductivity while the same increase would lead to a decrease in TDS and TSS. This indicates that the distance between the source of pollution in the form of industries operating in the research site and the river is directly correlated to the level of pollution observed on the river within the research site. As such, increase in the distance will lead to a subsequent decrease in pollution and vice versa.

As shown in *Table 3* and *Figure 6,* six pollution parameters were positively correlated to the distance between the river and the sources of the pollutants. This indicated that for pH, BOD, COD, Total Hardness, Chlorides and Electrical Conductivity, a change in the distance between the industry and the river would lead to a change in the same direction of the pollution parameter. For instance, a decrease in distance which was translated into an increase in pollution potential would lead into an increase in the pollution parameter which was translated into an increase in pollution. As such, an increase in pollution potential (i.e. a decrease in distance would lead to an increase in pH, an increase in BOD, an increase in COD, increase in Total hardness, increase in Chlorides and increase in Electrical Conductivity) where chlorides would have the highest increase due to the fact that they had the highest correlation with distance/pollution potential while pH would have the lowest increase due to the fact that pH had the lowest correlation with distance/pollution potential as shown in *Table 3* and *Figure 6.* The correlation analysis indicated that the distance between the industry which was the source of pollutants and the river determined the extent to which the river would be polluted. As such, as the distance decreases, the values of pH, BOD, COD, Turbidity, Total Hardness, electrical conductivity and Chlorides increased leading to a decrease in water quality as a result of the increased pollution potential occasioned by the close proximity of the source of pollutants.

As shown in *Table 4* above, the results of the singular regression analysis between the distance from the industries to the river and the results of each specific pollution parameter in all the sampling points indicated there was a positive relationship between distance from the source of pollution i.e. the industries to the river and the specific pollution parameter in all the eleven pollution parameters used except pH and Total Hardness which showed a negative relationship. This is indicated by the positive values of the alpha coefficient which state that for instance on average where the source of pollution is zero meters from the river the average value of BOD in Athi River would be equivalent to 1,335.2 mg/l. On the other hand, based on these results, where the source of pollution is zero meters from the river, the value of total hardness would be -71.3 mg/l. This indicated that the value of BOD decreased with an increase in the distance between the river and the source of pollution i.e. the industries. The regression analysis provides evidence to the fact that the industries located within the research site had an impact on the level of pollution in Athi River. However no one factor such as distance could significantly influence the level of pollution. As such, various factors combined to form Athi River's pollution profile leading to a statistically significant impact on the level of pollution in Athi River.

Based on the findings of the regression analysis, it is evident that no one single factor such as distance from the river to the industries was found to be of significant impact on the quality of water in Athi River. This indicates that for the alternative hypothesis to hold, various factors have to combine to lead to an overall statistically significant effect on the quality of water flowing in Athi River.

d. The level of coliforms in Athi River

As shown in the analysis of the results of the parameters tested in the laboratory, a high coliform pollution profile is characterized by high BOD, High COD in excess of 500 mg/l and low levels of pH below 6 in the water as cited by Matano et al. (2013). This indicates that the low levels of BOD and COD as well as the neutral nature of pH indicate that the level of coliforms in the water is also very low. This is further evident from the responses provided by the respondents where sewer lines, septic tanks and recycling were cited as the most common human waste handling methods.

This indicates that based on the level of coliforms in Athi River, the alternative hypothesis holds where the anthropogenic activities in Athi River locality were found to be no significant impact to the level of pollution in Athi River.

e. Recommendations

Based on the findings of the research which found significant evidence to support the influence that anthropogenic activities have on the quality of water flowing in Athi River, the Alternative hypothesis only holds when several factors such as distance, different sources of pollution, other pollution parameters etc combine to generate a sufficient and statistically significant pollution profile that can impact the quality of the River's waters. Otherwise none of the factors analyzed could individually lead to a statistically significant impact on the quality of the water in Athi River. In addition, the research was carried out on the border line between the dry and rainy seasons. The research started during the dry season between January 2017 and Mid-March 2017 and continued into the rainy season that started in late March 2017. As such, the fresh rains could have affected the content of the waterflowing through Athi River due to factors such as surface runoff that carry particles and debris from other locations outside the research site. This comes out as one of the limitations of the research because it could not have been verified whether the results obtained were as a direct result of the impact of the anthropogenic activities which formed the focal point of the research. As such, future researchers may chose to focus on one weather season i.e. either the rainy season or the dry season.

Based on the findings of the research, it is recommended that the users of the information such as the findings of this research take note of the findings and use such findings to develop environmentally friendly policies that would help Athi River preserve its healthy environmental blueprint as it strives to accommodate an ever growing industrial homage. However, more importantly as cited by various respondents, recycling efforts play a very significant role in minimizing the effect of pollution on the quality of water in Athi River. As such, the government and other stake holders to highly encourage recycling efforts and reward industries that make use of such efforts to minimize pollution either via tax incentives of other reward measures.

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