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PHYSICOCHEMICAL ANALYSIS OF STORMWATER RUNOFF FROM A CEMENT MANUFACTURING PLANT IN NIGERIA

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ABSTRACT

This study evaluates the physicochemical characteristics of stormwater runoff from a cement manufacturing plant in Kogi State, Nigeria, during the rainy season (June to August 2024). The objective was to assess the environmental impact of cement production processes on stormwater quality. The parameters analyzed include pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride and sulphate ions, and heavy metal concentrations. Results revealed pH values ranging from 6.52 to 11.50, with alkaline runoff exceeding regulatory limits during peak production activities. The TSS levels (288 ± 2.65 to 420 ± 5.57 mg/L) and TDS concentrations (200 ± 2.74 to 312 ± 3.21 mg/L) were within the permissible limits of the National Environmental Standards and Regulations Enforcement Agency (NESREA) of Nigeria. The BOD and COD values occasionally exceeded thresholds, indicating organic pollution during certain conditions. Sulphate levels were significantly elevated (up to 540 mg/L), suggesting atmospheric deposition of industrial emissions. Heavy metal analysis revealed variable concentrations of Fe, Zn, Cu, Pb, and Mn ions, with some samples exceeding NESREA limits for Fe and Cu. The findings underscore the need for effective stormwater management strategies in cement plants to mitigate environmental impacts and ecological risks associated with industrial stormwater discharges in Nigeria, and to ensure compliance with regulatory standards.

Keywords: Cement, physicochemical analysis, heavy metals, stormwater runoff.

INTRODUCTION

The expansion of industrial activities worldwide has continued to increase environmental pollution in the form of water, air, and soil pollution with negative effects on the ecosystem. In addition to industrial and municipal wastewater, stormwater runoff has been identified as a major source of pollution from urban and industrial environments [1]. Stormwater can impact negatively on the quality of surface water, seepage water, and groundwater [2]. The stormwater diverse contaminants include suspended and dissolved solids, heavy metals, polycyclic aromatic hydrocarbons, and various organic and inorganic substances [3]. An understanding of stormwater characteristics is necessary in the design and implementation of urban and industrial structures for effective stormwater controls and treatment [4].

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The cement industry is a well-known industrial sector that plays a significant role in the global economy. However, its manufacturing processes generate significant harmful pollutants mainly in the form of air pollution which have links to so many diseases [5]. These pollutants usually discharge from stack and non-stack points in the raw mill, cement kiln, clinker, grinding, and bagging sections of cement facilities. Pollutants especially those with high density settled around the facilities because of the dry atmospheric deposition process and eventually get washed down as stormwater by the action of rain. Particles of lower density get leached out of the atmosphere as wet deposition on the facility resulting in contamination of the stormwater [5-6].

In this study, the physicochemical characteristics of stormwater from the cement manufacturing facility during the peak of raining season (June to August 2024) were investigated to determine pollution impact on the environment. The physicochemical parameters including pH, EC, TSS, TDS BOD, COD, chloride and sulphate ions, and heavy metal ion concentrations of the stormwater runoff from the facility were analyzed and the results obtained were compared with the permissible limits set by NESREA.

MATERIALS AND METHODS

Collection of stormwater samples

The cement production facility is located at Oworo District of Lokoja Local Government Area, Kogi State, Nigeria, at coordinates 6°27’39″ E and 7°54’39″ N [7]. The samples were collected from the stormwater runoff drainage of the cement facility from June to August 2024, using grab sampling method. The samples were collected in pre-washed polyethylene bottles within the first 30 minutes of the rainfall event, followed by 5 minutes-interval. A total of six rainfall events were monitored during the period of study and the samples were labelled as A, B, C, D, E, and F respectively.

Physicochemical analysis

The pH of the stormwater samples was determined using a PHS-3C Searchtech pH meter and the EC was measured using a Hana Hi2030 conductivity meter. The TSS, TDS, BOD in 5 days at 20 ºC, COD, and Chlorides were determined using standard methods. The sulphate ions were analyzed using the turbidity method and the concentration determined using Beckman Coulter DU 730 UV spectrophotometer. The heavy metal ion concentrations were determined using Buck Scientific 210 VGP Atomic Absorption Spectrophotometer [8]. Analytical-grade chemical reagents were used, and all the instruments were calibrated.

