Seasonal distribution of microbial biomass carbon and some heavy metals around the industrial area of Kano Metropolis, Northwestern-Nigeria

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Abstract. The accumulation of toxic heavy metals in excessive quantities has a detrimental effect on soil quality which interferes with key biochemical processes in soils. It is very imperative to explore soil microbial activities concerning to environmental conditions for sustainable soil management. The study aimed to assess the seasonal distribution of soil microbial biomass carbon (MBC), some heavy metals and pH, and their relationship in the soil ecosystem. Field investigation and laboratory analysis were the main methods adopted as sources of generating data and analyses. Ten soil samples were collected using composite sampling techniques on seasonal bases and then analyzed in the laboratory. The results were subjected to statistical analyses using t-test and the Analysis of Variance (ANOVA) at 𝛂<0.05. Pearson’s correlation and regression analysis was analyzed to determine the relationship among the variable at P<0.05. The results show that locations with higher values of MBC corresponded with locations with high Cr, Cd, and Pb. High values of Cr, Cd, and Pb were observed in the dry season. On the other hand, in the wet season, rainfall enthused dilution, leaching, and runoff of Cr, Cd, and Pb and then removed from subsurface. High MBC in the wet season is due to favorable conditions for the microbial population and rapid mineralization due to high moisture and temperature than the dry season where there are low moisture and temperature. The analysis revealed that MBC was positively related to Cr, Pb, and was negatively related to Cd. However, the variation of MBC was explained by Cr, Cd, and Pb by 64% and 52% for dry and wet season respectively. It was concluded that the toxicity of heavy metals in soil depends on the pH level and therefore, determination of MBC, Cr, Cd, Pb, pH, and temperature of soil reflect the microbial activities in the soil and could be considered as soil quality indicators.

Keywords: soil microbes; mineralization; organic matter; contamination; heavy metals, soil

1. Introduction

The contamination and subsequent pollution of the environment by toxic heavy metals have become an issue of global concern due to their sources, widespread distribution, and multiple effects on the soil ecosystem (Ofoegbu et al., 2013). Rapid population growth, industrialization, and economic development of Kano metropolis necessitated people to use contaminated water including land and soil for irrigation activities. Nevertheless, heavy metals are continuously introduced to the soil via various ways including industrial and domestic activities (Mohammed et al., 2015). This situation is even more worrisome in Kano metropolis which research effort on the seasonal distribution and impact of heavy
metals on Microbial Biomass Carbon (MBC) is limited and there is desire attention on the assessment of the seasonal distribution and impact of heavy metals on MBC of soil in terms of monitoring the status of the environment for the sustainability of the soil ecosystem.

Soil is a multifaceted system, which supports plant growth, purify water, and as a provider of some ecological services such as carbon dioxide sink and nutrient recycling. Nevertheless, changes in soil conditions affect the services offered seasonally (Soumyabrata & Niharendu, 2020). Insurances of sustainable life, that is bound to the preservation of the natural courses of the processes and are ultimately secured by the "quality of soil" in physical, chemical, and biological terms. Soil also acts as a principal component of natural ecosystems. Indeed, environmental sustainability largely depends on the sustainable soil ecosystem, and any alteration as a result of either pollution or contamination ultimately alters the soil ecosystems and agricultural activities are also greatly affected (Ayeni et al., 2010).

The reuse application of wastewater/effluents to agricultural soils is a useful source of plant nutrients, particularly nitrogen and phosphorous, and also the organic matter that can potentially improve soil fertility and physical properties (Mohammed, 2017a). Among the inorganic chemicals, heavy metals are often present in appreciable quantities and chelated by the organic matter in the effluents. When effluents discharged into the environment, the heavy metals enter the soil and get fixed to the soil components. Thus, the continuous application of effluents tends to accumulate large quantities of heavy metals in soil, which persists there for an indefinite period and consequently have long-lasting effects in the soil environment (Mohammed, 2017b).

Heavy metals affects the population, diversity and microbial activity of soil microorganisms because the low concentration of heavy metals could simulate microbial growth and increase microbial biomass, whereas high concentration could decrease soil microbial biomass significantly (Chao et al., 2014). The toxicity of heavy metals depends on the soil properties such as pH, temperature, inorganic anions and cations, clay minerals, hydrous metal oxides, organic matter form and amount, and chemical forms in which metals occurs (Iwegbue et al., 2013).

