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C O N T E N T S

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Research Paper

Design and Implementation of a Graphical User Interface for Outlier Data Analysis: A Case Study on the Yeşilırmak River**

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Abstract: Water quality control, especially in large-scale monitoring regions or networks, requires easy and automatic processes for detecting potential outliers in a reproducible manner. This study focuses on removing outlier values from a dataset collected by an online monitoring station on the Yeşilırmak River between 2007 and 2009. Seven different parameters were evaluated: dissolved oxygen (luminescence dissolved oxygen, LDO), temperature, pH, conductivity, total organic carbon (TOC), nitrate nitrogen (NO_3-N), and ammonium nitrogen (NH_4-N). Five methods – median, mean, Grubbs', generalized extreme studentized deviate (GESD), and interquartile range (IQR) – were used for outlier removal. The developed models were integrated into a graphical user interface (GUI) in the MATLAB environment, facilitating practical and easy access. This study enables users to input any dataset into the software and remove outlier values using various methods in a few steps, thus preparing the data for modeling studies. It was observed that the median algorithm removed the most data points among the outlier data-removal methods.

Keywords: *River water quality data, outlier detection, statistical methods, graphical user interface (GUI)*

Introduction

Water is an indispensable resource for all living organisms, playing a critical role in sustaining life and maintaining environmental balance. In recent years, the rapid escalation in population growth, coupled with intensified industrial activities and unsustainable agricultural practices, has significantly heightened the strain on global water resources. This situation has prompted a surge in the establishment of governmental standards for water quality monitoring, underscoring the necessity of robust and efficient monitoring systems.

As delineated by Berendrecht *et al*. (2023), the process of water quality monitoring is multifaceted, encompassing the definition of objectives, the selection of appropriate methodologies, and culminating in the detailed evaluation of results. A critical component of this process is the development of an effective monitoring network, which is particularly crucial in continuous monitoring scenarios. Selecting the most suitable installation, sampling, and measurement techniques is vital for ensuring accurate and reliable data collection.

The advent of online and real-time monitoring systems has marked a significant advancement in the field. These systems provide comprehensive district-level control and enable detailed trend analysis, thereby accumulating substantial volumes of data. Alongside these technological advancements, the evolution of data mining and data logging technologies has greatly facilitated the processing and interpretation of this data. However, a major challenge in data interpretation arises from the presence of outliers, which may result from environmental fluctuations, human errors, or sensor inaccuracies. Outlier detection is thus a critical preliminary step in data preprocessing, essential for enhancing data reliability and facilitating accurate analysis. The preprocessing typically involves two main steps: standardizing data to a mean of zero and a standard deviation of one and applying statistical methods to render time-series data stationary (Jamshidi *et al*., 2022).

Various methods for outlier detection in surface water have been extensively documented in the literature. For instance, Muñiz *et al*. (2012) employed functional data analysis to detect outliers in water quality data within the San Esteban estuary. Cho *et al*. (2013) introduced a two-step process for

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removing outliers in ocean temperature data, which involved using approximate and complex components coupled with harmonic analysis. Saberi (2015) enhanced the univariate method by implementing an auto-regressive moving average model within a moving data window. Furthermore, Di Blasi et al. (2015) analyzed several water quality parameters for outlier detection, utilizing a functional data analysis approach. Additional contributions to the field have been made by researchers such as Plazas-Nossa et al. (2016), Jingang et al. (2017), Dogo et al. (2019), Bae et al. (2019), and Sun et al. (2019). Each of these studies introduced varying methodologies for the effective detection of outliers, thereby enriching the existing body of knowledge.

Despite the abundance of research in outlier detection, a notable gap exists in the literature concerning the design of graphical user interfaces (GUIs) specifically for this purpose. This study addresses this gap by developing a user-friendly interface that applies five distinct statistical outlier detection methods to seven crucial water quality parameters: Luminescent Dissolved Oxygen (LDO), temperature, conductivity, pH, Total Organic Carbon (TOC), Nitrate Nitrogen (NO_3-N), and Ammonium Nitrogen (NH_4-N). Integrating statistics-based models, this interface significantly enhances the practicality and efficiency of data preprocessing for subsequent modeling studies.

Materials and Methods

Study Area and Data Collection

Data for this research were obtained from two real-time in-situ monitoring stations. The first station was located in the Aynalı Cave area, downstream from the sewage system and Tersakan stream. The second station was positioned at the Administration of Hydraulic Works' Durucasu site, approximately 26.876 kilometers from the Aynalı Cave station and further downstream from the yeast factory. A monitoring office was established at Ankara University to facilitate central monitoring and data management. Data from these stations were transmitted to the university via GPRS technology. Figure 1 depicts the geographical positions of the monitoring stations and outlines the data collection and transmission process.

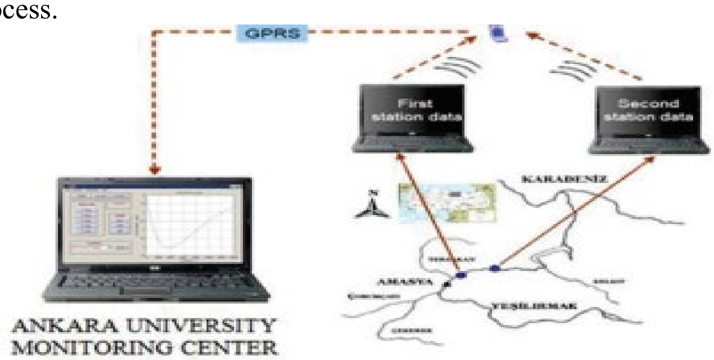

Figure 1. Locations of the online measurement stations and the data collection & transmission process

The selected study area encounters diverse pollution sources. The stations were programmed to record real-time data at five-minute intervals. This data encompassed various parameters, including luminescent dissolved oxygen (LDO), pH, conductivity, nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total organic carbon (TOC), orthophosphate, chloride, temperature, turbidity, suspended solids, and flow rate. This study focused on seven parameters with 18,815 data points: LDO, pH, conductivity, temperature, TOC, NO_3-N, and NH_4-N.

Outlier Detection Methods

Outlier detection in statistical analysis can be broadly categorized into parametric and non-parametric methods, depending on the data distribution. Parametric tests, such as Grubbs' and Generalized Extreme Studentized Deviate (GESD) tests, are typically applied to datasets with uniform distributions. It is important to recognize that there is no universally applicable method for automatically cleaning outlier data; the selection of a test often varies based on the specific requirements of the study. In this research, we employed five distinct methods for outlier detection, each suited for different data characteristics:

Mean Method for Outlier Detection: The mean, also known as the arithmetic mean, is a fundamental statistical measure calculated as the sum of all values in a dataset divided by the number of values. While straightforward, this method can be less robust than the median method, especially in the presence of extreme outliers. The mean is calculated using the following formula (Eq.1):

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

Where:
μ represents the mean value.
n is the total number of values in the dataset.
x_i represents the ith value in the dataset.
Standard deviation (σ) measures the spread of data values around the mean. It is calculated as (Eq.2):

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2} \qquad (2)$$

Where: σ represents the standard deviation.

Outliers are typically identified using the Z-score, which indicates how many standard deviations a value is from the mean (Eq.3):

$$Z = \frac{z_i - \mu}{\sigma} \qquad (3)$$

A value is generally considered an outlier if $|Z|>3$, meaning it is more than three standard deviations away from the mean.

This method presupposes that the data follow a normal distribution and is sensitive to extreme values, which can markedly affect both the mean and standard deviation. Hence, it is the most effective in datasets that are normally distributed and do not contain extreme outliers.

Median Method for Outlier Detection: The median method for outlier detection is a non-parametric approach that is particularly useful when dealing with skewed data distributions or when the dataset contains extreme values (outliers) that could significantly influence the results of parametric methods, such as those based on the mean.

In this method, the data is sorted from smallest to largest or smallest when it is the middle value of the distribution. Outliers are more than three scales from the median or as MAD (mean absolute deviations) element, which is the absolute deviation of the arithmetic mean.

Outliers are data points that lie a significant distance from the median. A common threshold is data points that are more than 1.5 times the MAD above or below the median. This threshold can be adjusted based on the specific context or distribution of the data. The median method is more robust to outliers than the mean. Since it uses the median and MAD, it is not as affected by extreme values.

Suitability for Non-Normal Distributions: This method does not assume a normal distribution of data, making it suitable for a broader range of datasets, particularly those that are skewed or have heavy tails. However, the method might be less sensitive in detecting subtle outliers, especially in symmetric distributions. The scaled MAD is calculated by using Equation 4.

$$\mathrm{MAD} = \mathrm{median}(|x_i - \mathrm{median}(x)|) \qquad (4)$$

The Median method is renowned for its wide applicability across various fields, including finance, environmental science, and engineering. These disciplines often encounter data that are skewed or contain extreme values, making the Median method particularly useful. Its robustness against outliers renders it an invaluable tool in these areas, where accurate data representation is crucial.

In addition to its practical applications, the Median method plays a pivotal role in the initial stages of data cleaning. Before delving into more complex statistical analyses, this method provides an efficient way to cleanse the dataset, ensuring that subsequent analyses are not skewed by outliers.

The significance of the Median method is further underscored by its prominent presence in statistical education and literature. It is a well-established technique, extensively covered in numerous statistical textbooks and academic papers. This widespread coverage is a testament to its effectiveness in managing datasets with outliers, highlighting its importance as a foundational tool in statistical analysis.

Grubbs' Test for Outlier Detection: Grubbs' Test, introduced by Frank E. Grubbs in 1969, is a statistical method designed to detect outliers in datasets that are assumed to follow a normal distribution. The test is based on two hypotheses:

Null Hypothesis (H_0): There are no outliers in the dataset.
Alternative Hypothesis (H_1): The dataset has at least one outlier.
One-sided Left-tailed Test: This version of the test assesses the probability of the minimum value being an outlier. It is calculated using Equation 5:

$$\mathrm{Gmin} = \frac{\bar{x} - x_{min}}{\sigma} \qquad (5)$$

One-sided Right-tailed Test: This test evaluates the probability of the maximum value being an outlier, as given in Equation 6:

$$\mathrm{Gmax} = \frac{x_{max} - \bar{x}}{\sigma} \qquad (6)$$

Double-sided Test: This test investigates both the minimum and maximum values for potential outliers. The calculation of the critical G value is outlined in Equation 7:

$$G = \max(\mathrm{Gmax}, \mathrm{Gmin})\,;\; G_{critic} \approx \frac{(N-1)t_{\frac{\alpha}{2N}N(N-2)}}{\sqrt{n(n-2+t^2{}_{\frac{\alpha}{2N}N(N-2)})}} \qquad (7)$$

Here, σ is the standard deviation, $t_{\frac{\alpha}{2N}N(N-2)}$ is critical table value of t distribution, N-2 is degrees of freedom.

A notable limitation of Grubbs' Test, as identified by Chelishchev et al. (2018), is the masking effect. This effect arises in datasets containing multiple outliers, where the presence of one outlier can conceal or 'mask' another. The result is that once the most obvious outliers are removed, others may appear that were not initially detectable. Ben-Gal (2005) discusses how this effect can complicate the outlier detection process, especially in datasets with numerous outliers. Similarly, Vera et al. (2013) describes the 'swamping effect', where non-outliers may be incorrectly identified as outliers in the presence of actual outliers. These phenomena highlight the need for careful analysis when using Grubbs' Test, particularly in datasets with potential multiple outliers.

Despite this limitation, Grubbs' Test is extensively utilized in various scientific and engineering disciplines, notably in laboratory quality control settings. In such environments, the accurate detection of single aberrant measurements is often critical. The test is also valuable in other research areas where the integrity of data is paramount and the assumption of a normal distribution is valid.

Grubbs' Test is recognized as a standard method in statistical outlier detection and is extensively covered in various statistical textbooks and academic papers. Its importance is also reflected in its widespread implementation in numerous statistical software packages and programming languages, making it an accessible and practical tool for data analysts and researchers.

Generalized Extreme Studentized Deviate (GESD) Test: The GESD Test, commonly referred to as the Rosner test, is a parametric outlier detection method designed to identify outliers in datasets where the number of outliers is not precisely known, and the data is assumed to follow a normal distribution. This test is particularly adept at calculating both single and multiple two-tailed outliers. Similar to Grubbs' Test, the GESD Test operates on two fundamental hypotheses:
Null Hypothesis (H_0): The dataset contains no outliers.
Alternative Hypothesis (H_1): The dataset contains at least one outlier.
In the GESD Test, Equation 8 is calculated for each data point x_i, where $\bar{x}$ is the arithmetic mean and σ is the standard deviation of the dataset.

$$R_i = \frac{x_i - \bar{x}}{\sigma} \qquad (8)$$

The test sequentially identifies the most extreme observation (outlier) and then recalculates the test statistics for the remaining data. This process continues, iteratively identifying and removing outliers.

Unlike Grubbs' Test, the GESD Test can adjust the critical values based on the number of data points remaining after each iteration, allowing for more dynamic outlier detection. This feature makes the GESD Test particularly valuable in scenarios where multiple outliers are suspected, requiring only an upper limit on the number of potential outliers (Grubbs, 1969).

The GESD Test is highly useful in fields where the precise identification of multiple outliers is crucial, such as in quality control, laboratory data analysis, and environmental data assessment. Its implementation in various statistical software packages makes it a practical tool for rigorous outlier detection in statistical analyses. The GESD Test is well-documented in statistical literature and represents a significant enhancement of the Grubbs' Test. It offers greater flexibility in handling complex datasets that may contain multiple outliers, making it a valuable extension in the domain of statistical outlier detection.

Interquartile Range (IQR) for Outlier Detection: The Interquartile Range (IQR) is a critical statistical measure used to identify outliers, particularly in datasets that are not normally distributed or contain a significant number of extreme values. The IQR is the difference between the 75th percentile (Q_3) and the 25th percentile (Q_1) of the dataset, representing the range of the middle 50% of the data.

Outliers in a dataset are typically identified as data points that fall above or below 1.5 times the IQR from Q_1 and Q_3, respectively. Values outside this range are considered outliers. This method provides a robust way to determine outliers, particularly in data with skewed distributions or extreme values (Bonakdari et al., 2022).

