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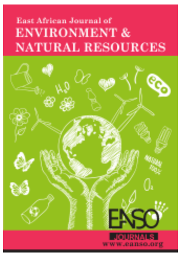

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Original Article

Impact of Cement Industry on Water Quality in the Athi River, Machakos County, Kenya

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ABSTRACT

Cement is one of the most often used building materials and its production is increasing globally. Simultaneously, cement production is energy intensive and produces harmful emissions such as gases, noise, and wastewater. The aim of the study was to determine the impact of the cement industry on water quality in Athi River, Kenya. The cement industry had significant impacts on water physicochemical variables such as temperature (p = 0.0003), conductivity (p = <0.001), total suspended solids (p = <0.001), ammonium (p = 0.04), pH (p = 0.02), and turbidity (p = 0.0001). Mean values for physicochemical variables such as conductivity, total suspended solids, total dissolved solids, turbidity, and lead exceeded the limits set by World Health Organization (WHO) for drinking water quality. Water pollution control strategies need to be implemented to improve water quality in the Athi River and prevent further deterioration of the environment. Future studies should evaluate the effect of the cement industry on other water resources (e.g., groundwater) and air quality.

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INTRODUCTION

Cement production and consumption have both been on the rise in recent years, although the latter continues to outpace the former due to an increase in construction projects (Eshikumo & Odock, 2017). Apart from water, cement is ranked as the

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most consumed substance in developed and developing countries (Zhu *et al.,* 2022). Cement is typically mixed with sand, gravel, and water to form concrete. Concrete is the most commonly used material in construction compared to other building materials (Gagg, 2014). Despite the importance of cement in the construction industry, cement plants emit contaminants into the environment. These contaminants have adverse effects on the environment and human well-being. For example, the carbon dioxide produced by cement plants constitutes about 10-15% of the carbon dioxide released into the environment on an annual basis among the key industries, including refineries, iron and steel, and other industries (Zhu *et al.,* 2022). The limestone extraction process and various procedures involved in the production of cement cause hazardous effects on the environment, including degradation of landscapes, pollution of air through dust emission and dumping of solid waste materials (Kuter, 2013; Biajawi *et al.,* 2022).

Cement industries produce a wide range of contaminants that affect human health. Emission of dust particles, metals, sulfides, and other contaminants into the environment has potentially negative effects on human health (Shuhmacher *et al.,* 2004; Dong *et al.,* 2015; Etim *et al.,* 2021; Giobanu *et al.,* 2021). The wastewater and solid wastes produced by cement industries can pollute aquatic ecosystems, soil, drinking water and agricultural products. Therefore, monitoring and treatment of pollutants emanating from cement plants are undertaken in various countries (Adebisi & Omoyeni, 2017; Giobanu *et al.,* 2021; Zhu *et al.,* 2022). For example, Jadoon *et al.* (2016) monitored the impact of the cement industry on soil quality in Iraq and found that soil pollution increased in study sites located closest to the cement industry. Another study by Ipeaiyeda and Obaje (2017) monitored the impact of the cement industry on river water quality in Nigeria and found that release of wastewater effluents led to an increase in levels of pH, nitrate, phosphate, total suspended and dissolved solids, turbidity and biological oxygen demand at the downstream site. The study also found that the levels of zinc and lead at the downstream site exceeded the criteria set by WHO. Other studies found that effluents from the cement industry led to a reduction in biodiversity, degradation of landscape and deterioration of environmental quality and human health (e.g., Choudhary and Gupta, 2017; Lamare and Singh, 2020; Arimoro *et al.,* 2021; Ojango and Onywere, 2022).

Water is a commodity that is consumed by people and animals to sustain their life. It is used for purposes such as drinking, cooking, irrigation, and industrial use. Water also acts as a carrier of other substances, such as heavy metals, inorganic chemicals, disease vectors and energy (Shmeis, 2018). The quantity of water remains constant while the quality changes both temporally and spatially, especially if influenced by human activities. Changes in the quality of water cause a great strain on the supply systems. The water quality degradation problem is not a new phenomenon in Kenya. Initial research reports on the problem in the country date back to the 1950s (Marshall, 2011). These reports provide a clear indication of the effects of industrial growth on the quality of water.