The MBC is the living part of soil organic matter, excluding plant roots and soil animals which larger than 5×103 µm³. It comprised of some species of bacteria and fungi, together with relatively larger soil organisms such as yeast, algae, and protozoa (Gregorich et al., 2000). Estimation of soil MBC offers a means of assessing the response of the total microbial population to the changes in soil management practices (Dai et al., 2004). The soil MBC acts as the transformation agent of the organic matter in the soil. As such the biomass is both a source and sink of the nutrients C, N, P and S contained in the organic matter, it is the center of the majority of biological activity in soil ecosystem (Lenart-Boron & Piotr, 2014). Soil MBC plays a key role in the ecosystem processes of C and N cycle, therefore, seasonal changes in MBC is very important in regulation soil microbial turnover and nutrient availability (Sorensen et al., 2018).

The seasonal changes in environmental conditions such as moisture content and temperature expedite the microbial biomass cycle, carbon mineralization rate, availability of nutrients from the soil solution. Low contaminated soil with high moisture content stimulates the microbial population and activities and consequently enhance the availability of nutrient from dead soil microbes (Dian, 2018). Heavy metals have noteworthy effect on soil microbial activities like microbial respiration, nitrogen fixation, and enzymatic that relied on soil pH, temperature, and organic matter. Moreover, cyclical changes in soil temperature, pH, and organic matter control the quality of soil, land use type, and management decision (Emre & Turgay, 2020).

Some previous studies by Ezegiofor et al. (2013) and Chiroma et al. (2014) discovered heavy metals in the domestic and industrial effluents discharged into River Salanta and Getsi in Kano metropolis. However, these studies focused on the assessment of heavy metals level in the affluent but they neither reflects their environmental consequences on the soil ecosystem nor assess the seasonal variations and their relationship with MBC. To prevent negative soil ecological consequences, MBC, heavy metals, pH, and temperature of soil were considered on seasonal bases because they are key indicators of soil health. Nevertheless, some attempts were made by Sadiq et al. (2017) and Imam et al. (2015) to examine the concentrations of the heavy metals in the soils of the region, conversely the studies were limited in scope because they only focused on heavy metal concentration in the soil and they did not consider the relationship that exists between MBC and heavy metals.
Due to the limited data on the seasonal distribution and relationship of heavy metals with MBC of soil in Kano metropolis, this work set out to generate and upgrade the soil database to achieve environmental sustainability and harmony of soil ecosystem. This study provides useful data for soil management, policy formulation, and decision-making concerning soil management for agricultural sustainability in Kano metropolis, Nigeria. The objectives of the research are to: assess the seasonal distribution of MBC, some heavy metals, pH and temperature, and evaluate their relationship.

2. Methodology

2.1. Study Area

The study conducted in irrigated land around two major industrial areas as Sharada industrial area located between latitude 11° 57’N to 11° 59’N and longitude 8° 30’ E to 8°32’E and situated within Municipal and Kumbotso Local Government Area, and Bompai industrial area that located between latitude 12° 10’ N to 12° 12’ N and longitude 8° 33’ E to 8°35’E (Fig. 1), and fall within Nassarawa, Ungogo and Fagge Local Government Area (Mohammed, 2010). The climate of the area is tropical wet and dry type (Ayoade, 1983; Adamu, 2014). The rainfall in the area normally started around June, reaching its peak around August and last for around October (Buba, 2014) which favored the activities of soil microbes (Brady and Weil, 2015). However, the dry season is around January to May and September to December within this period the activities of soil microbes is very low due to inadequate moisture (Mohammed, 2017a). The mean annual temperature is about 26 °C, but mean monthly values range between 21 °C in coolest months (December/January) and 31 °C in the hottest months (April/May) and temporal variation from one year to the other are very marginal (Buba, 2014). The soils of the study locations are ferruginous tropical soils type whose equivalent to Nitisols according to the Food and Agriculture Organization and they are also equivalent to Ultisol and Alfisol according to the United States Department of Agriculture (USDA, 1987).