Grubbs' Test: Highly effective for datasets with suspected single outliers and a normal distribution. GESD Test: More suitable for identifying multiple outliers in normally distributed data. Median Method: Offers robustness in skewed distributions or datasets with extreme values. Mean Method: Generally effective but can be unreliable when extreme outliers are present. The selection of an appropriate outlier detection method should be tailored to the specific nature of the data and the objectives of the analysis. It is often advantageous to employ multiple methods to cross-validate results, particularly in complex datasets. This approach ensures a comprehensive understanding and accurate identification of outliers.

Graphical User Interface Design

In this study, we developed a user-interactive graphical interface within the MATLAB (Matrix Laboratory) environment. This interface facilitates the outlier removal process, enhancing usability and efficiency for data analysts. The interface's general layout is depicted in Figure 2.a. Upon uploading a dataset to the software, the interface automatically calculates and displays the number of variables present in the dataset, as illustrated in Figure 2.b.

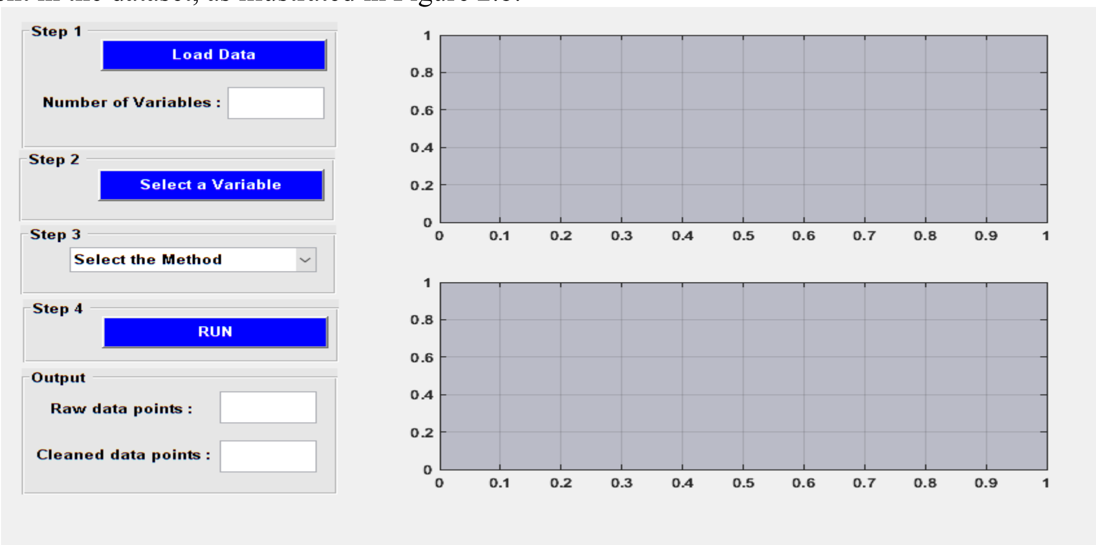

Figure 2.a. Overview of the Graphical User Interface

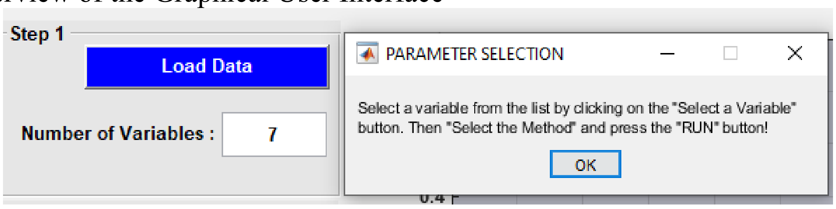

Figure 2.b. Display of the Number of Variables in the Dataset

As indicated in Figure 2.c, the user selects the specific parameter to undergo the outlier cleaning process. Subsequently, the user selects the desired outlier removal method, and the program initiates the process (Figure 2.d). Post-processing, the program provides a comparative display of the original (raw) and cleaned data counts. Additionally, graphical representations of both datasets are showcased on the interface's right side, as seen in Figure 2.e. This interface offers flexibility, allowing users to alter parameters and methods to observe varied results. The cleaned data, post-processing, are saved by the software, enabling users to utilize this refined dataset for further analysis or application as required.

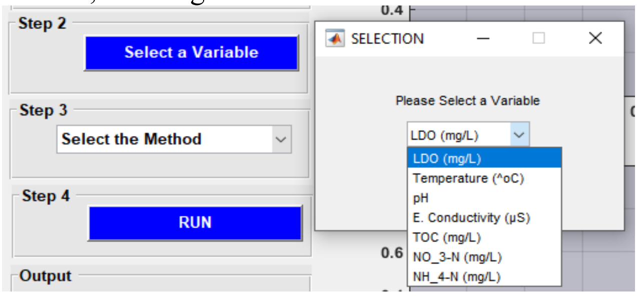

Figure 2.c. Parameter Selection for Outlier Removal

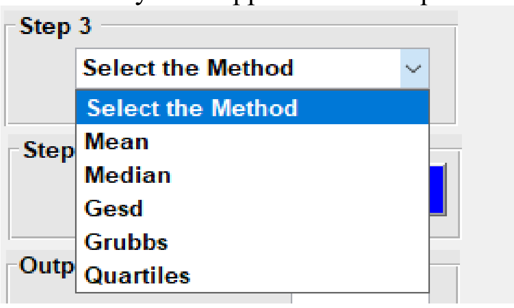

Figure 2.d. Method Selection for Outlier Removal

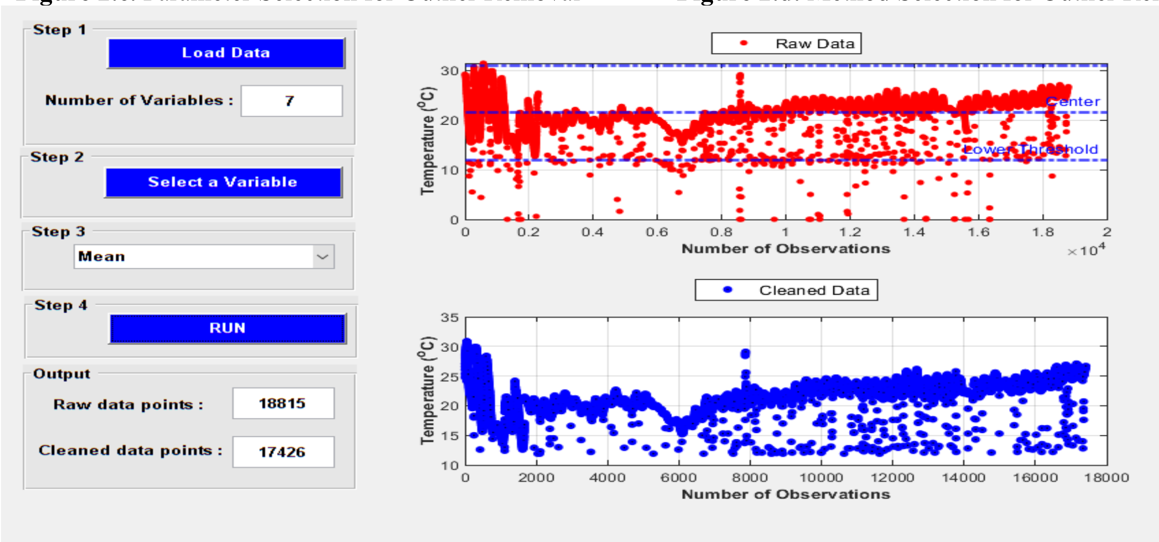

Figure 2.e. Results Display Post-Processing

Results and Discussion

The results of the outlier detection methods, as applied to various parameters through the developed GUI, are presented in this section. It's important to note that employing the same method across different parameters in the matrix-format dataset results in the same number of cleaned data points. This is because outlier values in one parameter necessitate the removal of corresponding values across all parameters.

Outlier Detection Results for LDO Parameter: The outcomes of different outlier detection methods for the LDO parameter are illustrated in Figure 3.

Analyzing Figure 3, which uses 18,815 original data points, reveals that the median method detected the highest number of outliers, whereas the Grubbs method detected the fewest.

Outlier Detection Results for Temperature Parameter: The results for the temperature parameter, as displayed by the GUI, are depicted in Figure 4.

In this graph, data points outside the defined lower and upper limits were classified as outliers. The graph with blue dots represents the data remaining post-cleaning.

Outlier Detection Results for pH Parameter: Figure 5 presents the outlier detection results for the pH parameter. Outliers are visibly identifiable as data points exceeding the upper or lower limits in the graph.

Outlier Detection Results for Conductivity Parameter: The results for the conductivity parameter are provided in Figure 6.

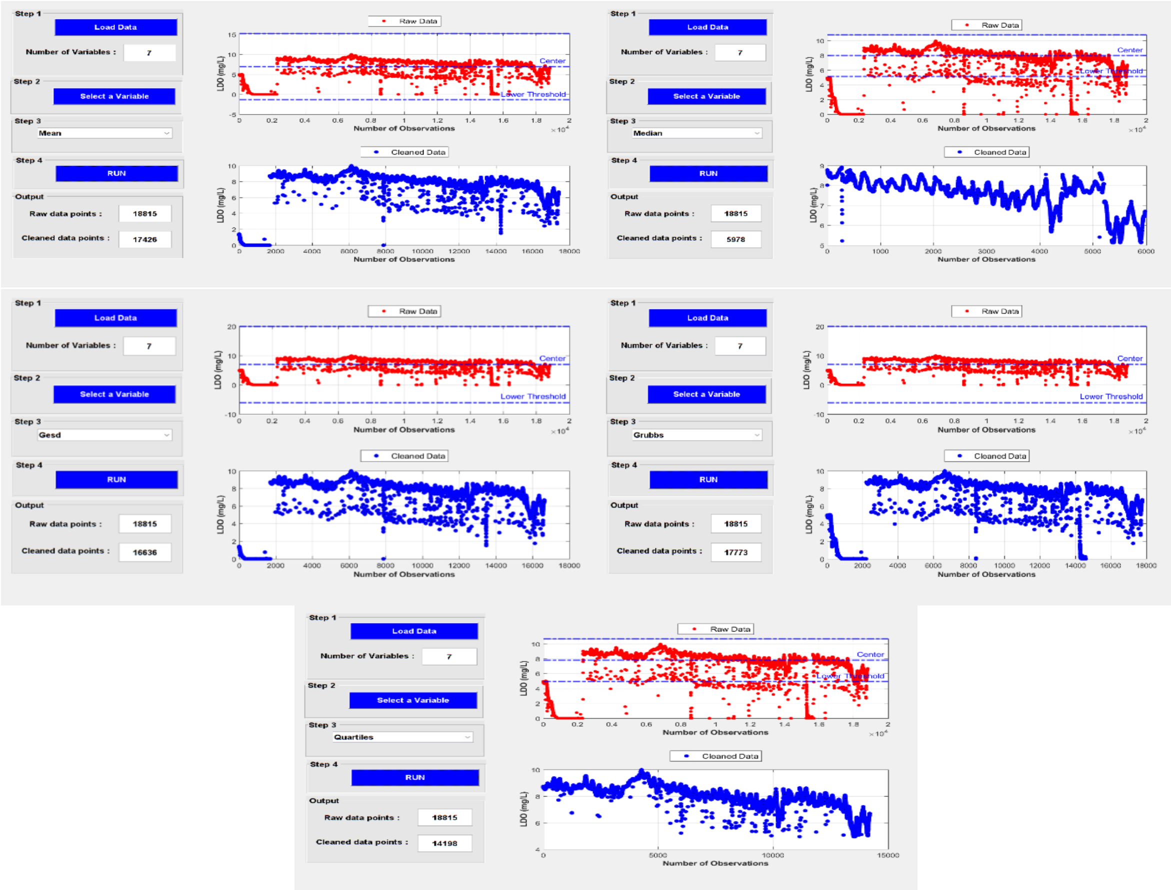

Figure 3. Outlier Detection Results for LDO Parameter (Mean, Median, GESD, Grubbs, Quartiles)

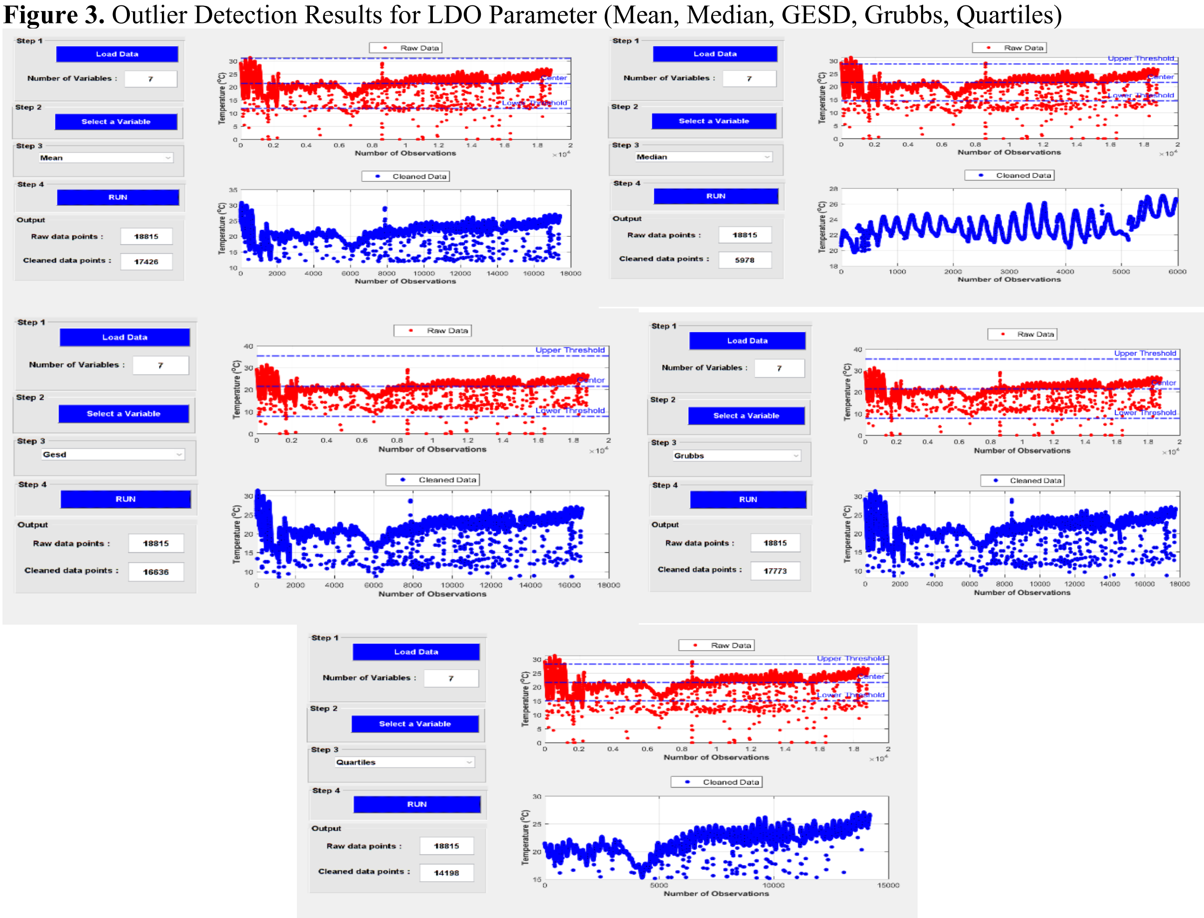

Figure 4. Outlier Detection Results for Temperature Parameter (Mean, Median, GESD, Grubbs, Quartiles)

