Physicochemical Characterization of Wastewaters from a Cluster of Industries in Jos, Nigeria

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ABSTRACT

This work was carried out to establish the effects of the activities of a cluster of industries in Jos-South Local Government Area of Plateau State, Nigeria, on the environmental quality of the industrial area. Some physicochemical parameters – temperature, pH, turbidity, suspended solids (SS), total solids (TS), total hardness, alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), heavy metals (Cu^{2+}, Co^{2+}, Fe^{2+} & Zn^{2+}), phosphates, nitrates, sulphates and chlorides – of the wastewaters from the various industries were investigated using standard protocols. The ranges of the parameters were as follows: temperature: 22 – 32^{0}C, pH: 5.5 – 10.4, SS: 0 – 1,300mg/L, TS: 200 – 1.400mg/L, sulphate: 0.37 – 1.37mg/L, nitrites: 0.10 – 1.09mg/L and phosphate: 14.80 – 21.83mg/L. The phosphate values, especially, are in excess of the maximum contamination limit specified by Federal Environmental Protection Agency (FEPA) and World Health Organization (WHO); and are capable of triggering eutrophication, which will in turn increase BOD/COD values. Concentrations of heavy metals, determined by Atomic Absorption Spectophotometry (AAS), ranged as follows: 0.07 – 2.01mg/L for Cu^{2+}, 0.58 – 3.27mg/L for Fe^{2+}, 0.01 – 3.18mg/L for Zn^{2+} and 0.11 – 0.18mg/L for Co^{2+} whose specified standard is not available. BOD values ranged between 5.34 – 25.88mg/L while COD values ranged from 727.30 – 8,308.66mg/L. Some BOD values were in excess of the allowable limit while all COD values were observed to be very high. This implies an appreciable level of pollution exists here and recipient water bodies of these wastewaters are at risk of being polluted.

INTRODUCTION

Water is a prime need for human existence therefore; it is natural that people gather to live together in communities or locations where potable water is; to meet their needs. Though 75% of the earth's surface is water[1], not all the water is available for human consumption. Most of it is in oceans, ice caps, underground aquifers (ground water-bearing beds) and in the air (as moisture). The accessible portion of water for human use is also greatly affected by various human activities such as agriculture, industrial processing of raw materials, mining activities, oil explorations, etc. These activities are necessities for improved standard of living but the accompanying effects of waste generation, which in most cases result in environmental degradation/pollution, are a source of great concern.

Some of the common pollutants include heavy metals (e.g. Hg^{2+}, As^{3+} Cu^{2+}, Zn^{2+}, Ni^{2+}, Cr^{3+}, Pb^{2+}, Cd^{2+}, etc.), phosphates, nitrates, sulphates, oils and grease; and organic materials, whose presence is indicated by biological oxygen demand (BOD) and chemical oxygen demand (COD) values. Introduction of any of these substances alters the natural composition and chemistry of the receiving waters. Industrial wastewaters are common carriers of these pollutants.

Characteristics of industrial wastewaters vary from industry-to-industry and are very significant because they give an indication of the treatment works required. The need for industrial effluent discharges to be monitored and controlled right from the source is of paramount importance in relation to pollution control.

Heavy metals in industrial wastewater and municipal sewage are the main cause of water and soil pollution. At higher concentrations than specified, they become toxic to aquatic life and harmful to humans that prey on them. In some cases, oxygen depletion can also occur with these inorganic pollutants e.g. the oxidation of sulphites and nitrites to sulphates and nitrates[2]:

$$SO_3^{2-} + \frac{1}{2}O_2 \longrightarrow SO_4^{2-}$$

$$NO_2^{-} + \frac{1}{2}O_2 \longrightarrow NO_3^{-}$$

The reduced level of dissolved oxygen results in high BOD values, which indicates high level of water pollution. Therefore, such chemical transformations leading to oxygen depletion have been considered as one of the potential factors for cases of mass mortality, often associated with some imbalance in environmental parameters.

Despite the various differences in the nature of industrial wastes, basic tests – suspended solids (SS), total solids (TS), BOD, COD, pH, phosphates, nitrates, temperature, alkalinity, salinity and hardness – could be used for their characterization[3] so as to understand their threats to the environment and design appropriate mitigation measures.