![Figure 1. Study Area and Sampling Sites](image-url)

A Variety of hydromorphic soils occur in the depression on the low terrace and abandoned parts of the channels which is referred to as fadama soils as observed along rivers on the studied areas. The residential, commercial, and industrial land use types are the dominant land use in the study locations (Mohammed, 2017a).
2.2. Materials

The materials used in this study include Global Positioning System (GPS) for recording the coordinates of sampling locations, soil auger, and spade for soil sampling, polyethylene bags for storing soil samples, a marker for labeling the samples, pH meter to determine the soil pH, soil thermometer for recording the soil temperature and calorimeter for the determination of microbial biomass carbon.

2.3. Sample Collection Techniques

Two industrial areas were selected purposively as Sharada and Bompai because they are the major industrial areas where a huge amount of wastewater is discharged into the stream and used for irrigation. Each location was divided into two different areas being adjacent to each other delineated: wastewater affected and control locations. In each area selected 1 km² was delineated and then divided into ten small square where samples are collected in each small square using point composite sampling techniques from 0 – 15 cm depth. The soil samples collected were placed into polyethylene bags, labeled appropriately, air-dried, and then taken to the laboratory for the analysis of MBC, Cr, Cd, Pb, and pH.

2.4. Laboratory Procedures

The microbial biomass carbon was determined by fumigation-extraction methods as described by Vance et al. (1987) in the modification described by Nannipieri et al. (2003). Thus, 15 g of fresh soil sample was placed into two 50 ml beakers and the beakers were placed into two paired desiccators (control and Fumigated). In the fumigated desiccator, a 100 ml beaker containing 25 ml chloroform (alcohol-free) was placed in the center of the desiccator, boiling chips were added to the chloroform which assisted in rapid volatilization of the chloroform. The second desiccator contains non-fumigated (control) samples in which the desiccator was closed and the sealant was uniformly distributed.

The Vacuum was applied to the fumigated treatment up till chloroform boiled. The desiccators were closed and stored in dark conditions for 72 hours at room temperature. The desiccators were opened and the soil samples were transferred into the shaking bottle, 50 ml of 0.5 M K₂SO₄ was added and shake on a wrist action shaker for 25 minutes and the suspension was filtered with Whatman paper No. 42 filter paper. The samples were digested and the MBC was analyzed with calorimeter and then calculated using equation 1.

\[
\text{MBC} \left( \text{mg C kg}^{-1} \right) = \frac{EC_f - EC_{uf}}{K_{EC}}
\]

Where: \(EC_f\) is the Organic carbon extracted from fumigated soil, \(EC_{uf}\) is the Organic carbon extracted from non-fumigated soil and \(K_{EC}\) is the 2.64 constant (Vance et al., 1987).

The selected heavy metals parameters i.e. Cr, Cd, and Pb were determined using Atomic Absorption Spectrophotometer (AAS, 210 VGP, American Model). Weighed 10 g of air-dried soil in a clean 300 ml calibrated digestion tube and 5 ml of concentrated sulphuric acid (H₂SO₄) was added in the fume hood and swirled, and the tubes were placed in the tubes racks and then placed in the block-digester. The temperature setting was increased from 60 °C to 145 °C for one hour. Five (5 ml) of tri-acid mixtures (HNO₃, H₂SO₄, and HCl) were added and then heated to 240 °C for further one hour and kept overnight to avoid excessive foaming. Then filtered through Whatman No. 42 filter papers and stored in pre-cleaned polyethylene bottles for further analysis. The AAS was set up at a wavelength for Cr (358 nm), Cd (229 nm) and, Pb (220 nm). The digested and filtered samples were aspirated and the results were dispensed on the readout unit of the atomic absorption spectrophotometer (Sarkar & Haldar, 2005).