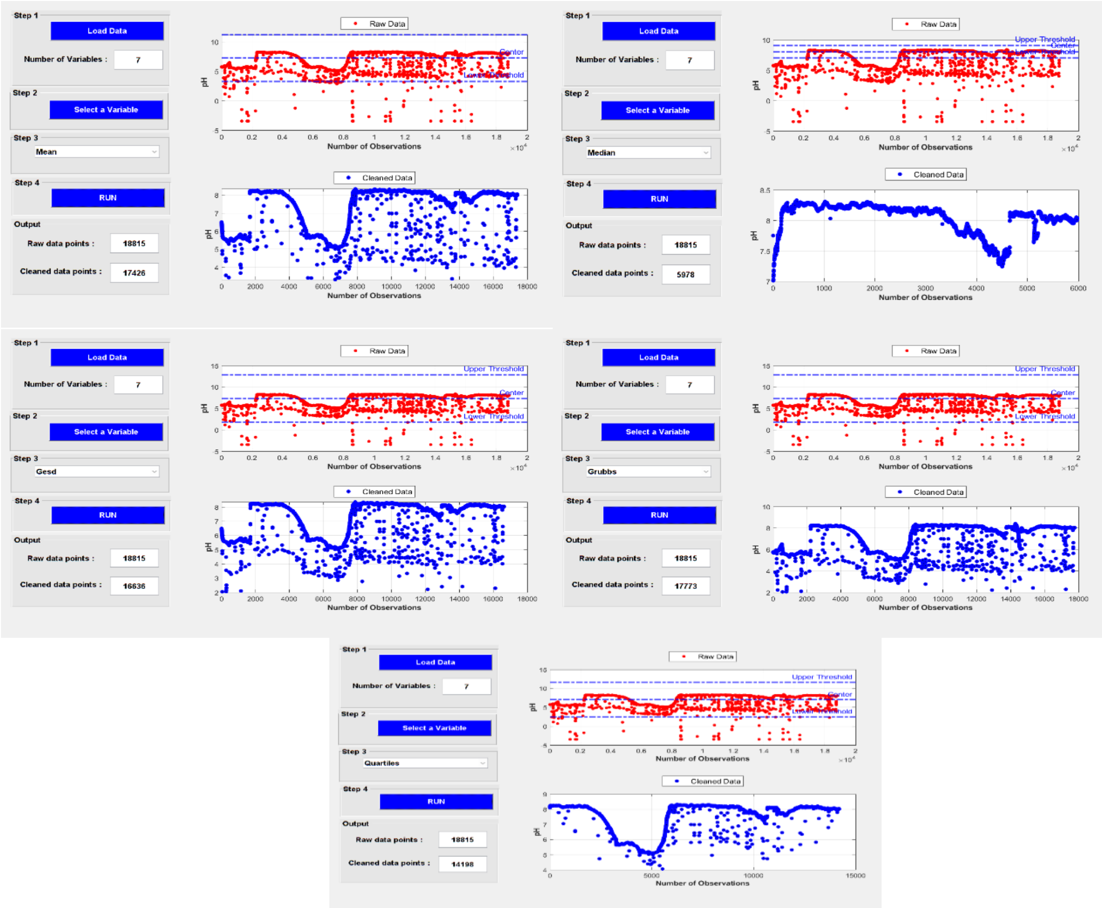

Figure 5. Outlier Detection Results for pH Parameter (Mean, Median, GESD, Grubbs, Quartiles)

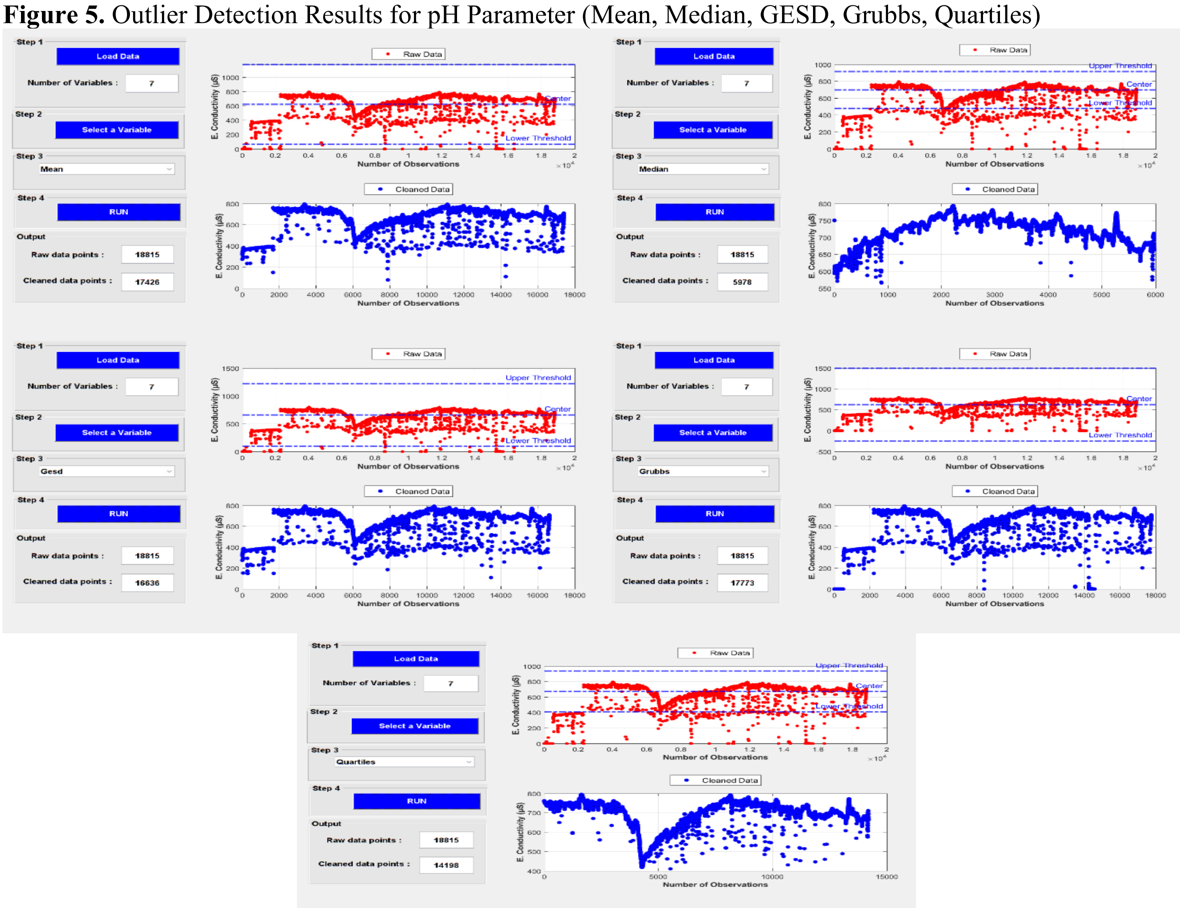

Figure 6. Outlier Detection Results for Conductivity Parameter (Mean, Median, GESD, Grubbs, Quartiles)

Outlier Detection Results for TOC Parameter: The outcomes for the TOC parameter are shown in Figure 7.

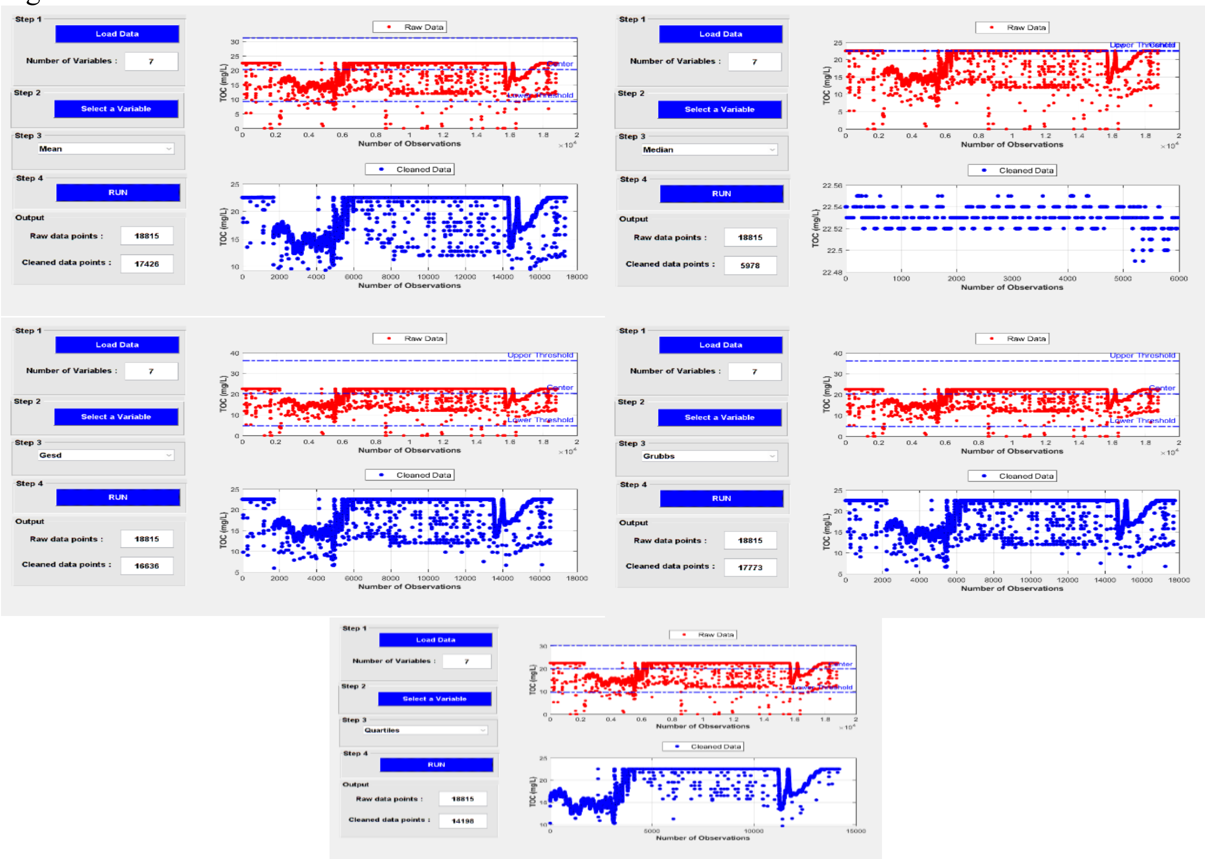

Figure 7. Outlier Detection Results for TOC Parameter (Mean, Median, GESD, Grubbs, Quartiles)

Outlier Detection Results for NO_3-N and NH_4-N Parameters: The detection of outliers for the nitrogen parameters (NO_3-N and NH_4-N) is displayed in Figures 8 and 9.

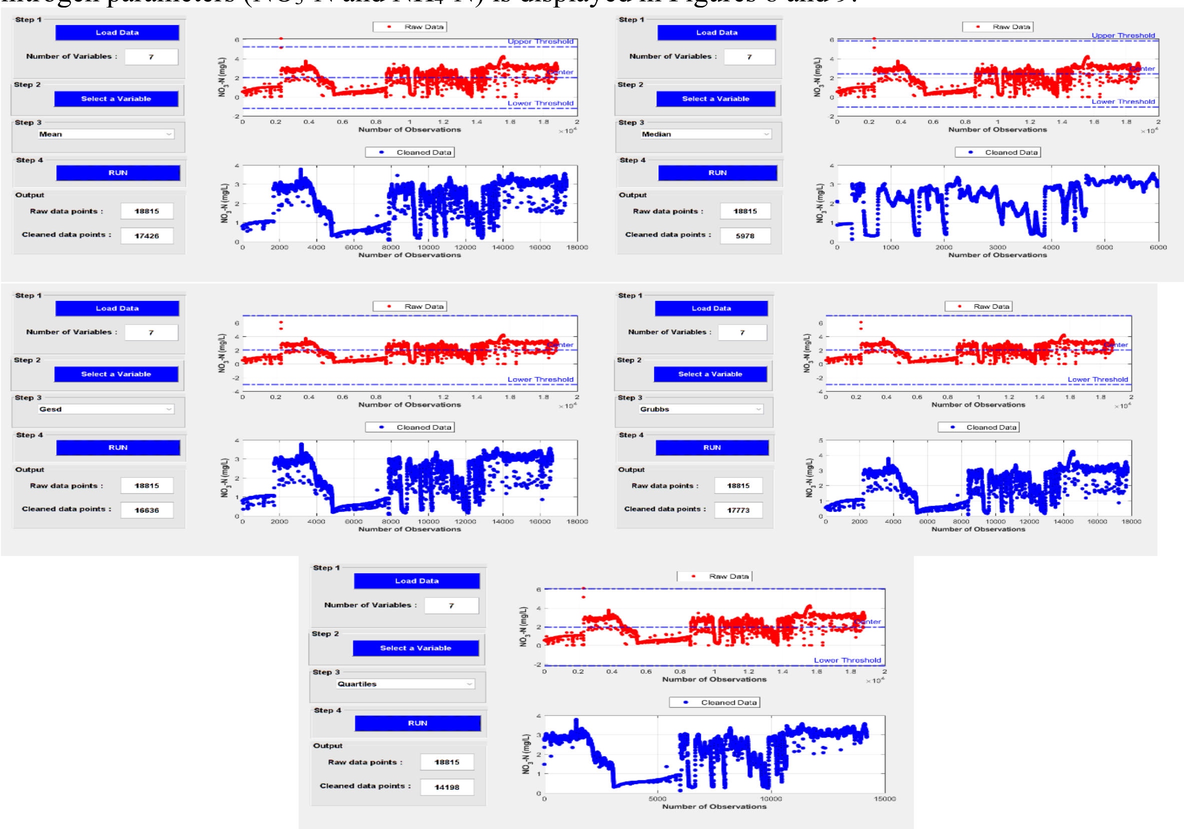

Figure 8. Outlier Detection Results for NO_3-N Parameter (Mean, Median, GESD, Grubbs, Quartiles)