Aquatic biotas are sensitive to extremes of pH. They cannot survive excess salinity they are not adopted to; largely because of osmotic effects[4]. Heavy metals are reported[4] to have tremendous affinity for sulphur and disrupt enzyme function by forming bonds with sulphur groups in enzymes. Copper ions bind to cell membranes, hindering transport process through the wall. Heavy metals may also precipitate phosphorous biocompounds or catalyze their decomposition. Copper and zinc are essential elements but toxic to plants and algae at higher levels. Iron is an essential nutrient but damages fixtures by staining.

The present study, therefore, aims at characterizing the wastewaters from a cluster of industries using standard protocols for above-mentioned basic tests and heavy metal (Cu^{2+}, Zn^{2+}, Fe^{2+}, Co^{2+},) determinations.

MATERIALS AND METHODS

Study Area: Jos, located in the North-Central Nigeria, is the capital of Plateau State. The study area is located between Anglo-Jos and Barakin Larawi (Railway Quarters) in the Jos-South Local Government Area of the state. Located within this area is Nasco Household Products Limited (NHPL; a chemical industry), Nigerian Bottling Company (NBC; Coca-Cola), Nasco Foods Limited (NFL) and Jos International Breweries (JIB), each having a furrow of wastewater that eventually confluences into one wastewater body and empties into a nearby stream. Farming activities also take place within the study area.

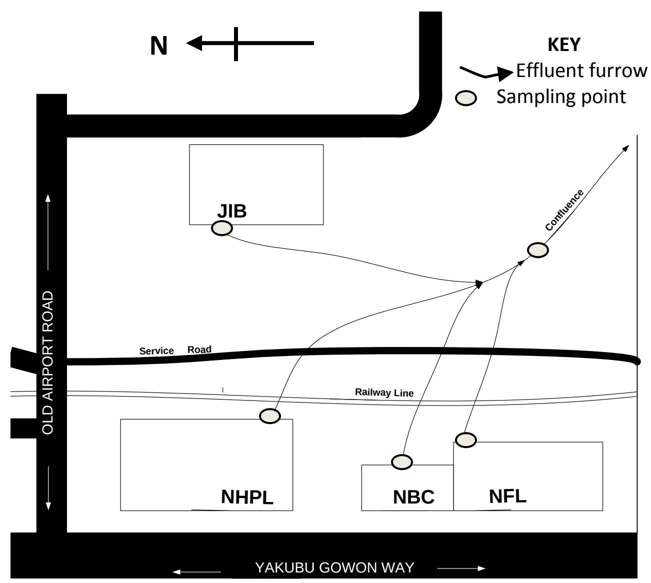

Figure 1: Map of study area showing location of industries and sampling points.

Sampling: Wastewater samples from each of the industries were collected at point-sources

(Fig.1) twice a week for a full seasonal cycle at peak production period (morning and evening).
Samples not analyzed immediately were kept in the refrigerator (4^0C) in pre-rinsed plastic containers having airtight plastic covers for preservation. Analyses were, however, carried out within 24 hours at the NHPL laboratory.

Sample Analyses*:* Analyses were carried out according to standard methods[5, 6] for water and wastewater analyses. Heavy metals were determined using Atomic Absorption Spectophotometer (UNICAM – model 969, SOLAAR) while phosphates were determined using Milton Roy Spectronic 21D spectrophotometer.

RESULTS AND DISCUSSION

Average values for the results of the determinations were as presented in Tables 1-4 below. Table 1 show that wastewaters from NHPL and NBC had significantly higher temperatures than the ambient. This suggests presence of insoluble salts in these effluents and signifies that effluent discharges from these industries have a potential for thermal pollution of the receiving water and the immediate surroundings.
The pH of the wastewaters ranged from 5.50 to 10.40 (Table 1) as against 6.50 – 8.70 allowable for pollution control in surface waters. The wastewaters were generally alkaline with that from NFL and the confluence almost neutral while the JIB sample was acidic (pH=5.5). The acidic pH could be attributed to fermentation by-products as well as raw materials[7] such as enzymes, lactic acid, benzoic acid and yeast commonly used in breweries. Low pH (<4.0) increases the toxicity of heavy metals (As, Cr, Cu, Zn) while high pH values increase the toxicity of ammonia to aquatic life[8].