The soil pH was determined using standard measurement in 0.01 M CaCl₂ which is the most commonly used technique to characterized soil reaction because it is less dependent on the recent fertilizer history (Hendershot et al. 2008). Weighed 10 g of air-dried soil was placed in a 50 ml beaker and 25 ml of 0.01 M CaCl₂ was added and the suspension was stirred at regular intervals for 1 hour. The pH meter was switched on at least 15 minutes and then pH was measured with the glass electrode by immersing it into the suspension and recorded once the reading is constant. The standardization process was checked after every ten determinations. The soil temperature was recorded using a soil thermometer and expressed in degree centigrade.
2.5. Statistical Analysis

Descriptive statistics is used to analyze the mean values of MBC, Cr, Cd, Pb, pH, and temperature. One way analysis of variance (ANOVA) test was used to compare MBC, Cr, Cd, and Pb among the study locations (two contaminated and two control locations) at $\alpha$ values of < 0.05 was considered as significant. The student's t-test was conducted to test the differences in the mean values of MBC, Cr, Cd, Pb, and pH between contaminated and control locations and also between wet and dry seasons at $\alpha$ < 0.05. The relationship of MBC with Cr, Cd and Pb was determined using Pearson's correlation and regression analysis at $P < 0.05$ because of its power efficiency (Buba & Falola, 2008).

3. Results and Discussion

The results of the analyses for soil samples in both dry and wet seasons for MBC, Cr, Cd, Pb, pH, and temperature were presented in Table 1 which shows that contaminated locations have the highest mean values of MBC, Cr, Cd, Pb, pH, and temperature than their control locations. The distribution of MBC in the study locations shows that the values ranges from 0.17 to 0.22 gC/kg, 0.1 to 0.18 gC/kg, 0.18 to 0.43 gC/kg and 0.12 to 0.21 gC/kg for Sharada contaminated, its control, Bompai contaminated and its control location respectively (Figure 2).

| Seasons | MBC (Mg C/kg) | Cr (mg/kg) | Cd (mg/kg) | Pb (mg/kg) | pH (CaCl$_2$) | Temp. ($^\circ$C) |
|---------|---------------|------------|------------|------------|---------------|----------------|
| Sharada Contaminated |               |            |            |            |               |                |
| Dry     | 0.19          | 46.41      | 7.5        | 44.36      | 8.99          | 24             |
| Wet     | 2.66          | 32.63      | 3.4        | 34.76      | 8.3           | 26             |
| Sharada Control |           |            |            |            |               |                |
| Dry     | 0.15          | 18.53      | 6.66       | 28.38      | 6.44          | 21.45          |
| Wet     | 3             | 10.35      | 1.9        | 31.23      | 6.21          | 25.8           |
| Bompai Contaminated |           |            |            |            |               |                |
| Dry     | 0.29          | 64.81      | 4.36       | 43.61      | 7.65          | 24.74          |
| Wet     | 3.72          | 17.86      | 12.56      | 11.83      | 7.32          | 25.55          |
| Bompai Control |          |            |            |            |               |                |
| Dry     | 0.17          | 18.72      | 3.6        | 32.04      | 7.11          | 21.64          |
| Wet     | 2.75          | 3.95       | 9.76       | 15.53      | 7.03          | 25.52          |

This indicates that all contaminated locations have the highest mean values of MBC than their respective control locations. High mean values of MBC in contaminated locations corresponded with the locations where the temperature is higher. This indicates the impact of temperature on the microbial activity in the soil which instigated high MBC in the area. This is explained by Brady & Weil (2015) that soil microbial activities virtually ceases below 5 $^\circ$C and increases more than double for every 10 $^\circ$C rise in temperature up to an optimum of about 35 $^\circ$C to 40 $^\circ$C. The ANOVA show that there are significant variations in the mean values of MBC among the study locations with a critical f-value of 14.773, at $\alpha$ < 0.05. It was further discovered that locations with high values of MBC correspond to locations with high values of Cr, Cd, and Pb.

This is probably attributed to the high pH level in the area because, despite the presence of Cr, Cd, and Pb in high concentration, the pH level may not allow the Cr, Cd, and Pb to dissolve in the soil so...
that they could not be absorbed by soil microbe and plant. Therefore, Cr, Cd, and Pb could not antagonize the activities of soil microbe thereby the production of MBC will be higher. This indicates the influence of soil pH level on the availability, solubility, and toxicity of Cr, Cd, and Pb in the soil ecosystem.