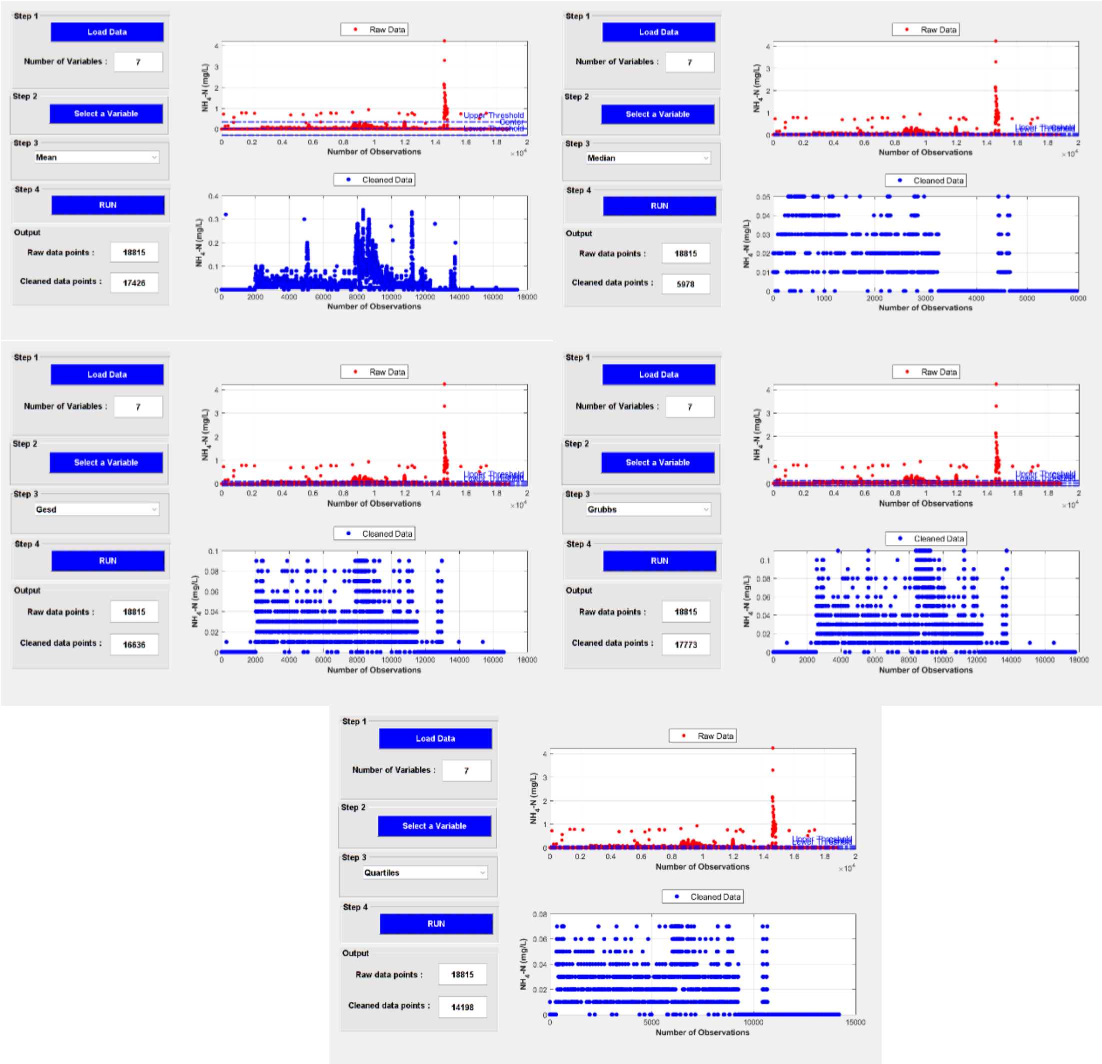

Figure 9. Outlier Detection Results for NH_4-N Parameter (Mean, Median, GESD, Grubbs, Quartiles)

The comparative analysis of original and cleaned data is succinctly summarized in Table 1. According to the results presented in Table 1, Grubbs' Test identified the least number of outliers in the dataset, indicating its conservative nature in outlier detection. Conversely, the Median method detected the highest number of outliers, reflecting its sensitivity to extreme values. These findings underscore the varying effectiveness of different outlier detection methods depending on the nature of the data.

Table 1. Original and Remaining Data Numbers by Method

Methods	Original Data Number	Remaining Data Number
Mean	18,815	17,426
Median	18,815	5,978
GESD	18,815	16,636
Grubbs	18,815	17,773
Interquartile	18,815	14,198

This study on the design and implementation of a graphical user interface (GUI) for outlier data analysis on the Yeşilırmak River differs from existing literature, such as TODS (Lai et al., 2021), which focuses on time series data outlier detection, and other studies involving MATLAB-based GUIs for IoT sensor measurements (Bashir et al., 2022) and patient monitor event logs (Friel et al., 2004), by specifically targeting environmental data from water quality monitoring, emphasizing the integration of multiple statistical methods for robust outlier detection in river data.

The next phase of this study will involve comprehensive modeling studies. These will provide a deeper insight into the performance of the various outlier detection algorithms used. In the modeling stage, the impact of each outlier detection method on the accuracy and reliability of the models will be critically assessed. This step is crucial, as it will help determine the most effective pre-processing technique for enhancing the quality of the dataset, thereby ensuring robust and accurate modeling outcomes.

Conclusion

This study successfully developed a comprehensive and user-friendly graphical user interface (GUI) for outlier detection, integrated with advanced algorithms. Utilizing a dataset of 18,815 data points, we focused on six critical river quality parameters: Luminescent Dissolved Oxygen (LDO), temperature, pH, conductivity, Total Organic Carbon (TOC), Nitrate Nitrogen (NO_3-N), and Ammonium Nitrogen (NH_4-N). These parameters were meticulously cleaned and preprocessed for future modeling studies.

In our analysis, five different outlier detection methods were employed: Mean, Median, Generalized Extreme Studentized Deviate (GESD), Grubbs, and Interquartile Range (IQR). Among these, the Median method was found to detect the highest number of outliers, indicating its sensitivity and effectiveness in outlier identification.

The GUI developed in this study significantly simplifies the process of data loading and outlier detection. It allows users to efficiently process data and obtain results with just a few clicks. This feature is particularly advantageous for researchers and practitioners in environmental science and data analysis, streamlining their workflow and enhancing productivity.

The cleaned datasets, obtained after the outlier removal process, are primed for use in various predictive and analytical modeling applications. The effectiveness of these subsequent models will further validate the efficiency of the pre-processing methods used in this study. This approach not only contributes to the field of environmental data analysis but also sets a precedent for future research in data preprocessing and model optimization.

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Research Paper

Bed Sediment Analysis of Ntawogba River in Port Harcourt, Nigeria

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Abstract: The aim was the analysis of soil types, physico-chemical parameters of water and sediments, heavy metals, benthos, zooplankton and phytoplankton. Experimental research design and data were analysed using mean and standard deviation, Analysis of Variance (ANOVA) and one sample T-test. The result revealed that the soil type was mainly sandy clay. The mean value of the physico-chemical parameters were within the World Health Organization (WHO) standard prescribed limit; There is no significant variation in the mean distribution of physico-chemical parameters in Ntawogba creek along the ten locations ($F_{9, 110}$= 0.79, P >0.05); There is no significant variation in the mean distribution of heavy metals parameters in Ntawogba creek along the 10 locations ($F_{9, 50}$= .021, $P > 0.05$); There is significant difference in the concentration level of oil and grease in Ntawogba creek (DF= T = 42.037, P<0.05); There is no significant variation in the distribution of benthos in the ten locations of Ntawogba creek ($F_{9, 80}$ = 1.307, P >0.05); There is no significant variation in the distribution of phytoplanktons in the ten locations of Ntawogba creek $F(9,120) = 0.535$, $P > 0.05$); There is no significant variation in the distribution of zooplankton in the ten locations of Ntawogba creek ($F(9,70)$= .0510, P <0.05). The study further revealed that the benthos, phytoplanktons and zooplanktons were varied in their distribution across the 10 locations in the study area. Conclusion of bed sediment characteristics of river system highly affected by anthropogenic activities. Recommendation of periodic analysis of bed sediment characteristics of the river.
Keywords: *Anthropogenic, Parameters, Physico-chemical Sediments, Urbanization*

Introduction

Sediment refers to the conglomerate of materials, organic and inorganic, that can be carried away by water, wind or ice. The term is often used to indicate soil-based, mineral matter (e.g. clay, silt and sandy). Decomposing organic substances and inorganic materials are also considered sediment. Most mineral sediment comes from erosion and weathering, while organic sediment is typically detritus and decomposing material such as algae. These particulates are typically small, with clay defined as particles less than 0.00195mm in diameter, and coarse sand reaching up only to 1.5mm in diameter. However, during a flood or other high flow event, even large rocks can be classified as sediment as they are carried downstream. Sediment is a naturally occurring element in many bodies of water, though it can be influenced by anthropogenic factors.

In an aquatic environment, sediment can either be suspended (floating in the water column) or bedded (settled on the bottom of the water). When both floating and settled particles are monitored, they are referred to as Suspended and Bedded Sediments (SABS). Suspended sediment can alter the water chemistry, and cause temperature decreases, and turbidity increases. Deposition of sediment may change the character of the substrate, block interstices, and reduce interstitial volume. Anthropogenic sediment in freshwaters is a by-product of several activities. These activities could be agricultural, industrial and commercial in both urban and rural areas. This problem has adverse effect on marine ecosystem. For instance, turbidity levels as low as 5NTU can decrease primary productivity by 3-13%. An increase of suspended sediment levels increases the drift fauna and may reduce benthic densities as well as alter community structure.

At any point on the surface of the earth where human activities are found belong to a particular basin area where sediment and water flows to a particular stream after a rain event (Oku, 2016). This

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means that all activities both natural and human induced impacting on the soil are transported to streams either as suspended sediment or bed sediment. Our contemporary world is increasingly faced with the challenges of managing the emerging risks impacting ecological niches due to its peculiar sediment chemistry. The negative processes feedback of diverse spatial activities has increasingly complex impact on sediment quality generated most especially in the urban area resulting from multiple land-use processes (Zhang, 2016).

Bed sediment and hydrobiological parameters such as benthos, phytoplanktons and zooplanktons are important aspect of the marine ecosystem. Their concentration and distribution have been affected by anthropogenic activities, especially in the urban areas of Ntawogba river basin in Port Harcourt metropolis as result of rapid increasing human activities especially urbanization and dumping of wastes of all kinds into the river. This has reduced and impacted on the microbial activity of the microorganisms in the river and as well as bed sediments transport and deposition along the river channel.

The aim of this study is to assess the bed sediment characteristics of the Ntawogba River in Port Harcourt Metropolis. Specific objectives include the following:

i. Investigate the physico-chemical parameters of Ntawogba river channel
ii Investigate the distribution of benthos species in Ntawogba rivers channel.
iii Determine the concentration level of heavy metal presence in Ntawogba river channel
iv Analyze the distribution of phytoplankton presence in Ntawogba river channel
v. Investigate the distribution of zooplankton presence in Ntawogba river channel
vi. Determine the presence of oil and grease in Ntawogba river channel
vii Manage the marine ecosystem in a sustainable manner to enhance the environmental quality of Port Harcourt metropolis.

Materials and Methods

Geographically, the Port-Harcourt metropolis is located between Latitudes 4°45′ N, and 4°55′N and Longitudes 6°55′E and 7°05′E (Fig. 1). Port-Harcourt metropolis is located at about 25km from the Atlantic Ocean and it is situated between the Dockyard Creek/Bonny River and the Amadi Creek (Oyegun & Adeyemo, 1999). Port-Harcourt, originally known, as "Igwe-Ocha" was founded in 1913 by the British in an area traditionally inhabited by the Ikwerres. It was named after Lewis Viscount Harcourt, the then Secretary of State for Colonies. The main City of Port Harcourt is the Port-Harcourt City Council. It serves as the capital state (Alagoa & Derefaka, 2012). Today, the Port-Harcourt metropolis is made up of two Local Government Areas, namely Port-Harcourt L.G.A and Obio-Akpor LGA.

This study used the experimental research design where reliance was on the collection of bed sediment samples from the field for strict laboratory analysis of the parameters being examine. This study depended heavily on primary data which was generated from the field through sample collection and analysis. This means that the primary data generated from the field formed the focus of evaluating the variables of interest in line with the conjectural statement earlier posed for the study. Similarly, the study utilized secondary information, which was derived from gazettes of regulatory agencies, government, works of scholars in textbooks, journals, and monographs among others.

The Ntawogba river channel overall length was difficult to deduce due to rapid urban land use processes affecting first and second order streams. Hence, the study used 1km of the lower course of the mainstream channel before entering the sea, that is, its freshwater section outside the tidal range. This section enabled the researcher to document the net impact of urban processes on bed sediment characteristics of the Ntawogba river channel. The study took a sampling interval of 10m apart, which gave a sampling frame of 100 sampling points. This constituted the sampling frame of the present study.

The parameters of the study constituted all biological, physical and chemical characterization of the bed sediments to establish the probable impact of urban processes on the variables of interest. Thus, the major samples collected for laboratory investigation were stream bed sediment. Data collection protocol was observed and bed sediments were collected with the aid of the crab. The crab is a device that goes underground to bring out sea soil. This enabled sample integrity within established sample collection protocol for sediment analysis. Hence, sterilized containers were used to collect sediment samples for biological parameters examination as well as foil containers for physical and sediment chemistry. These containers were dipped below the surface at designated sampling points for soil sample collection for laboratory analysis. The samples collected were stored in a cool box for transportation to accredited laboratories for analysis of parameters of interest.