RESULTS AND DISCUSSION

pH

The pH values ranging from 6.52 ± 0.06 to 11.50 ± 0.08 were recorded for the stormwater samples (Figure 1). Alkaline pH above 9.0 observed in samples A, C, and D were above the NESREA limit of 6.0 to 9.0 [9]. This observation was made at the

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time of mixing and blending of raw materials in the raw meal section and kiln/clinker operations taking place. Dust particles from limestone and other cement materials released during manufacturing processes (mostly alkaline in nature) get settled on the facilities and are washed down by the action of the rain, as alkaline runoff water [10]. The pH values of 6.83 ± 0.21 and 6.52 ± 0.06 observed in samples B and F can be attributed to the fact that at the time of the sampling, no visible production process was taking place at the mixing and clinker section except bagging. This implies that most of the alkaline atmospheric deposition may have been washed away in the previous fall-out.

Electrical Conductivity

The EC of the stormwater samples varied from 130.5 ± 4.20 to 300 ± 2.73 µS/cm (Figure 2) and these values fall within the permissible limit of 300 µS/cm set by NESREA for discharge. The relatively high EC values obtained is an indication that the runoff water contains some level of dissociated ions; a factor responsible for the electrical conductivity of solutions [11]. This finding supports a similar report on water-soluble ions measured in particulate matter next to a cement production facility [12].

Total Suspended Solids Dissolved Solids

The results obtained for TSS and TDS during the period of study are presented in Figure 3. The concentration of the TSS for the runoff water samples ranged from 288 ± 3.15 to 420 ± 2.08 mg/L. From the results, the TSS for all the samples were below the tolerance limit of 500 mg/L for discharge into inland water, hence, has no negative impact on the receiving waterbody and the environment. A high TSS can lead to a reduction in the amount of light that penetrates an aquatic environment thereby decreasing photosynthetic activities which can affect the food chain and cause clogging of fish respiratory passage [13]. The TDS concentration varied from 200 ± 2.74 to 312 ± 3.21 mg/L. These values fall within the recommended limit of 500 mg/L by NESREA. All dissolved materials usually in colloidal form are referred to as TDS. A high level of TDS affects freshwater osmoregulation in aquatic organisms, increases water density, and reduces oxygen solubility in water [14].

Biological and Chemical Oxygen Demand

The results obtained for BOD and COD of the stormwater runoff are presented in Figure 4. The BOD is the amount of oxygen required by microorganisms to break down organic matter in water under aerobic conditions [15]. COD is defined as the amount of oxygen required to decompose organic pollutants (resistant to biological degradation) in the presence of a strong oxidizing agents [16]. The values obtained for BOD and COD for the period of study varied from 16 ± 1.87 to 55.6 ± 2.05 mg/L and 20.75 ± 1.28 to 130 ± 1.55 mg/L respectively. Except for sample C with BOD value of 55.6 ± 0.79 mg/L and samples C and F with COD valves of 130 ± 2.65 and 115 ± 2.65 mg/L, all other samples fall within the tolerance limit of 50 mg/L and 100 mg/L for BOD and COD respectively. This is an indication that most of the runoff water samples are of low organic loading because, cement raw

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materials, intermediate, and finished products are mainly composed of inorganic compounds [17]. Also, the stockpiles and coal used as fuel for the calcination process were housed inside the facility thereby preventing the contact with stormwater. In addition, volatile organic compounds, aromatic hydrocarbons, oxides of sulphur and nitrogen, carbon dioxide, hydrogen chloride, and other substances emitted from fuel combustion, and high flame temperature operations are dispersed further away by the action of wind [17].