![Figure 2. The Distribution of MBC in The Study Area](image)

This is explained by Lal (2006) that availability, solubility, and toxicity of heavy metals decreases as soil pH increases, this is due to the increases in negative charges on variable charge surface in soil and the propensity for Cr, Cd, and Pb to precipitate as springily soluble compound as soil pH increases. This is further supported by Utgikar et al. (2003) who reported that low (1 – 5) and high (> 7.5) pH may contain high heavy metals without any sign of toxicity to the soil ecosystem. Furthermore, most of the heavy metals were not soluble at that pH range, whereas toxicity may develop in soil environment at much lower heavy metals in the slightly acid soils because they can dissolve and be available for the microbes to absorb.

This presupposes that toxicity is determined by solubility, whereas solubility is a function of pH level (Nwuche & Ugoji, 2008). It was also reported that no matter the concentration of heavy metals in the soil if the appropriate pH for maximum dissolution is not in place, the toxicity of such heavy metals is seriously hindered if not entirely diminish (Brady & Weil, 2015). It most probable that the level of toxicity recorded could have been higher in control locations where the pH values are lower than their respective contaminated locations.

The mean values of Cd, Cr, and Pb were higher in contaminated locations than their control counterpart which is probably attributed to the industrial and domestic waste discharged into the stream and then utilized for irrigation in the area. This is supported by Meuser (2013) who reported that the major source of Cd, Cr, and Pb in agricultural land is the application of sewage sludge, domestic, and industrial waste. This implies that the use of wastewater for irrigation has a significant impact on increasing the concentration of Cd, Cr, and Pb in the soil. The mean values of Cr, Cd, and Pb obtained in this work were higher than the mean values of the same heavy metals obtained by Bichi and Bello (2013). This indicates that there is a gradual accumulation of Cr, Cd, and Pb in the soil of the area via an industrial and domestic waste discharge into the stream and consequently contaminated the soil through direct application of wastewater, leaching, and runoff. The ANOVA show that there is significant variability in the mean values of Cr, Cd, and Pb among the study locations at $\alpha < 0.05$ with
F-values 125.37, 34.12, and 56.21 for Cr, Cd, and Pb respectively. This implies that there is a significant difference in the source of each heavy metal in contaminating the soil of the area.

The general variation in soil pH values among the study locations implies that there is a gradual decrease of pH from strongly alkaline in Sharada contaminated location to an acidic condition in Sharada control, while Bompai locations both contaminated and control are slightly alkaline. The pH values recorded in this work is higher than the pH values obtained by Adamu & Yusuf (2014). This is probably due to the gradual accumulation of base cation in the area. This is supported by Brady & Weil (2015) who explained that low level of the base cation in soil results in an acidic condition of the soil, although a high level of base cation increase the soil pH because at high pH more hydrogen ion and aluminum dissociated themselves so that more base cation can be adsorbed.

3.1. Seasonal Variability of Microbial Biomass and Heavy Metals

The mean values of MBC in dry and wet seasons (Fig. 3) show that the wet season recorded higher values than the dry season. This is probably due to the high temperature and abundance moisture (rainfall) contained in the soil for the wet season which enhances the activity of soil microbes (MBC inclusive). However, in a dry season low temperature was recorded and observed that the soil is dry due to absence or inadequate rainfall (in the dry season) which decreases the activities of soil microbes such as decomposition of organic matter and MBC production. This is adduced by Mondal et al. (2015) that high MBC is attributed to the favorable environmental conditions for microbial population, growth, and activities due to rainfall, high temperature, and rapid mineralization rate in the wet season. This is evidence that high temperature was recorded in the wet season where MBC is higher. This implies that MBC responds more to seasonal change and consequently be an early and sensitive indicator of soil quality change.

Seasonal change in soil moisture and temperature have a significant effect on MBC which in turn affect the ability of soil to supply nutrient to plant through organic matter turn over (Boerner et al., 2005). This is further supported by Saxena & Singh (2013) who are on the view that seasonal variation of MBC was directly related to the availability of moisture and temperature conditions of the soil.