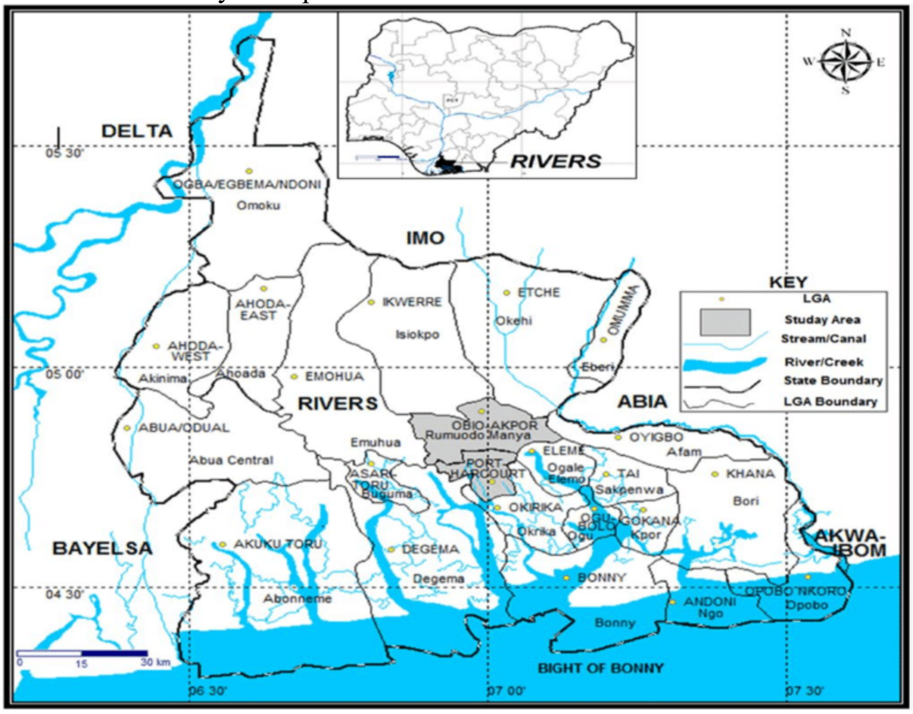

Figure 1. River's state showing port Harcourt metropolis. **Source:** Ministry of Land and Survey, 2017

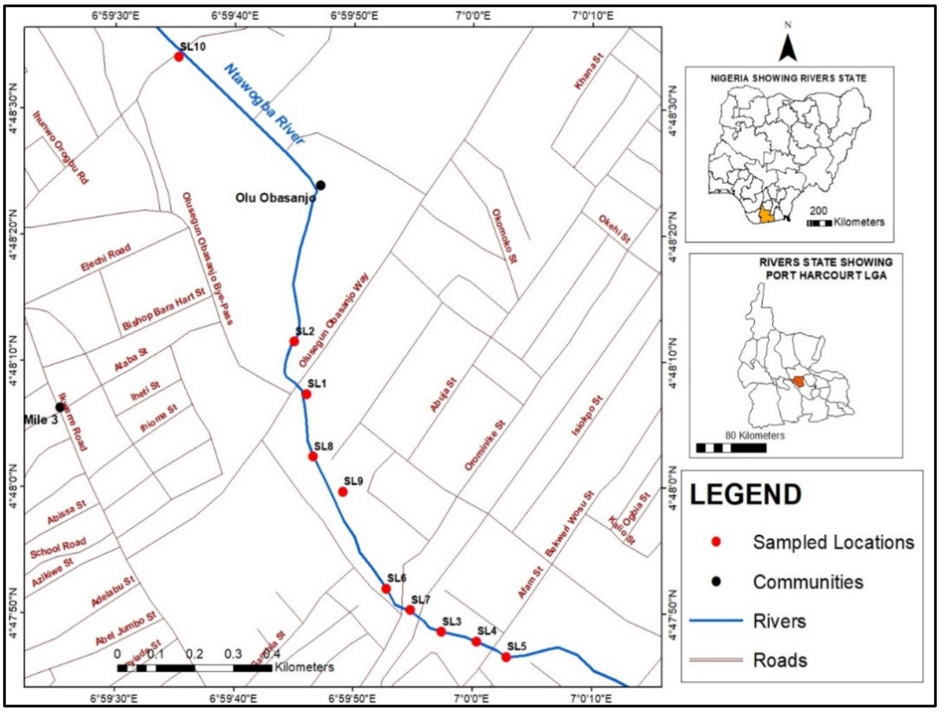

Figure 2. Ntawogba River Showing the sampled locations (SL). **Source:** Researchers' Fieldwork (2021)

Data was analysed by the combination of descriptive statistics and inferential statistics. Simple percentage was used to analyse soil particulate size distribution while mean and standard deviation were used to analyse the physico-chemical parameters, heavy metals, benthos, phytoplankton and zooplankton species. The hypotheses were analysed with the analytical tools of one-way analysis of variance (ANOVA) and one-sample t-test. The results were displayed in tables.

Results And Discussion of Findings

This section of the chapter deals with the result of the laboratory analysis carried out in respect to the physico-chemical parameters, heavy metals, benthos, parameters, soil parameters, phytoplankton parameters and zooplankton parameters of surface water samples in the ten locations across Ntawogba creek in Port Harcourt metropolis. This data presentation also includes the descriptive analysis of the aforementioned parameters across the ten locations and as well as in the individual location as contained in Table 1. The ten locations covered in the study were Olu-Obasanjo Point 1; Olu-Obasanjo Point 2; Railway/Okija; Afam/Library Point 1; Afam/Library Point 2; Okija Point 1; Okija Point 2, Between Okija and Olu-Obasanjo Point 1; Between Okija and Olu-Obasanjo Point 2; and behind Mile 3 (Timber Market). The geographical location characteristics of the ten locations are presented in Table 1.

Table 1. Geographical Coordinates of The Ten Locations Across Ntawogba Creek, Port Harcourt Metropolis
Source: Researchers' Fieldwork (2021)

S/n	Location	Latitude ($0_1{}^o$)	Longitude ($0_1{}^o$)	Altitude (m)
1	Olu-Obasanjo Point 1	N4^0, 48' 7.404"	E.6^0, 59' 46.313"	7m
2	Olu-Obasanjo Point 2	N4^0, 48' 11.559"	E.006^0, 59' 45.258"	6m
3	Railway/Okija	N4^0, 47' 49.731"	E.006^0, 59' 55.668"	5m
4	Afam/Library Point 1	N4^0, 47' 48.006"	E.007^0, 00' 58.212"	5m
5	Afam/Library Point 2	N4^0, 47' 47.139"	E.007^0 05' 20.312"	5m
6	Okija Point 1	N4^0, 47' 50.867"	E.006^0 59' 54.126"	5m
7	Okija Point 2	N4^0, 47' 50.292"	E.006^0 59' 55.061"	5m
8	Between Okija & Olu-Obasanjo 1	N4^0, 48' 6.228"	E.006^0 59' 46.223"	7m
9	Between Okija & Olu-Obasanjo 2	N4^0, 47' 59.685"	E.006^0 59' 49.362"	7m
10	Behind Mile 3 Timber Market	N4^0, 48' 34.099"	E.006^0 59' 35.531"	4m

The twelve physico-chemical parameters of the surface water quality investigated were temperature, pH, electrical conductivity, salinity, moisture content; nitrate, sulphate, calcium, phosphate, magnesium, potassium and sodium. The six heavy metals analysed were manganese, chromium, zinc, cadmium, iron, and lead. The benthos parameters of the study include Capitella-capitata and *Notomastus intereceus* (capitelliadae), *Nephathys hom*bergi (Nephthyldidae); nereisis diversicolor, *Nereis pelagic, Nereis virens* (Nereidae); *Polydora capensis* (spiondare); *Epidopatra gilchristi* (Eanicidae); *Poyebia deltaura* (callianussipidae).

The phytoplankton parameters include *Melosira varians, Melosira distans, Cosinodiscus lacustris; Pragilaria vivenscens, Synedra ulna, Cyclotella operculata* (Baccilaoriophycene). *Tetraodon* sp; *Netrianodigitus*; (Chlorophycene); *Anabarenopsos anoldic, Rivalaria planctonica* (Cyanophyceae); *Ceratium hirudinella, Peridium pusillium* and *Peridinium cinatum* (Phyrophyceae). The eight Zooplankton parameters are *Temora longicornis, Eurytemora hivandoides* (Temondae); *Anomalocera petersoni* (Pontellidae); *Pareuchaeta norvegica* (Euchaetidae); *Calamus finmarchicus* (calanoidae); *Paracyclops affinis* (Cyclopidare); *Tintinnopsis sinensis* and *Tintinnopsis wanji* (protozoa).
With respect to soil texture distribution across the ten locations, this was done through sieving method and the result is presented in Table 2.

Soil Texture Distribution

The result of the soil texture analysis from the laboratory is presented in Table 2

Table 2. Soil texture characteristics across the ten stations. **Source:** Researchers' Laboratory Analysis Report (2021)

S/n	Location	Soil – texture
1	Olu-Obasanjo Point 1	Sandy-Clayey
2	Olu-Obasanjo Point 2	Sandy-Clayey
3	Afam library	Sandy-Clayey
4	Afam/Library Point 2	Sandy-Clayey
5	Between Okija & Olu-Obasanjo Point 1	Sandy-Clayey
6	Between Okija & Olu-Obasanjo Point 2	Sandy-Clayey
7	Okija Point 1	Sandy-Clayey
8	Okija Point 2	Sandy-Clayey
9	Railway/Okija	Sandy-Clayey
10	Behind Mile 3 Timber Market	Sandy-Clayey

The result of the laboratory soil texture analysis revealed that in the ten locations across the Ntawogba creek in Port Harcourt metropolis, the soil texture was sandy-clayey all through. This could be as a result of the geologic structure of the area weathering activities and as well as anthropogenic activities. The soils of this study area belong to the coastal plain sands which were deposited by receding water during the Miocene-pleistocene age. They noted that the coastal plain sands are continental deposits from a probably upper deltaic depositional environment; and were derived from unconsolidated sedimentary deposits.

The descriptive and inferential statistics of the study are analysed in this section. The descriptive statistics employed the analytical techniques of mean, standard derivation, standard error, variance, coefficient of dispersion, co-efficient of variation and range. The inferential statistics utilized one way analysis of variance (ANOVA) and one sample t-test to test the hypotheses for the study. This was achieved by using the raw data from the laboratory analysis of the various parameters investigated. This section is therefore divided into two sections which are descriptive analysis of data and testing of hypotheses.

The water sample from Ntawogba creek across the ten locations were analyzed for physico-chemical parameters, heavy metals presence, soil type, benthos presence, phytoplankton presence and zooplankton presence. The results of the water physico-chemical parameters concentration were compared with natural and international standards for water quality Nigeria's National Standard for Drinking Water Quality –(NSDWQ) (2015), and World Health Organization (WHO, 2017) for potable drinking water Quality because the study does not cover surface water drinking quality. The result of the soil type was not also compared with the Food and Agriculture Organization (FAO) standard for soil quality for crop planting as the study does not cover this aspect. These results are presented in Table 7-11.

Temperature: The measured water temperature values were in the range of 24.2ºC and 28.2ºC in Olu-Obasanjo point 2 and Okija point 1 respectively with a range value of 4ºC across the ten locations. The water mean temperature was 25.98ºC with a standard deviation of 1.399ºC and a coefficient of variation of 1, 940.3% and as well as a standard error of 8.219^{0}C. Water temperature may affect water quality through biological activities. However, the obtained temperature range is normal and thus imposes no risk. The increasing the temperature of water may affect the oxygen concentration in the water which may affect the living things in the water.

pH: The pH is an important indicator for assessing the quality and pollution of any aquifer System as it is closely related to other chemical constituents of water. The presence of hydrogen ion concentration is measured in terms of pH range. Thus, water in its pure form shows a neutral pH which indicates hydrogen ion concentration. When pH results are higher than 8.0 water is not proper for efficient disinfection by chlorine; however, results less than 6.5 increases attrition in the pipes. In the present study, the range of pH varies between 4.46 (minimum) at between Okija and Olu-Obasanjo point 2 to 6.10 (maximum) at Okija point 2 which is acidic. The result also revealed a range value of 1.64, a mean value of 5.313; a standard deviation of 0.617; a standard error of 1.680 and a coefficient of variation of 861.1% which is very high indeed. Generally, the study recorded low pH values across the ten locations. With respect to human consumption, the ideal range of pH is 6.5-8.5.