Just like in other developing countries, the quest to get industrialised within the shortest period of time has worsened the pollution of water bodies in Kenya. For example, Kiithia (2012) observed that the problem of water pollution and quality degradation in developing countries is increasingly becoming a threat to natural resources and that this phenomenon can be attributed to the increasing quest for these countries to become industrialised.

Athi River town and its suburbs are a host to several industries, and there is poor waste management (Takawira, 2021). The increase in industries has not been matched with the development of infrastructure to deal with the increased volume of waste generated. This leads to pollution of the environment and reduction of biodiversity. For example, Muiya (2011) and Muiruri *et al.* (2013) performed a survey of the Athi River and its tributaries and found that the water and tilapia were contaminated with

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microbes and heavy metals. The objectives of the current study are to (i) determine the physical and chemical characteristics of the Athi River water and (ii) assess the strategies that can be used to improve water quality in the Athi River.

METHODOLOGY

Description of Study Area

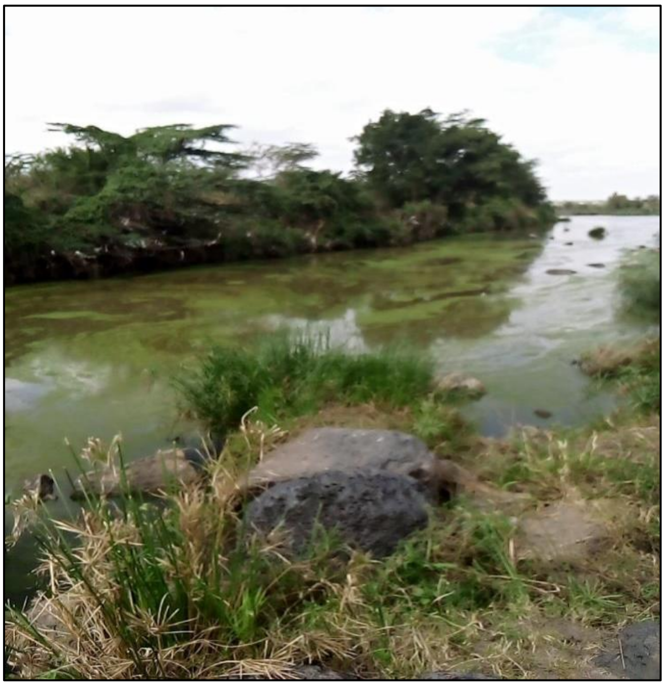
The study was conducted along the Athi River within the Athi River town, which lies along a latitude of 1º45’77’’S and a longitude of 36º97’85’’E. The town is located about 25 km southeast of Nairobi City and is characterised by rapid industrial development. There are six cement manufacturing companies in the Athi River area, and they include Bamburi Cement, Mombasa Cement, East African Portland Cement, Savannah Cement, National Cement Company and Athi River Mining. Other companies in the area process chewing gum, steel and iron sheets, seeds, and cooking oil. Athi River town has different business activities, and the area has witnessed rapid real estate development in the recent past. There is also the development of schools and colleges in the area. The town is connected to Nairobi, the capital city of Kenya, via the Nairobi-Mombasa Road. The town has a population of 81,302 people, according to the 2019 population and housing census (KNBS, 2019). The area has a bimodal rainfall pattern, with much of the rain falling between April and June and the dry periods usually occurring between January and March.

Study Sites

A purposive sampling technique was used in the selection of study sites along the river. The samples of water were collected from study sites located at an upstream area without a cement industry (i.e., site 1), a site located near a cement industry (i.e., site 2), and a site located further downstream (i.e., site 3) from the cement industry. The rationale for selecting site 1 was to act as a reference site (Stoddard *et al.,* 2006). On the other hand, sites 2 and 3 were aimed at evaluating the impact of the cement industry immediately after the wastes are released into the river (i.e., within 10 m from the effluent discharge point) and the impact further downstream (i.e., > 1 km), respectively.

The upstream site (site 1) (*Plate 1*) was located 300 m from any cement industry. There were shrubs and trees along the banks and some macrophytes. The human activities in this area include car washing, and there were human settlements about 200 m from both banks.

Plate 1: The upstream site along the Athi River



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The second sampling point (site 2) (*Plate 2*) was located at a point where a cement industry released wastewater into the Athi River. The site was 5 m downstream from the wastewater release point. There were small-scale farms on the left and right banks, and there were macrophytes and grasses along both banks. The water had an odour.