Chloride and Sulphate Ions

The concentration of chloride and sulphate ions measured ranged from 10.01 ± 1.04 to 38.30 ± 1.42 mg/L and 30 ± 1.78 to 540 ± 2.10 mg/L respectively (Figure 5). The concentration of chloride in all the samples was below the level of 250 mg/L permitted by NESREA for discharge. Chloride ion concentrations above 250 mg L^{-1} in drinking water can impart a salty taste [18]. Sulphate ions occur naturally in water at very low concentrations but its discharge into water bodies at elevated concentrations, as a result of industrial activities has toxic effects on sulphate-sensitive aquatic organisms [19]. The considerable amount of sulphate ions detected in some of the samples can be attributed to the interaction of emitted oxides of sulphur with the stormwater [20]. From the results obtained, concentrations of sulphate ion in samples A (540 ± 2.10 mg/L), B (530 ± 3.0 mg/L), and F (480 ± 1.73 mg/L) were higher than the 250 mg/L NESREA limit expected for discharge.

Heavy Metal Ion Concentrations

The range of concentration of metal ions detected in the cement runoff water (Table 1) was 1.1 ± 0.03 to 19.73 ± 0.46 mg/L for Fe, 0.04 ± 0.01 to 3.09 ± 0.05 mg/L for Zn, 0.02 ± 0.01 to 2.19 ± 0.06 mg/L for Cu, < 0.001 to 0.08 ± 0.03 mg/L for Pb and 0.05 ± 0.02 to 1.0 ± 0.16 mg/L for Mn ions respectively. The relatively high concentration of Fe ions observed in samples A and F above the recommended limit of 5.0 mg/L for discharge into inland water can be attributed to the leaching of Fe ions from the particulate matter [21]. For other metal ions, only the concentration of Cu, Zn, and Pb ions in sample E were slightly above the recommended limits. The concentration of Mn ions in all the samples were below the tolerance limit. In addition to the leaching of metal from the cement particles, washed of corroded roof parts, surfaces, and components of the facility by the action of rain may have contributed to the concentration of metal ions detected in the stormwater runoff [22].

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Table 1 Metal ions concentration in stormwater runoff

Sample	Fe (mg/L)	Zn (mg/L)	Cu (mg/L)	Pb (mg/L)	Mn (mg/L)
A	11.0 ± 0.24	0.47 ± 0.02	0.17 ± 0.02	< 0.001	0.12 ± 0.03
B	1.1 ± 0.1	0.04 ± 0.01	0.02 ± 0.01	0.1 ± 0.02	0.05 ± 0.02
C	2.88 ± 0.07	0.19 ± 0.01	0.13 ± 0.02	0.03 ± 0.01	0.12 ± 0.03
D	4.22 ± 0.06	0.56 ± 0.04	0.78 ± 0.03	< 0.001	0.34 ± 0.16
E	2.76 ± 0.04	3.09 ± 0.09	2.19 ± 0.06	0.08 ± 0.03	1.0 ± 0.16
F	19.73 ± 0.46	0.36 ± 0.02	1.08 ± 0.07	< 0.001	0.38 ± 0.06
NESREA limits	5.0	2.0	1.0	0.05	2.0