Table 3. Analytical report of sediment samples. **Source**: The Researchers' Fieldwork Laboratory Analysis (2021)

	Parameters	METER	Oluobasanjo Point 1 GPS N40,48' 7.404" E60,59' 46.313"	Oluobasanjo Point 2 GPS N40,48' 11.559" E0060,59' 45.258"	Railway/ Okija GPS N40,47' 49.731" E0060,59 ' 55.668	Afam/Library Point 1 GPS N40,47' 48.006" E0070,00' 58.212"	Afam/Library Point 2 GPS N40,47' 47.139" E0070,05' 20.312"	Okija Point 1 GPS N40,47' 50.867" E0060,59 ' 54.126"	Okija point 2 GPS N40,47' 50.292" E0060,59 ' 55.061"	B/w Okija & Oluobasanjo Point 1 GPS N40,48' 6.228" E0060,59' 46.223"	B/w Okija & Oluobasanjo Point 2 GPS N40,47' 59.685" E0060,59' 49.362"	Behind Mile 3 Timber GPS N40,48' 34.099" E0060,59 ' 35.531"	Total %
1.	Temperatur E ^0C	Meter	26.5	24.2	27.2	26.1	24.3	28.2	27.1	26.6	25.3	24.3	
2.	PH	PH Meter	5.85	4.48	5.12	5.10	5.08	6.10	6.10	5.82	4.46	5.02	
3.	Electrical Conductivity,	Conductivity Meter	56.4	56.2	67.2	67.2	66.2	68.1	67.2	56.4	55.3	54.4	
4.	Salinity mg/kg	Meter	16.1	15.0	19.2	19.0	18.99	19.2	18.3	16.0	15.9	16.2	
5.	Moisture Content	Gravimetric Method	3.92	3.90	4.33	3.32	4.33	4.32	4.33	3.93	3.92	3.91	
6	PSD% Clay	Sieving method	6.59	5.49	28.61	27.63	28.63	30.63	28.65	6.58	6.51	6.54	
	Silt		14.11	14.8	29.43	29.44	30.01	30.47	30.44	14.10	14.2	14.08	
	Sand		79.30	75.31	41.92	40.92	43.93	43.93	41.91	79.33	77.30	79.29	
7.	Texture	Sieving method	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	Sandy-Clayey	
8.	Nitrate, mg/kg	APHA 4500-N0^3	0.423	0.425	0.319	0.320	0.318	0.320	0.322	0.424	0.425	0.422	
9.	Sulphate, mg/kg	APHA 4500-S0^4	9.104	9.100	7.217	7.219	6.299	8.218	7.220	9.102	9.104	9.100	
10	Phosphate, mg/kg	APHA 4500-P0^4	2.552	2.532	2.813	2.815	2.810	4.816	4.915	2.551	2.554	2.550	
11	Ca, mg/kg		105.62	106.60	124.89	124.87	124.88	126.89	125.85	105.62	106.64	105.60	
12	Mg,mg/kg		92.57	92.51	107.51	106.52	107.51	107.52	105.50	92.55	92.53	92.51	
13	K, mg/kg	APHA 3111b	30.20	29.21	39.00	40.01	38.99	40.02	41.04	31.19	30.22	30.20	
14.	Na, Mg/Kg		50.60	50.44	63.90	63.90	62.91	66.80	65.79	52.62	50.46	50.59	
15	Mn, mg/kg		1.07	1.05	2.54	2.81	2.79	2.84	2.75	1.04	1.02	1.01	
16	Cr, mg/kg		0.11	0.10	0.19	0.22	0.20	0.20	0.23	0.13	0.09	0.10	
17	Zn,mg/kg		0.35	0.33	0.46	0.45	0.44	0.48	0.46	0.36	0.32	0.33	
18	Cd, mg/kg		0.18	0.19	0.21	0.24	0.22	0.24	0.22	0.19	0.20	0.17	
19	Fe, mg/kg		231.43	231.44	302.28	304.25	303.20	302.29	301.30	230.46	231.4	231.4	
20	Pb, mg/kg		0.33	0.31	0.36	0.33	0.34	0.36	0.34	0.35	0.33	0.32	
21	Oil & Grease	APR 45	0.45	0.43	0.55	0.52	0.51	0.54	0.53	0.51	0.52	0.50	

Table 4. Benthos results. **Source:** The Researchers' Fieldwork Laboratory Analysis (2021)

Taxonomic Group	Oluobasanjo Point 1	Oluobasanjo Point 2	Railway/ Okija	Afam/library point 1	Afam/library point 2	Okija point 1	Okija point 2	B/w Okija & Oluobasanjo point 1	B/w Okija & Oluobasanjo point 2	Behind mile 3 timber	Total %
Polychaeta	.		.	.	.						
Capitellidae											
1. Capitellacapitata	3	2	4	3	1	2	2	3	3	2	
2. Notomastus latreiceus	3	1	6	4	5	2	5	4	2	3	
Nephthyididae											
3. Nephthys hombergi	4	3	1	1	1	0	1	0	1	1	
Nereidae											
4. Nereis diversicolor	2	1	5	3	1	4	3	2	3	3	
5. Nereis pelagic	3	2	5	4	.2	3	1	1	3	2	
6. Nereis virens	2	1	3	2	2	3	2	3	1	2	
Spionidae											
7. Polydora capensis	2	2	4	2	3	1	3	2	2	1	
Eunicidae											
8. Epidiopatra gilchristi	2	1	3	3	2	3	3	2	2	1	
Total											
CRUSTACEA											
Callianasspidae											
9 Pogebia deltaura	5	3	12	9	7	10	8	8	7	5	

Table 5. Zooplankton results. **Source:** The Researchers' Fieldwork Laboratory Analysis (2021)

	Taxonomic Group	Oluobasanjo Point 1	Oluobasanjo Point 2	Railway/ Okija	Afam/Library Point 1	Afam/Library Point 2	Okija Point 1	Okija Point 2	B/w Okija & Oluobasanjo Point 1	B/w Okija & Oluobasanjo Point 2	Behind Mile 3 Timber	Total %
	Copepoda	.		.	.	.						
	Temoridae											
1.	Temora Longicornis	23	20	17	14	13	15	14	10	13	8	
2.	Eurytemora hirundoides	14	10	18	12	11	16	11	15	14	9	
	Pontellidae											
3.	Anomalocera Patersoni	6	3	12	9	9	9	10	8	8	7	
	Euchaetidae											
4.	Parcuchaeta norvegica	5	4	10	10	7	9	7	8	8	6	
	Calanoidae											
5.	Calamus finmarchicus	7	5	5	3	5	4	4	3	3	2	
	Cyclopidae											
6.	Paracyclops affinis	8	8	10	10	8	8	6	5	4	3	
	Total =											
	Protozoa											
7.	Tintinnopsis Sinensis	2	2	0	0	0	0	0	0	0	0	
8	Tintinnopsis Wanji	6	4	2	2	1	2	2	2	2	1	
	Total =											
	Total No: Individuals											

Table 6. **Phytoplankton results. Source:** The Researchers' Fieldwork Laboratory Analysis (2021)

	Taxonomic Group	Oluobasanjo Point 1	Oluobasanjo Point 2	Railway/ Okija	Afam/Library Point 1	Afam/Library Point 2	Okija Point 1	Okija Point 2	B/w Okija & Oluobasanjo Point 1	B/w Okija & Oluobasanjo Point 2	Behind Mile 3 Timber	Total %
	Baccilariophyc eae	.		.	.	.						
1	Melosira varians	12	10	13	11	9	12	11	8	8	6	
2.	Melosira distans	18	15	23	21	23	20	20	18	16	13	
3	Cosinodiscus lacustris	5	3	11	11	9	11	10	9	10	7	
4	Fragilaria vivenscens	10	7	20	20	20	17	17	15	13	11	
5	Synedra ulna	6	5	13	11	10	8	9	8	10	8	
6	Cyclotella operculata	22	19	8	8	6	7	6	5	7	6	
	TOTAL											
	CHLOROPHYCEAE											
7	Tetraodon sp.	1	1	0	0	0	0	0	0	0	0	
8	Netrium digitus	6	4	2	2	1	2	1	2	2	1	
	TOTAL											
	CYANOPHYCEAE											
9	Anabaenopsos anoldic	2	2	8	7	5	7	5	4	4	2	
10	Rivularia planctonica	6	6	1	1	1	1	0	0	1	1	
	TOTAL											
	PHYROPHYCEAE											
11	Ceratium hirudinella	3	2	7	6	7	5	7	6	5	4	
12	Peridium pusillium	8	8	3	3	2	3	2	4	1	1	
13	Peridinium cinatum	2	2	12	10	8	11	10	7	8	6	
	TOTAL											
	Total No: Individuals											
	Total number: Species.											

Electrical Conductivity: Electrical conductivity is a measure of the ability of any substance or solution to conduct electrical current through the water. Electricity conductivity is directly proportional to the dissolved material in a water sample as it has a direct relation with total dissolved solids (TDS). The values of electrical conductivity ranged from 54.4µs/cm to 68.1µs/cm with a range value of 13.7µs/cm and a mean value of 61.46µs/cm. The minimum EC value of 54.4µs/cm was recorded at behind Mile 3 Timber market while the maximum value of 68.1µs/cm was recorded at Okija point 1. Other descriptive statistics result revealed that the standard deviation is 6.024µs/cm; standard error of 19.437µs/cm and a coefficient of variations of 1,011.9%. High EC in some locations might suggests the mixing of sewage in surface water at these locations as there are in very dense urbanization area.

Salinity: salinity generally describes the amount of salt in water. In this study, the salinity values generated from the ten locations of Ntawogba creek varies considerably from 16.0 ppt (minimum) at Okija and Olu-Obasanjo point 1 to 19.2 ppt (maximum) at Okija point 1. The mean value across the ten locations is 17.39 ppt, standard deviation of 1.682 ppt; standard error of 5.499 ppt; range of 3.2 ppt and a coefficient of variation of 1,033.8%.

Table 7. Descriptive statistics of water sample physico-chemical parameters across the ten locations in port Harcourt metropolis. **Source:** The Researchers' Fieldwork Laboratory Analysis (2021)

S/n	Location	pH	Temper-ative (O^C)	EC S/cm	Salinity (ppt)	Moisture (ppt)	Nitrate (mg/kg) (NO_3)	SO_4 (mg/kg)	Ca (mg/kg) PO_4	Mg (mg/kg) Ca	K (mg/kg) Mg	K (mg/kg)	Na (mg/kg)
1	Olu-Obsanajo Point 1	5.85	26.5	56.4	16.1	3.92	0.423	9.104	2.552	105.62	92.57	30.20	50.60
2	Olu-Obasanjo Point 2	4.48	24.2	56.2	15.0	3.90	0.425	9.100	2.532	106.60	92.51	29.21	50.44
3	Railway/Okija	5.12	27.2	67.2	19.2	4.33	0.319	7.217	2.813	124.89	107.51	39.00	63.90
4	Afam /Library Point 1	5.10	26.1	67.2	19.0	3.32	0.320	6.219	2.815	124.87	106.52	40.01	63.90
5	Afam/Library Point 2	5.08	24.3	67.2	18.99	4.33	0.318	6.299	2.810	124.88	107.51	38.99	62.91
6	Okija Point 1	6.10	28.2	66.2	19.2	4.32	0.320	8.218	4.816	126.89	107.52	40.02	66.80
7	Okija Point 2	6.10	27.1	68.2	18.3	4.33	0.322	7.220	4.915	125.85	105.50	41.04	65.79
8	Between Okija & Olu-Obasanjo Point 1	5.82	26.6	67.2	16.0	3.93	0.424	9.102	2.551	105.62	92.55	31.19	52.62
9	Between Okija & Olu-Obasanjo Point 2	4.46	25.3	56.4	15.9	3.92	0.425	9.104	2.554	106.64	92.53	30.22	50.46
10	Behind Mile 3 (Timber)	5.02	24.3	55.3	15.2	3.91	0.422	9.100	2.550	105.60	92.51	30.20	50.59
	Mean (x)	5.313	25.98	54.4	17.389	4.021	0.372	8.168	3.191	115.25	99.72	35.01	57.80
	SD	0.617	1.399	61.46	1.682	0.320	0.548	1.083	1.181	10.28	7.601	5.115	7.33
	Range	1.64	4	6.074	3.2	0.43	0.107	2.885	2.383	21.29	14.94	10.84	16.36
	CD	8.611	19.403	13.7	10.338	12.566	0.679	7.542	2.702	11.260	13.119	6.845	7.885
	CV (%)	861.1	1,940.3	10.12	1,033.8	1.256.6	67.9	754.2	27.0	1,126	1,311.9	684.5	788.5
	SE	1.680	8.216	19.44	5.499	1.272	0.118	2583	1.009	36.607	31.537	11.072	18.280
	NSDWQ	Ambient	6.0							0.20	-		6.0
	WHO	27-32	6.5-8.5	≤5750	5(psu)		50mg/l	500mg/l	≤0.05	2	200	-	50-200 mg/l

Moisture: Moisture refers to water content in a substance. In the soil along the Ntwogba Creek, moisture concentration along the ten locations varies between 3.98% and 4.33% with a range value of 0.43% and a mean value of 4.021%. The lowest moisture content was recorded at Okija point 2. Further result analysis reveal a standard deviation of 0.320% standard error of 1.272% and a coefficient of variation of 1,256.6%.

Nitrate: Nitrate is a naturally occurring ion and is a significant component of the Nitrogen cycle. In Table 4.7 the highest nitrate value is observed to be 0.425mg/kg at between Okija and Olu-Obasanjo point 2 with a range value of 0.107mg/kg. The mean value is 0.372mg/kg with a standard deviation of 0.548mg/kg. The standard error was 0.118mg/kg and a coefficient of variation of 67.9%.

Sulphate (SO_4): Sulphate is a major ion and most Sulphate compounds are readily soluble in water (Olorunfemi, et. al., 2011). Contaminated water and waste water are usually high in sulphate concentration. In the present study, the concentration of Sulphate ranges between 6.299mg/kg (minimum) at Afam/Library point 2 and 9.114mg/kg (maximum) in two locations Olu-Obasanjo point 1 and between Okija and Olu-Obasanjo point 2 with a range value of 2.885 and a mean value of 8.168mg/kg and a standard deviation value of 1.083mg/kg. The standard error is 2.885 while the coefficient of variations is 754.2% with respect to drinking water quality, sulphate in high concentration is responsible for gastrointestinal irritation in human beings. In groundwater, sulphate is dissolved and centred from rocks containing gypsum, iron sulphide and other sulphur bearing compounds.

Sodium (Na) Sodium is generally regarded as highly reactive alkali metal and is present in most of the surface water and groundwater. Many rocks and soil contain sodium compound. In the study area, sodium ranges from 50.44mg/kg at Olu-Obasanjo point 2 to 66.80mg/kg at Okija point 1. The range value is 16.36mg/kg while the mean value is 57.80mg/kg with a standard deviation of 7.33mg/kg. The standard error is 18.28mg/kg while the coefficient of variation is 788.5%

Phosphate (PO_4): Phosphate is a cation. It sources include human sewage, agricultural run-off from crops, and sewage from animal feedlots within the area (Sokpuwu, 2017). The average value of phosphate recorded in this study was 8.168mg/kg. The minimum value was recorded at Olu-Obasanjo point 2 (2.532mg/kg) while the maximum value was recorded at Okija point 2 (4.915mg/kg), with a range value of 2.383mg/kg. Further results showed that phosphate had a standard deviation of 1.083mg/kg, a standard error of 1.009mg/kg and a coefficient of variation of 270.2%. As earlier stated, anthropogenic activities are the main contributors of excessive phosphate into a river channel; sewage discharge, runoff from agricultural sites, and the release of detergent during domestic washing especially along river channel sections are common practices. The load contribution of detergent raises the level of Phosphate in water channel due to the weight of inorganic condensed phosphates.

Calcium (Ca) - Calcium is also an important cation and in groundwater system, it enters into the aquifer system from the leaching of calcium bearing minerals. In drinking water quality, calcium serves in the body as vascular contraction, muscle contraction, blood clothing and nerve transmission. Less intake of calcium results in high risk of piephraliaisis, hypertension, obesity, etc.