The third sampling point (site 3) (*Plate 3*) was located about 2 km downstream from the industry near the Mto Mawe tributary. Some of the human activities carried out in this area include agriculture, animal keeping and fishing. Vegetation in the area includes shrubs, grass, and some emergent aquatic species. Livestock such as goats and sheep were observed grazing along the banks. Small-scale farming was also observed along the banks.

Plate 2: Site located immediately below a cement factory wastewater release point along the Athi River

Plate 3: Site located further downstream from the cement manufacturing industry along the Athi River.

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Water Samples Collection

A simple random sampling technique was used during the collection of water samples. Water samples were collected during three sampling occasions between 1st and 10th September 2022. Water samples were taken to the laboratory for analysis of both physical and chemical characteristics. During each sampling occasion, 5 samples were collected from each study site. Sample bottles were used to collect the samples. The samples were kept in an ice box before transportation to the laboratory, where they were refrigerated.

Physical and Chemical Analysis

Water temperature and turbidity were determined using a portable meter (WP-88 Turbidity meter). In the laboratory, pH, total dissolved solids (TDS) and conductivity were measured using a conductivity meter with a pH and TDS probe (Apera Al209-T Value pH Test Kit). After measuring the samples for conductivity and pH, 5ml of the sample was acidified with 10% nitric acid to a pH of less than 2 for analysis of Calcium, Magnesium, chromium, and Lead. Analysis of metals was done using contrAA 700 Analytik Jena device by Flame Atomic Absorption Spectrometry (FAAS) in air acetylene flame. The results were compared with World Health Organization (WHO) standards for drinking water. The analysis of the water samples was done at the Central Testing Laboratory, Water Resources Authority, Nairobi.

Data Analysis

The results were analysed using Microsoft Excel, where the mean values and standard error of the results were calculated. Differences in physicochemical variables among the sites were determined using a one-way analysis of variance. A value of p <0.05 was taken to be statistically significant. Statistical analyses were done using R (R Development Core Team, 2015).

RESULTS

Physical Variables

The highest mean water temperature (27.21 ± 0.09 ^{o}C) was recorded at site two, while the lowest mean water temperature (22.42 ± 0.12 ^{o}C) was recorded at site 1 (*Table 1*). There was a statistically significant difference ($p = 0.0003$) in mean water temperature among the three study sites. Mean total suspended solids, total dissolved solids and turbidity values were also highest at study site 2 compared to the other two study sites. Study site 1 had the lowest mean values for the three variables. Apart from total dissolved solids, total suspended solids and turbidity differed significantly among the three study sites ($p < 0.05$).

Chemical Variables

The highest mean values for conductivity, ammonium, chromium, lead, and pH were recorded at site 2, while the lowest mean values were recorded at site 1 (*Table 1*). There was a significant difference in the mean values for conductivity, ammonium, and pH among the study sites ($p < 0.05$). However, there were no significant differences ($p > 0.05$) in the mean values for lead and chromium. In contrast, magnesium had the highest mean value (1.07 mg/L) at site 3, and calcium had the highest mean value at site 1 (0.58 mg/L). The two variables differed significantly (p <0.05) among the study sites.

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Table 1: Mean (±SE) values for physical and chemical variables at the study sites located along the Athi River, Kenya

	Site 1	Site 2	Site 3	WHO standards	$F_{1,43}$	*p*-value
Temperature (ºC)	22.42 (0.12)	27.21 (0.09)	24.92 (0.03)	25	15.41	0.0003
Conductivity (µS/cm)	488.13 (11.71)	1870.07 (0.07)	1500.13 (0.09)	1000	42.89	<0.001
Magnesium (mg/L)	0.84 (0.004)	0.64 (0.001)	1.07 (0.004)	50	18.01	0.0001
Total suspended solids (mg/L)	220.2 (0.14)	528.33 (0.63)	480 (0)	50	68.5	<0.001
Total dissolved solids (mg/L)	1513.87 (1.05)	1931.33 (0.25)	1600 (0)	1000	1.71	0.19
Ammonium (mg/L)	0.38 (0.003)	2.01 (0.013)	0.88 (0.0091)	1.5	4.22	0.04
Calcium (mg/L)	0.58 (0.004)	0.30 (0.001)	0.45 (0.004)	75	11.33	0.01
Turbidity (NTU)	16.93 (0.067)	28 (0)	23.8 (0.107)	5	25.95	0.0001
Chromium (mg/L)	0.02 (0)	0.1 (0)	0.04 (0)	0.05	2.63	0.11
Lead (mg/L)	0.1 (0)	0.15 (0)	0.095 (0.03)	0.01	0.03	0.85
pH	6.98 (0.02)	8.62 (0.02)	7.54 (0.01)	6.5-8.5	5.51	0.02