Table 1 also shows total solids range as 200 – 1,400 mg/L. These values fall within the allowable value of 1,500mg/L. Suspended solids values ranged from 0.01 – 1,300mg/L and are all well in excess of the allowable value of 30mg/L, except that for NBC effluent. The 1,300mg/L value for JIB effluent is higher than that reported for Diamond (121mg/L), Life (100mg/L) and Premier (230mg/L) breweries[9] as well as Nigerian Breweries Plc (38.5mg/L)[10]. The value 0.01mg/L for NBC effluent is lower than that reported for NBC, Maiduguri (0.53mg/L)[11].
Suspended solids are an index of the sludge forming characteristic. They result from sediments and insoluble salts[12] in water and have the potential to absorb heat and raise water temperature to levels that could reduce dissolved oxygen levels to the detriment of aquatic life. The high SS value for the JIB effluent collaborates, therefore, the high temperature recorded for this effluent. The almost zero value for NBC effluent suggests that the industry either doesn't use salts (solids) or all the solids in use are water soluble salts.

Table 1: Physical parameters

Source	pH	Temperature (^0C)		Total Solids (mg/L)	Suspended Solids (mg/L)	Turbidity (mg/L)
		Ambient	Sample			
NHPL	8.00 ± 0.01	22.0 ± 0.2	31.0 ± 0.2	400 ± 1	200 ± 2	252.0 ± 0.01
NBC	10.40 ± 0.02	22.0 ± 0.2	32.0 ± 0.2	600 ± 1	0.01± 0.01	16.7 ± 0.02
NFL	7.10 ± 0.01	26.0 ± 0.1	24.0 ± 0.1	500 ± 2	100 ± 1	8.0 ± 0.01
JIB	5.50 ± 0.01	26.0 ± 0.2	22.0 ± 0.2	1,400 ± 1	1,300 ± 2	300.0 ± 0.01
Mixture	7.20 ± 0.01	26.0 ± 0.2	26.0 ± 0.2	500 ± 1	400 ± 1	750.0 ± 0.01
Standard	6.50-8.70		< 32.50	1,500	< 30	< 20

Turbidity values in Table 1 range from 8.0 – 750mg/L; with values for NHPL, JIB and confluence samples well above the allowable value of <20mg/L. These high turbidity values could be attributed to decomposing organic matter in the effluent as well as emulsification of oils (and greases). The weak correlation ($R^2 = 0.3469$) between turbidity and BOD, however, suggests the predominance of emulsification phenomenon over decomposition.

Results of total hardness, alkalinity, sulphates, nitrites and chlorides determinations were generally within allowable limits. The zero level total hardness for NHPL sample could be attributed to the use of STPP (sodium tripolyphosphate) and zeolite 4A as part of the raw material regime of the industry. These materials are good chelating agents and hence good water softeners. The high volume use of caustic soda (NaOH) alongside salts of weak acids such as borates, silicates and phosphates in same industry could be responsible for the high alkalinity (sum of all titrable bases) value recorded for its effluent.

The concentrations of phosphate (PO_4^{3-}) as shown in Table 2 are in excess of 5.0mg/L maximum contamination limit by WHO[13] and other standards[14,15]. These high values could be attributed to phosphate-containing raw materials used, human activities such as farming in which phosphate-containing fertilizers are used, human wastes and animal droppings (which are common phenomenon along the furrow). The high PO_4^{3-} concentrations are capable of triggering eutrophication process, which could result in growth of aquatic plants and algal scum to nuisance levels. Severe decrease in oxygen levels would consequently result, which would inhibit the growth and survival of desirable aquatic organisms.

Table 2: Chemical parameters

Source	Total Hardness (as $CaCO_3$, mg/L)	Alkalinity (as $CaCO_3$, mg/L)	Sulphate (mg/L)	Nitrite (as NO_2-N, mg/L)	Phosphate (mg/L)	Chloride (mg/L)
NHPL	0.00	1,000.00 ± 1	1.37 ± 0.01	0.53 ± 0.02	15.96 ± 0.03	20.96 ± 0.02
NBC	0.4 ± 0.01	12.00 ± 1	0.49 ± 0.01	0.33 ± 0.02	14.80 ± 0.02	272.53 ± 0.03
NFL	1.3 ± 0.02	10.00 ± 2	0.39 ± 0.01	1.09 ± 0.02	21.83 ± 0.01	28.59 ± 0.01
JIB	0.00	0.00	0.37 ± 0.01	0.10 ± 0.01	21.15 ± 0.02	22.87 ± 0.01
Mixture	0.6 ± 0.01	52.00 ± 1	0.40 ± 0.01	0.27 ± 0.02	21.26 ± 0.03	19.06 ± 0.01
Standard	< 40.00	NA	≤ 250.00	≤ 45.00	≤ 5.00	≤ 200.00

Results for chloride determination, as presented in Table 2, were generally within the allowable limit of ≤200mg/L, except for the NBC effluent (272.5mg/L). This high value could likely be accounted for by the raw materials in use as syrups used in food drinks contain NaCl. Sodium chloride is also used as preservative in food industries.