The mean concentration level of calcium in Ntawogba creek is 111.575 mg/kg with a standard deviation of 10.28mg/kg less and a standard error 36.607mg/kg. The lowest concentration level of 105.60mg/kg was recorded at behind mile 3 (timber) while the highest concentration level of 126.89mg/kg was recorded at Okija point 1. The study also recorded a range value of 21.29mg/kg with and a coefficient of variation of 1.126%.

Magnesium (Mg): The average magnesium value recorded in this study was 99.72mg/kg with a standard deviation of 7.601mg/kg and a standard error of 31.537mg/kg. across the ten locations. Magnesium concentration level ranges between 92.51 mg/kg (minimum) at Olu-Obasanjo point 2 and 107.51mg/kg (maximum) at Olu-Obasanjo point 2 and 107.51mg/kg (maximum) at Railway/Okija with a coefficient of variation of 1,311.9%. With respect to groundwater, magnesium sources is due to ion exchange of mineral in rocks and soil by water. It is also an important parameter responsible for the hardness of water.

Potassium (K): Potassium is an important cation and is present in many minerals and most of the rocks available on Earth; and many of these rocks are relatively soluble and releases potassium. In this study, the concentration level of potassium varies between 29.21mg/kg (minimum) at Olu-Obasanjo point 2 and 41.04mg/kg (maximum) at Okija point 2. The mean value concentration is 35.01mg/kg with a standard deviation of 5.115mg/kg and a standard error of 11.072mg/kg. Furthermore, the result revealed a range value of 10.84mg/kg and a coefficient of variation 684%. In groundwater system, the concentration of potassium increases with the.

Heavy Metals Data Analysis

The results of the descriptive statistics of the six heavy metals investigated in the study is presented in Table 8.

Manganese (Mn): The average value of manganese in the study locations was 1.892mg/kg. The values obtained for all the sampling points ranged from 1.01mg/kg to 2.84mg/kg in locations 10 and 6 respectively (behind mile 3 and Okija point 1). The range value was 1.83mg/kg. Furthermore, the result revealed a standard deviation of 0.904mg/kg; a standard error of 0.598mg/kg, and coefficient of variation of 209.3% which is a measure of variation, and which implies that manganese varies considerably across the ten sampling points.

Chromium (Cr): Chromium is also another important heavy metal found in soil, groundwater and as well as surface water. In the present study, the distribution of chromium ranged between 0.09mg/kg (minimum) between Okija and Olu-Obasanjo points 2 with a range value of 0.14mg/kg. Chromium recorded a mean value of 0.157mg/kg, a standard deviation value 0.558mg/kg, a standard error value of 0.050mg/kg, a coefficient of dispersion value of 0.281 and a low coefficient of variation value of 28.1% which implies that chromium does not vary much across the ten locations.

Zinc (Zn): The concentration level of zinc in the present study ranges between 0.32mg/kg and 0.48mg/kg with a range value of 0.16mg/kg. The lowest concentration level was recorded at between Okija and Olu-Obasanjo point 2 while the highest concentration level was observed at Okija point 1. The record showed a mean value of 0.398mg/kg and a standard deviation of 0.065mg/kg in all the ten locations. In addition, the result also showed a standard error value of 0.126mg/kg; a coefficient of dispersion value of 6.128mg/kg and a high coefficient of variation of 621.3% which signifies that zinc varies highly in Ntawogba creek across the ten sampling points. This high variation may be attributed to several factors.

Table 8. Descriptive statistics of heavy metals in Ntawogba creek. **Source:** Researchers' SPSS Analysis (2021).

S/n	Location	Mn	Cr mg/kg	Zn mg/kg	Cd	Fe	pb
1	Olu-Obasanjo Point 1	1.07	2.11	0.35	0.18	231.43	0.33
2	Olu-Obasanjo Point 2	1.05	0.10	0.33	0.19	231.44	0.31
3	Railway/Okija	2.54	0.19	0.46	0.21	302.28	0.36
4	Afam/Library Point1	2.81	0.22	0.45	0.24	304.25	0.33
5	Afam/library Point 2	2.79	0.20	0.44	0.22	303.20	0.34
6	Okija Point 1	2.84	0.20	0.48	0.24	302.29	0.36
7	Okija Point 2	2.75	0.23	0.46	0.22	301.30	0.34
8	Between Okija & Olu-Obasanjo Point 1	1.04	0.13	0.36	0.19	230.46	0.35
9	Between Okija & Olu-Obasanjo Point 2	1.02	0.09	0.32	0.20	231.4	0.33
10	Behind Mile 3 (Timber)	1.01	0.10	0.33	0.17	231.4	0.33
11	Mean (x)	1.892	0.157	0.398	0.206	266.945	0.337
12	SD	0.904	0.558	0.024	0.024	37.659	0.164
13	Range	1.83	0.14	0.16	0.07	73.79	0.05
14	CD	2.093	0.281	6.123	8.583	7.088	2.055
15	CV (%)	209.3	28.1	612.3	858.3	708.8	205.5
16	SE	0.598	0.050	0.126	0.065	84.422	0.107
17	NSDWQ	.	0.05	5mg/l	0.003	0.30	0.10
	WHO	01-0.4	0.05	5mg/l	0.003	0.30	0.10

Cadmium (Cd): According to Chemists, cadmium in its compound occurs as the divalent cadmium ion. Cadmium, together with mercury and lead, is one of the big three heavy metals poisons and is not known for any essential biological function. Cadmium is directly below zinc in the periodic table and has a chemical similarity to that of zinc which is an essential micronutrient for plants and animals. This may account in part for cadmiums toxicity, because zinc being an essential trace element, its distribution by cadmium may cause the malfunctioning of metabolic processes.

In the present study as seen in Table 4, cadmium concentration levels ranged between 0.17mg/kg (minimum) and 0.24mg/kg (maximum) at behind Mile 3 timber market and Afam/Library Point 1 respectively. Other descriptive statistics records include a range value of 0.07mg/kg, a mean value of 0.206 mg/kg; a Standard deviation value of 0.24mg/kg, a Standard error value of 0.065mg/kg, a Coefficient dispersion value of 8.583mg/kg and a Coefficient of variation of 858.3% which implies that cadmium varies considerably high in Ntawogba creek across the ten sampling points.

Iron (Fe): Iron occurs freely in both surface and groundwater. In groundwater, the most common sources of iron is weathering form ion bearing minerals and rocks while in surface water, it may be due to iron metals dropped in river water by human beings or by erosional activity. The concentration of ions in groundwater is often higher than those measured in surface water due to chemical reaction. If Fe^{2+} state is oxidized to Fe^{3+} state in contact with atmospheric oxygen or by the action of iron related bacteria, it forms insoluble hydroxides in groundwater.

The present study revealed that iron concentration level varies from 230.46mg/kg (lowest) to 304.25mg/kg respectively in location 8 and 4. The records showed a range value of 73.79mg/kg; a mean value of 266.945mg/kg; and Standard deviation value of 37.659mg/kg; a Standard error value of 84.422mg/kg. With respect to level of dispersion and variation, the result indicated a dispersion value of 7.088mg/kg and a high variation of 708.6% which implies that iron varies considerably along the ten locations in Ntawogba creek.

Lead (pb): Lead is a cation and is known to be the heaviest element in the world. According to Jarup (2003), lead in drinking water could have significant medical effect on renal functions. Other symptoms of acute lead concentration could result to headache, irritability and abdominal pain (Alasia, et. al., 2009). The present study revealed that the lead level concentration varies between 0.31mg/kg (minimum) at Olu-Obasanjo point 2 and 0.36 (maximum) at Okija point 1 and Railway/Okija. The result also revealed that three locations (Olu-Obasanjo point 1, Afam/Library Point 1 and between Okija and Olu-Obasanjo point 2) recorded the same value of 0.33mg/kg. The average mean value recorded across the ten sampling points was 0.337mg/kg with a standard deviation value of 0.164mg/kg. The results further revealed a range value of 0.05mg/kg which implies that the recorded values of the ten location. The results also showed a low standard error value of 0.107mg/kg; a low dispersion value of 2.055mg/kg and a low coefficient of variation of 205.5% which signifies that lead variation in the ten locations is low.

Benthos Data Analysis

Benthos is the assemblage of organisms inhabiting the sea floor. Benthic epifauna live upon the sea floor or upon bottom objects; the so-called infauna live within the sediments of the sea floor. Benthos are also known as benthos, is the community of organisms that live on, in or near the bottom of a sea, river, lake, or stream, also known as the benthic zone. This community lives in or near marine or freshwater sedimentary environments, from tidal pools along the foreshore, out to the continental shelf, and then down to the abyssal depths (*Maham et al*., 2012). The benthos identified in the study were *Capitellacapitata, Notomastus latrieiceus (Capitellidae); Nephthys (Nephthyididae). Polydora capensis (Spionidae); epidiopatra gilchristi (Eunicidae);* and *Pogebia deltaura (Callianasspidae*). The descriptive statistics of these benthos is presented in Table 9.

Table 9. Analysis of benthos distribution across the ten locations in Ntawogba creek **Source:** Researchers' SPSS Analysis (2021)

S/n	Location	Capitellacapitata	Notomastus latreiceus	Nephthys hombergi	Nereis virens	Polydora capensis	Epidiopatra gilchristi	Pogebia deltaura	Nereis diversicolor	Nereis pelagic
1	Olu-Obasanjo Point 1	3	3	4	2	2	2	5	2	3
2	Olu-Obasanjo Point 2	2	1	3	1	2	1	3	1	2
3	Railway/Okija	4	6	1	3	4	3	12	5	5
4	Afam/Library Point 1	3	4	1	2	2	3	9	3	4
5	Afam/Library Point 2	1	5	1	2	3	2	7	1	2
6	Okija Point 1	2	2	0	3	1	3	10	4	3
7	Okija Point 2	2	5	1	2	3	3	8	3	1
8	Between Okija & Olu-Obasanjo Point 1	3	4	0	3	2	2	8	2	1
9	Between Okija & Olu-Obasanjo Point 2	3	2	1	1	2	2	7	3	3
10	Behind Mile 3 (Timber)	2	3	1	2	1	1	5	3	2
	Total	**55**	**35**	**13**	**19**	**22**	**22**	**74**	**27**	**26**
	Mean	**5.5**	**3.5**	**1.3**	**1.9**	**2.2**	**2.2**	**7.4**	**27**	**26**
	SD	**3**	**5**	**4**	**2**	**3**	**2**	**9**	**4**	**4**

Capitallacapitata: The distribution of capitallacapitata across the ten location along Ntawogba creek ranges from 1 (lowest) at Afam /Library Point 2 to 4(highest) at Railway/ Okija with a range value of 3. A total number of 55 pieces of capitallacapitata was recorded with a mean value of 5.5.

Notomastus latrieiceus: Table 10 showed that a total of 35 samples of *Notomastus latrieiceus* were recorded on the ten stations along Ntawogba creek. The mean value was 3.5 with a range value of 5. The maximum value of 6 was recorded at railway/Okija while the minimum value of 1 was recorded at Olu/Obasanjo point 2.

Nephthys hombergi: The result of *Nephthys hombergi* revealed that there was low distribution of the microorganism in the ten locations. Okija point 1, and between Okija and Olu-Obasanjo Point 1 recorded while the largest samples of 4 was recorded at Olu-Obasanjo point 1. Six locations (Railway/Okija, Afam/Library Points 1 & 2; Okija point 2, between Okija & Olu-Obasanjo Point 2; Okija point 2, between Okija & Ou Obasanjo point 2 and behind Mile 3 market) recorded 1 piece of *Nephthys hombergi* each. The average mean value is 1.3 with a range of 4.

Nereis virens: *Nereis virens* distribution across the 10 locations along Ntawogba creek varies between 1 and 3 with a total of 19 samples recorded. The mean value is 1.9 while the range along is 2. Majority of the sampling points recorded 5 samples each. Sampling points 1 (Olu-Obasanjo point 2 and between Okija & Olu-Obasanjo point 2) recorded 1 sample each.

Polydora capensis: Across the ten locations along Ntawogba creek, the distribution of *Polydora capensis* varies between 1 and 3 with a range value of 2 and a mean value of 2.2. Most of the sampling points recorded 5 samples each. In all a total of 19 samples were recorded in the ten stations. Three sampling points recorded a maximum value of 3 samples while two sampling points recorded a minimum value of 1 sample each.

Table 10. Analysis of zooplankton distribution across the ten locations in Ntawogba creek. **Source:** Researchers' SPSS Analysis (2021)

S/n	Location	Temora longicornis	Eurytemora hirundoides	Anomalocera patersoni	Parcuchaeta norvegica	Calamus finmarchicus	Paracyclops affinis	Tintinnopsis sinensis	Tintinnoposis wanji
1	Olu Obasnajo Point 1	23	14	6	5	7	8	2	6
2	Olu-Obasanjo Point 2	20	10	3	4	5	8	2	4
3	Railway/Okija	17	18	12	10	5	10	0	2
4	Afam/Library Point 1	14	12	9	10	3	10	0	2
5	Afam /Library Point 2	13	11	9	7	5	8	0	1
6	Okija Point 1	15	16	9	9	4	8	0	2
7	Okija Point 2	14	11	10	7	4	6	0	2
8	Between Okija & Olu-Obasanjo Point 1	10	15	8	8	3	5	0	2
9	Between Okija & Olu-Obasanjo Point 2	13	14	8	8	3	4	0	2
10	Behind Mile 3 (Timber)	8	9	7	8	2	3	0	1
	Total	**287**	**130**	**81**	**76**	**41**	**70**	**4**	**24**
	Mean	**28.7**	**13.0**	**8.1**	**7.6**	**4.1**	**7.0**	**0.4**	**2.4**
	Range	**15**	**9**	**9**	**6**	**5**	**5**	**2**	**5**
	Minimum	**8**	**9**	**3**	**4**	**2**	**3**	**0**	**1**
	Maximum	**23**	**18**	**10**	**10**	**7**	**10**	**2**	**6**

Pogebia deltaura: A total of 74 pieces of *Pogebia deltaura* benthos were seen across the ten sampling points in Ntawogba creek with a mean value of 7.4 and a range value of 9. Among the nine benthos organisms investigated, *Pogebia deltaura* recorded the highest value. The lowest 3 samples of *Pogebia deltaura* was recorded at Olu-Obasanjo point 2 while the highest 12 samples were recorded at Railway/Okija.
Epidiopatra gilchristi: The distribution of *Epidiopatra gilchristi* in the study area recorded a total of 22 pieces with a mean value of 2.2 and a range value of 2. Olu-Obasanjo point 2 and behind mile 3 market recorded 1 piece each being the lowest while three sampling points/Railway/Okija, Afam/Library point1, Okija Points 1 and 2) recorded the highest values of 3 pieces of *Epidiopatra gilchristi* benthos. Four stations recorded 2 pieces of benthos each.
Nereis diversicolor: *Nereis diversicolor* distribution along the creek varies between 1 and 5 with a range value of 4 and a mean value of 2.7. Two sampling points (Olu-Obasanjo Point 2 and Afam/Library point 2) recorded the lowest value of 1 piece of *Nereis diversicolor* while Railway/Okija recorded the highest value of 5 pieces of the benthos. Furthermore, four sampling points recorded 3 pieces of the benthos, while, two sampling points Olu/Obasanjo point 2 and between Okija and Olu-Obasanjo 1 recorded 2 pieces of benthos per station.
Nereis pelagic: *Nereis pelagic* distribution ranges between 1 (minimum) and 5 (maximum) in the study area. It recorded a mean value of 2.6 and a range value of 4. A total of 26 pieces of *Nereis pelagic* benthos was recorded across the ten locations. Three locations points recorded 2 pieces of the benthos and as well 3 pieces of the benthos as well. Two location points recorded 1 piece each. One station Afam/library point 1 recorded 4 pieces of benthos. The same is also true for 5 pieces in one station. The distribution is seen not to be evenly distributed.