SE refers to standard error. Values in bold are statistically significant (p < 0.05). WHO refers to World Health Organization.

DISCUSSION

Physical Variables

The results of the study are in agreement with the results of other studies, which found that the cement industry had a significant effect on water quality in rivers in various countries (e.g., Meme & Nwadukwe, 2016; Kumar & Thakur, 2017; Aga *et al.*, 2020). For example, Meme and Nwadukwe (2016) evaluated the impact of cement factory wastewater on heavy metal levels in a Nigerian stream and found that release of wastewater into the river caused an increase in the concentration of heavy metals such as copper, lead, chromium and cadmium in sediment and water. Another study conducted in Nigeria demonstrated that the release of cement industry effluent into a river caused water temperature, total suspended solids, turbidity and dissolved oxygen levels to be higher than the WHO standards for drinking and agricultural water uses (Aga *et al.*, 2020). In India, Kumar and Thakur (2017) found that wastewater effluents from the cement industry led to the modification of physicochemical factors such as pH, biological oxygen demand and total suspended solids.

With regard to temperature, the wastewater emanating from the cement factory may have a higher temperature than the river water. This could be the reason why the highest mean water temperature was recorded at site 2. The release of wastewater from various human-related sources has been found to cause river water warming by previous studies (e.g., Raptis *et al.*, 2016; Liu *et al.*, 2020; Harmon, 2021). Warming of river water is a form of pollution and can have negative effects on biological processes and biodiversity in the aquatic environment (Hester & Doyle, 2011; Jin *et al.*, 2022).

The high turbidity, total dissolved solids, and total suspended solids at site 2 indicate that there are a lot of dissolved or suspended particles in the water column. Turbidity is the cloudiness of water

(APHA, 2005). Water which is turbid is aesthetically undesirable for drinking, and it makes the water look unpalatable. Turbidity can increase the cost of water treatment (Davis, 2010). The particles can affect organisms such as fish by clogging their gills and can act as media for toxic elements such as mercury, chromium, lead, cadmium, and organic pollutants (Coles *et al.*, 1999; Tarras-Wahlberg *et al.*, 2003). Water with high turbidity and solids can have elevated temperatures because the particles absorb heat from the sunlight. Subsequently, the concentration of dissolved oxygen may be decreased because warm water contains less dissolved oxygen than cold water. Temperature, total suspended solids, turbidity, and total dissolved solids mean values exceeded the limits recommended by the WHO standards for drinking water (WHO, 2006).

Chemical Variables

The highest mean values for pH, lead, chromium, ammonium, and conductivity were recorded at site 2, while the lowest mean values were recorded at site 1. This indicates that release of wastewater effluents from the cement industry into the river altered water chemistry. pH is one of the most important parameters of water quality and is defined as the negative logarithm of the hydrogen ion concentration (Edzwald, 2010). It is a measure of how acidic or basic water is, and very high or low values can make the water unsuitable for human use. High pH makes the water taste bitter and leads to a higher cost of water treatment due to the need for more chlorine during the disinfection process (Dezuane, 1997). On the other hand, low pH may lead to corrosion or dissolution of substances such as metals (APHA, 2005). Pollution can change the pH of water, which can have harmful effects on aquatic plants and animals (APHA, 2005). Low water pH increases the dissolution of metals such as cadmium, lead, and chromium, and this is crucial because many heavy metals are much more toxic when dissolved in water (Dezuane, 1997).