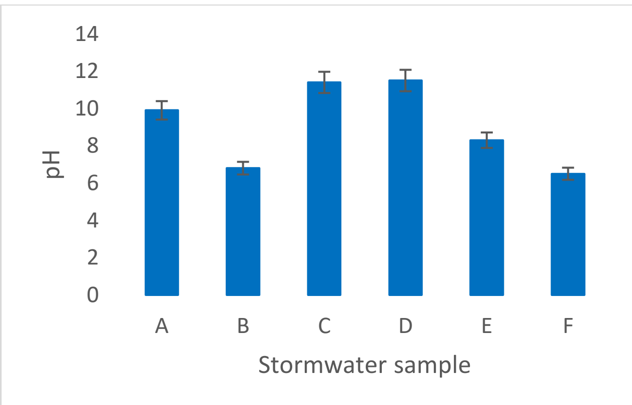

Figure 1 Variation of pH

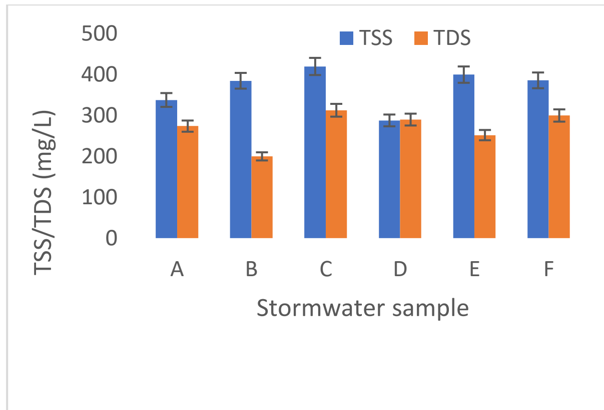

Figure 3 Variation of TSS and TDS

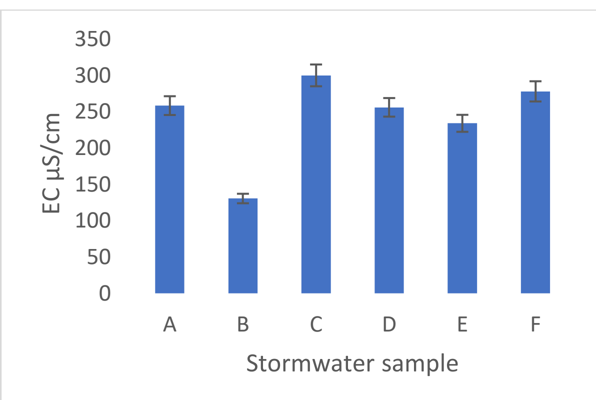

Figure 2 Variation of EC

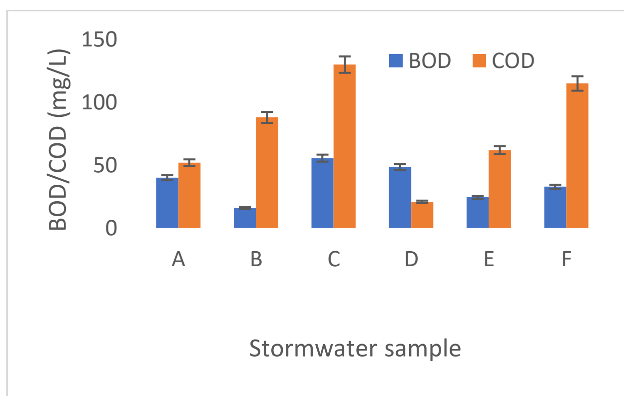

Figure 4 Variation of BOD and COD

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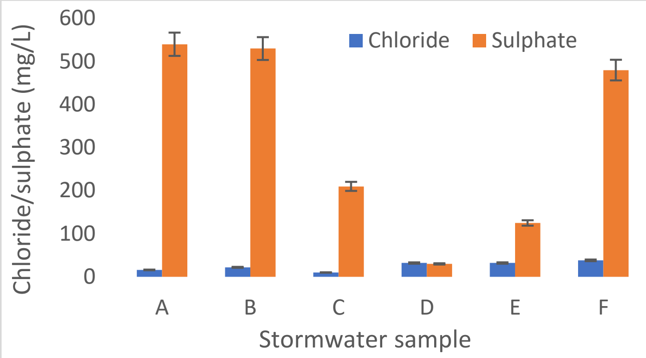

Figure 5 Variation of chloride and sulphate ions

CONCLUSION

This study assessed the physicochemical characteristics of stormwater runoff from a cement manufacturing facility in Nigeria, revealing significant insights into the environmental implications of cement processing. While most parameters were within permissible limits set by NESREA, elevated levels of pH, sulphate, and certain heavy metals highlight potential environmental risks. These findings underscore the critical need for improved management strategies for industrial runoff, including the implementation of effective pollution control measures and regular monitoring of effluent quality. These steps are essential to mitigate environmental impacts and ensure compliance with regulatory standards, thereby protecting aquatic ecosystems and surrounding communities from environmental challenges posed by industrial stormwater runoff.

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