The pattern of seasonal variation in MBC, obtained in this study is in line with the results obtained by Guicharnaud et al. (2010) who are on the opinion that MBC is affected by soil characteristics and environmental factors (temperature and moisture condition) which vary with seasons. Lenart-Boron & Piotr (2014) also observed that MBC increases with increases in soil moisture, temperature, and soil reaction. The student t-test analyses for MBC shows that there is a significant difference in the mean values of MBC between wet and dry seasons for all the study area at $\alpha < 0.05$. This implies that MBC varies with seasons due the seasonal changes factors influencing microbial activities which affect the MBC productions.

![Figure 3. Seasonal distribution of MBC in the study area](image)

The distribution of heavy metals shows that the mean values of Cr, Cd, and Pb were found to be higher in the dry season than wet season except that of Cr and Cd which are found to be higher in
Bompai control, while Pb is found to be higher in Sharada control location (Fig. 4). The low mean values of Cr, Cd, and Pb in wet season may be attributed to the effect of rainfall which expedites the dilution of Cr, Cd, and Pb, oxidation reaction, leaching, and runoff which are capable of removing Cr, Cd, and Pb from the subsurface soil. This is supported by Delbari & Kulkarni (2011) who discovered a high concentration of heavy metals in dry the season than the wet season and attributed it to the changes in a redox reaction, runoff, and leaching which are facilitated by rainfall. This is further supported by Lal (2006) who explained that seasonal variation of heavy metals influenced by runoff and leaching of dissolved metals which is assisted by rainfall. The student t-test analysis revealed that there are significant differences in the mean values of Cr, Cd, and Pb between wet and dry seasons at $\alpha < 0.05$. This indicates the impact of changes in environmental conditions on a biological and chemical reaction in the soil.

![Figure 4. Seasonal distribution of Heavy Metals (a) Cr, (b) Cd, and (c) Pb](image)

### 3.2. Relationship Between MBC with Cr, Cd, Pb, and pH

Table 2 shows that MBC was negatively related to Cd and was positively related to Cr, Pb, and pH. This indicates that Cd upset MBC production, while Cr, Pb, and pH have a positive impact on MBC. The positive relationship between MBC with Cr, Pb, and pH is probably due to their high concentrations in the soil compared to the concentration of Cd which is low and negatively related to MBC. The results obtained in this work are in line with the results obtained by Oliveira & Pampulha (2006) who reported a positive correlation of MBC with Cr and Pb. This is further adduced by Culman et al. (2012) also reported a positive correlation between MBC and pH which is probably evident that locations with high mean values of MBC coincided with locations with high mean values of soil pH.
The relationship between MBC with Cr, Cd, and Pb (Table 3) shows the coefficient of determination ($r^2$) values for dry and wet seasons. This indicates that Cr, Cd, and Pb accounted for 64% and 57% variation in MBC for dry and wet seasons respectively, leaving the remaining percentage (36% and 43%) for other factors to explain. This implies that heavy metals have a significant effect on the variation of MBC in the soil of the study area.

### Table 2. Correlation Between MBC, Heavy Metals, and pH

| Heavy metals | Correlation coefficient (r) | p-value |
|--------------|----------------------------|---------|
| Cr           | 0.579                      | 0.00009*|
| Cd           | -0.539                     | 0.00033*|
| Pb           | 0.3702                     | 0.01860*|
| pH           | 0.23                       | 0.0021* |

* Significant at P<0.05

### Table 3. Coefficient of Determination of MBC and Cr, Cd, and Pb

| Seasons     | R    | $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate |
|-------------|------|-------|----------------|---------------------------|
| Dry Season  | .799 | 0.639 | 0.514          | 0.0508732                 |
| Wet Season  | .756 | 0.572 | 0.444          | 0.35242                   |

a. Predictors: (Constant) Cr, Cd, Co and Pb  
b. Dependent Variable: MBC

4. Conclusions

From the findings, it was concluded that temperature and rainfall are the major causes of seasonal variability of MBC which expedited the biochemical reaction in the soil and enhance the population, growth, and activities of soil microbes. The toxicity of heavy metals in soil depends on the pH level and therefore, the determination of microbial biomass carbon, soil pH, and temperature reflect the microbial activities in the soil and could be considered as soil quality indicators.

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