The BOD (difference in value for dissolved oxygen observed at day one and after 5 days of incubation) results, as presented in Table 3, show all values being within the permissible[13-15] discharge limit (< 20 mg/L); except that for NHPL (25.88 mg/L). This relatively high value could be attributed to washings from a farmland that terminates close to the sample point, which likely contributes fertilizers, manures, human waste, etc. to the effluent.

The COD (a measure of chemically oxidizable organic matter in wastewater) values in Table 3 ranged from 727.30 – 8,308.66 mg/L. The very high values observed are indications of large amounts of chemically oxidizable organic matter in the effluent resulting from loss of products/raw materials. The COD values are far higher than BOD values because some organic matters are not biologically oxidized but are readily oxidized chemically; hence higher COD values than BOD values.

Table 4 presents results of the heavy metals analysis with the following concentration ranges: copper, 0.07 –

2.01 mg/L; iron, 0.58 – 3.27 mg/L; zinc, 0.01 – 3.18 mg/L; and cobalt 0.11 – 0.18mg/L. Except for iron, all other metal concentrations were within the permissible effluent discharge limits. No specified limit for cobalt.

Although copper toxicity is rare in humans, aquatic organisms are potentially at risks from exposures[16]. Effluent from NBC were observed to either have the highest or close to the highest concentration values for all the metals investigated, especially cobalt, copper and zinc. The presence of these metallic toxicants portends inactivation or death of the microorganisms in the effluent; leading to low BOD[17]. This explains the very low BOD values recorded for this effluent. It's been reported[17,18] that every 1mg Cu^{2+} per liter of wastewater suppresses BOD by 33% while every 1mg Zn^{2+} per liter of wastewater suppresses BOD by 17%.

Table 3: Oxygen demand parameters

Source	DO (mg/L)	BOD (mg/L)	COD (mg/L)
NHPL	5.25 ±0.01	25.88 ±0.03	1,669.48 ±0.05
NBC	1.08 ±0.01	5.34 ±0.02	762.85 ±0.01
NFL	1.28 ±0.01	6.31 ±0.01	727.30 ±0.02
JIB	2.91 ±0.01	14.38 ±0.02	8,308.66 ±0.03
Mixture	3.72 ±0.01	18.36 ±0.03	8,035.12 ±0.01
Standard	≥70.00	< 20.00	< 250

Table 4: Heavy metals concentration

Source	Copper (mg/L)	Iron (mg/L)	Zinc (mg/L)	Cobalt (mg/L)
NHPL	0.07 ± 0.01	0.58 ± 0.02	0.01 ± 0.01	0.11 ± 0.01
NBC	2.01 ± 0.02	1.15 ± 0.01	3.18 ± 0.02	0.18 ± 0.01
NFL	0.11 ± 0.01	1.94 ± 0.01	0.08 ± 0.01	0.14 ± 0.01
JIB	0.30 ± 0.01	3.27 ± 0.02	0.21 ± 0.02	0.16 ± 0.02
Mixture	0.18 ± 0.01	1.39 ± 0.02	2.96 ± 0.03	0.17 ± 0.01
Standard	<40.00	≤0.30	<40.00	NA

CONCLUSION

This investigation has demonstrated that all the industries within the Anglo-Jos industrial area of Jos-South Local Government Area, Plateau State of Nigeria, are polluting the environment; even though most of the parameters investigated were within acceptable effluent quality limits. Of major concern is the high values for phosphates, iron, SS, temperature, pH, turbidity, BOD and TS.

None of these industries treat their effluents before discharge and none had (at the time of investigation) environmental management system (EMS) installed. At their inception, there was no Environmental Impact Assessment (EIA) carried out. This suggests no immediate change in the observed scenario and continued discharge of these wastewaters into the environment may result to severe accumulation of the pollutants. The immediate threat of this body of wastewater to the environment is, therefore, eutrophication.

Irrigation of farm lands (vegetables and maize farms) is one major use the wastewater stream is put to. Plants are known to accumulate elements (heavy metals) by uptake to levels that present risk to other members of the food chain[19, 20] and sometimes the plant themselves[20]. Crops cultivated on these farmlands stand the risk of accumulating these toxicants. Investigation of elemental uptake by crops from the farmlands within the study area is, therefore, imperative.

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