The high value of ammonium at site 2 indicates that wastewater from the cement factory has high quantities of nitrogen-containing organic matter. Ammonium-nitrogen is one of the four forms of nitrogen in water (APHA, 2005). Nitrogen also exists in other forms, such as organic nitrogen, nitrite-nitrogen, and nitrate-nitrogen (APHA, 2005). The release of wastewater into the aquatic environment leads to an increase in organic and ammonium nitrogen, which are modified by microorganisms into nitrates and nitrites (Tchobanoglous *et al.*, 2003). An increase in nitrate-nitrogen in surface waters can lead to the rapid growth of aquatic plants, such as algae, and lead to the degradation of water quality (Tchobanoglous *et al.*, 2003). Consumption of water with a high concentration of nitrate-nitrogen is a health threat to infants because nitrate ions react with blood haemoglobin, reducing blood's ability to hold oxygen, and may lead to blue baby syndrome (Knobeloch *et al.*, 2000).

The high conductivity value at site 2 indicates that the wastewater released into the river had a high concentration of ions. Conductivity indicates the ability of a solution to conduct electric current (Tchobanoglous *et al.*, 2003). Given that electric current is conducted by ions in solution, conductivity increases with an increase in the concentration of ions. Thus, conductivity is one of the main factors used to assess the suitability of water for purposes such as irrigation, drinking and industrial applications (Mathur, 2015).

High concentrations of chromium and lead at site 2 indicate that the cement factory may be releasing wastewater with high quantities of toxic inorganic substances. Different types of toxic inorganic substances are found in water in trace quantities (Davis, 2010). Even though in small amounts, they can be dangerous to humans (Davis, 2010). Some of these substances originate from natural sources, but others may originate from improper management of hazardous wastes emanating from industrial activities (Thangamalathi & Anuradha, 2018). Examples of toxic inorganic substances include metallic compounds such as chromium, lead, mercury, and arsenic (Järup, 2003). These substances have negative effects on human health and can damage the functioning of organs such as the brain, lungs,

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and liver (Jaishankar *et al.*, 2014; Balali-Mood *et al.*, 2021). The mean values for chemical variables such as pH, lead, chromium, conductivity, and ammonium exceeded the limits recommended by WHO for drinking water.

Strategies for Improving Water Quality in Athi River

The water quality of Athi River can be improved through the implementation of water pollution control policies, inventory and identification of drainage basins water pollutants sources, treatment of wastewater before disposal into the river, setting pollution load capacity, and increasing communities' knowledge and participation in water management. According to Nel *et al*. (2013), improvement of water quality in rivers requires several approaches, such as the determination of pollutants sources, treatment of wastewater effluents before discharge, determination of drainage basins vulnerability to pollution, prioritisation of rivers requiring improvement of water quality, implementation of water pollution control policies and setting of water quality standards. It has also been advocated that water resources should be managed at the level of drainage basins, local communities and other stakeholders should participate in the management of water resources, and institutions and policymakers should be strengthened to enhance the management of water resources (Molobela & Sinha, 2011; Shahady & Boniface, 2018).

Water quality can also be improved through licensing, land use planning, supervision and reduction of activities that are likely to cause pollution, control of disposal of wastewater into the river, provision of environmental education and outreach to increase the awareness of the public concerning the environment and engaging stakeholders with the aim of strengthening institutional relationships (Styles *et al.,* 2009; Bohnet, 2015; Alvarez *et al.*, 2016; Wuijts *et al.*, 2018). Other strategies for improving water quality include tree planting in the riparian zones, river clean-up exercises, safe use of wastewater and restoration and protection of the ecosystem (Osborne & Kovacic, 1993; Alam & Marinova, 2003; Carr *et al.*, 2004; Dosskey *et al.*, 2010).

CONCLUSIONS AND RECOMMENDATIONS

The study found that the cement industry has significant impacts on water quality variables such as temperature, conductivity, magnesium, total suspended solids, total dissolved solids, ammonium, calcium, turbidity and pH. However, the cement industry did not have a significant impact on lead, chromium, or total dissolved solids. Physico-chemical factors such as temperature, total suspended solids, pH, lead, chromium, conductivity and ammonium exceeded the limits recommended by the WHO standards for drinking water. Mitigation measures such as control of disposal of wastewater effluents, safe use of wastewater effluents, river clean up, implementation of water pollution control policies and involvement of stakeholders in the management of water resources need to be considered to prevent further deterioration of water quality. Future studies should determine the effect of cement manufacturing on other water resources, such as groundwater. Other studies should evaluate the socio-economic and health effects of cement industries.

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