Zooplankton Data Analysis

The result of the descriptive statistics of the distribution of eight species of zooplankton in the ten stations across Ntawogba creek in Port Harcourt metropolis is shown in table 4.11. The zooplankton consists of two taxonomic groups (Copepoda and Protozoa). The Copepoda taxonomic group is made up of five (5) families (*Temoridae, Pontellidae*, *Euchaetide, Calanoidae* and *Cyclopidae*. The *Temoridae* family was made up of two species (*Temora longicoris* and *Eurytemora hirundoides*); the *Pontilidae* family is made up of one species (*Anomalocera patersoni*); the *Euchaetidae* is made up of one specie (*Parcuchaeta norvegica*); the *Calanoidae* family is made up of one specie (*Calamus finmarchicus*); the *Cyclopidae* family is made up of one specie *Paracyclops affinis*). On the other hand, the protozoa taxonomic group is made up of two species only which are *Tintinnopsis sinensis* and *Tintinnopsis wanji.*

Phytoplankton Data Analysis

The result of the phytoplankton distributed across the ten locations along Ntawogba creek in Port Harcourt metropolis is presented in Table 11. The phytoplankton microorganism consists of a total of thirteen species classified into four taxonomic groups. This taxonomic groups and species are: Baccilariophyceae group (*Melosira varians, Melosira distans, Cosinodiscus lacustris, Fragilaria vivenscens, Synedra ulna, Cyclotella operculata*), Chlorophyceae taxonomic group (*Tetraodon sp* and *Netrium digitus*); Cyanophyceae taxonomic group (*Anabaenopsos anoldic* and *Rivularia planctonica*); Phyrophyceae taxonomic group (*Ceratium hirudinella, Peridium pusillium* and *Peridinium cinatum*).

Melosira varians: The distribution of *Melosira varians* Plankton varies between 6 samples at behind mile 3 timber being the lowest and 13 samples at Railway/Okija being the highest with a range value of 7 samples. A total of 100 samples which implies that an average of 10 samples of *Melosira varians* were recorded in each location. Based on the mean result, it therefore concludes that *Melosira varians* is evenly distributed across the ten locations along Ntawogba creek.

Melosira distans: *Melosira distans* distribution ranges from 1 sample (minimum) at behind mile 3 Timber and 23 (maximum) at two locations (Railway/Okija and Afam/library point 2). Two locations (Okija points 1 and 2) paired up to produce 20 samples each. Furthermore, the result revealed that a total of 187 samples of *Melosira distans* were recorded in the ten stations with a mean value of 18.7 and a range value of 10. Based on the mean value of 18.7, the conclusion drawn here is that an average of 18.7 samples of *Melosira distans* were found in each location.

Cosinodiscus lacustris: The result of the distribution of *Cosinodiscus lacustris* across the ten locations along Ntawogba creek revealed that a total of 86 samples of the plankton was recorded. The minimum value of 3 samples was recorded at Olu-Obasanjo point 2 while the maximum value of 11 samples were recorded in three locations (Railway/Okija, Afam/Library point 2 and Okija point 1). Furthermore, the result analysis indicated a mean value of 8.6 and a range value of 8. It can be seen from the result on the above Table 11 that *Cosinodiscus lacustris* varies considerably along the ten locations in Ntawogba creek.

Table 11. Analysis of phytoplankton distribution across the ten locations in Ntawogba creek. **Source:** Researchers' SPSS Analysis (2021)

S/n	Location	Melosira varians	Melosira distans	Cosinodiscus lacustris	Fragilaria vivenscens	Synedra ulna	Cyclotella operculata	Tetraodon sp	Netrium digitus	Anabaenopsos anoldic	Rivularia planctonica	Ceratium hirudinella	Peridium pusillium	Peridinium cinatum
1	Olu-Obasanjo Point 1	12	18	5	10	6	22	1	6	2	6	3	8	2
2	Olu-Obasanjo Point 2	10	15	2	7	5	19	1	4	2	6	2	8	2
3	Railway/Okija	13	23	11	20	13	8	0	2	8	1	7	3	12
4	Afam/Library Point 1	11	21	11	20	11	8	0	2	7	1	6	3	10
5	Afam /Library Point 2	9	23	9	20	10	6	0	1	5	1	7	2	8
6	Okija Point 1	12	20	11	17	8	7	0	2	7	1	5	3	11
7	Okija Point 2	11	20	10	17	9	6	0	1	5	0	7	2	10
8	Between Okija & Olu-Obasanjo Point 1	8	18	9	15	8	5	0	2	4	0	6	4	7
9	Between Okija & Olu-Obasanjo Point 2	8	16	10	13	10	7	0	2	4	1	5	1	8
10	Behind Mile 3 (Timber)	6	13	7	11	8	6	0	1	2	1	4	1	6
	Total	**100**	**187**	**86**	**150**	**88**	**94**	**2**	**23**	**46**	**18**	**52**	**35**	**76**
	Range	**7**	**10**	**8**	**13**	**8**	**17**	**1**	**5**	**6**	**6**	**5**	**7**	**10**
	Mean	**10**	**18.7**	**8.6**	**15.5**	**8.8**	**9.4**	**0.2**	**2.3**	**4.6**	**1.8**	**5.2**	**3.5**	**7.6**

Fragilaria vivenscens: *Fragilaria vivenscens* is an important phytoplankton seen in most surface water. Its distributions vary from 7 samples (minimum) at Olu-Obasanjo point 2 to samples (maximum) at three locations (Railway/Okija and Afam/Library points 1 and 2). Two locations (Okija points 1 and 2) paired up to record 17 samples of *Fragilaria vivenscens* each. Furthermore, descriptive statistics result showed that a total of 150 samples of *Fragilaria vivenscens* were recorded in the ten locations with a mean value of 15.0 and a range value of 13. Based on the mean result of 15, it implies that an average of 15 samples of *Fragilaria vivenscens* were recorded in each location.

Synedra ulna: The result displayed in the table above shows that a summation of 86 samples *Synedra ulna* was observed in the ten locations where the hydro biological analysis was carried along Ntawogba creek. The mean value was 8.8 while the range value was 8. The distribution of the phytoplankton varies considerably from 5 samples (minimum) at Olu-Obasanjo point 2 to 13 samples (maximum) at Railway/Okija. The result also showed that two locations (Okija point 1 and between Okija & Olu-Obasanjo point 1 produced the same number of 8 samples each. Based on the mean value of 8.8, the overall distribution of the phytoplankton is 8.8 samples per location.

Cyclotella operculata: As can be seen from the result displayed on the above table, *Cyclotella operculata* distribution across the ten locations in Ntawogba creek varies between 5 and 22 samples with a range value of 17. Most of the locations recorded low samples of *Cyclotella operculata*, usually between 5 and 8 samples of the phytoplankton. The result revealed that the total samples of 94. *Cyclotella operculata* were observed in the ten locations with a mean value of 9.4 *Cyclotella operculata* per location. Two locations (Rail-ways /Okija and Afam /Library point 1) tied up to produce 8 sample and another two locations also (Okija point and between Okija & Olu-Obasanjo Point 2) paired up to produce 7 samples each. Furthermore, three locations (Afam/Library point 2; Okija Point 2; and Behind Mile 3 Timber) produced 6 samples of *Cyclotella operculata* each. The lowest sample of 5 was recorded at Olu-Obasanjo Point 2 and the highest 22 samples of the phytoplankton was recorded at Olu-Obasanjo Point 1).

Tetraodon sp: The result revealed that among the thirteen types of phytoplankton distribution analysed in this study, *Tetraodon sp* had the lowest rate of distribution across the ten stations. Apart from two locations (Olu-Obasanjo Point 1 and 2) that recorded one sample each of the phytoplankton, the rest eight locations produced 0 sample. A total of 2 samples of *Tetraodon sp* were recorded with a mean value of 0.2 and a range value of 1 Based on this finding, the inference deduced here is that *Tetraodon sp* is poorly distributed along Ntawogba creek in the ten locations identified. This calls for greater attention to the investigation of *Tetraodon sp* on surface water.

Netrium digitus: The phytoplankton, *Netrium digitus* was sparsely distributed as seen in Table 11. It recorded a total of 23 samples in the ten locations with a mean of 2.3 samples. Its distribution ranges from 1 to 6 samples with a range value of 5. Three locations (Afam/Library points 2, behind Mile 3 Timber and Okija, Point 2) recorded the lowest distribution of 1 sample each on the other hand, five locations (railway, Okija, Afam, Library Point 1, Okija Point 1, between Okija and Olu-Obasanjo Points 1 and 2) recorded 2 samples each. Lastly, Olu-Obasanjo Points 1 and 2 recorded 6 and 4 samples respectively.

Anabaenopsos anoldic: The result of Table 11 showed that *Anabaenopsos anoldic* was fairly distributed across the ten stations as it varies between 2 and 8 samples. The minimum distribution of 2 samples was recorded in three locations (Olu-Obasanjo Point 1 and 2 and Behind Mile 3 Timber) while the maximum distribution of 8 samples was recorded at Railway/Okija. The result also revealed that 12 locations each paired up to jointly produce 4.5 and 7 samples each. Their overall sum distribution was 46 samples with a mean of 4.6. The range value recorded was 6.

Rivularia planctonica: The result of *Rivularia planctonica* revealed that this phytoplankton varied sparsely across the ten locations. It recorded a total sum of 18 samples with a mean value of 1.8 per location. It varies between 0 and 6 with a range value of 6. Majority of the locations (6) recorded one sample per plot. Two locations (Okija Point 2 and between Okija and Olu-Obasanjo Point 1. Paired to record 0 while another two locations (Olu-Obasanjo Points 1 and 2) jointly recorded 6 samples per plot and as well is the maximum value recorded. The sparse variation recorded could be as a result of anthropogenic factors which are limiting the growth and expansion or *Rivularia planctonica* in the study area.

Ceratium hirudinella: As can be seen from Table 4.11, *Ceratium hirudinella* is evenly distributed across the ten stations. The result revealed that the minimum value of 2 samples was recorded at Olu-Obasanjo point 2 while the maximum value or 7 was recorded in three locations (Railway/ Okija, Afam, Library Point 2 and Okija Point 2). A total of 52 samples of *Ceratium hirudinella* was observed in the ten locations with a mean value of 5.2 sample per location. The range value was 5. The result also indicated that two locations (Afam/Library Point 1 and Between Okija & Olu-Obasanjo Point 1) jointly recorded 6 samples each while another two locations Afam/library point 2 and Between Okija & Olu-Obasanjo Point 1) paired up to record 6 samples each.

Peridium pusillium: *Peridium pusillium* distribution across the ten locations along Ntawogba creek varies between 1 (minimum) at two locations between Okija & Olu- Obasanjo point 2 and Behind Mile 3 Timber Market and 8 (maximum) at two locations also (Olu- Obasanjo points 1 and 2). It recorded a range value of 7. In the ten locations, a total of 35 samples were recorded with mean of 3.5 sample per plot. As can be seen also, three locations (Railway/Okija, Afam /Library Point 1 and Okija Point 1) jointly recorded 3 samples each while two locations (Afam/Library Point 2 and Okija Point 2) paired up to produce 2 samples each. However, only one location (Between Okija & Olu-Obasanjo Point 1) recorded 4 samples. The variation in the distribution of this phytoplankton could be attributed to the different human activities carried out along Ntawogba creek.
Peridinium cinatum: The result in Table 4.11 revealed that *Peridinium cinatum* was evenly distributed in the study area with a minimum of 2 samples and a maximum of 12 samples. The minimum and maximum values were recorded in three stations with two stations (Olu-Obasanjo Point 1 & 2) recording the minimum value while Railway/Okija recorded the maximum value. As can be seen from the result, a total of 76 samples were recorded with a mean of 7.6 samples per plot. Furthermore, the result revealed that two locations that are wide apart (Afam/Library point 1 and Okija Point 2) jointly recorded 10 samples each while another two locations that are equally distant apart (Afam/Library Point 2 and Between Okija & Olu-Obasanjo Point 2) paired up to produce 8 samples each.

Hypotheses Testing
This section deals with the analysis of data of the variables (physico-chemical parameters, heavy metals, Benthos, phytoplankton and zooplankton) across the ten locations in Ntawogba creek of Port Harcourt metropolis. This analysis involves testing of hypotheses using one way analysis of variance (ANOVA) and one sample t-test at 0.05 level of significance. The decision rule for accepting or rejecting the null alternate hypothesis is based on the p-value (sig) produced by the Statistical Package for Social Sciences (SPSS) software as against the chosen alpha level of significance of 0.05 on a two-tail test. If the p-value obtained by the SPSS software is greater than the chosen alpha value of 0.05, the null hypothesis was retained while the alternate hypothesis was rejected. One the other hand, if the P-value obtained by the SPSS is lower than the chosen alpha level of 0.05, the alternate hypothesis was retained while the null hypothesis was rejected. The results of the seven hypotheses are displaced on table.
Physico-chemical Parameters Hypotheses Testing
The twelve (12) physico-chemical parameters (pH, temperature, electrical conductivity, salinity, moisture contest, nitrate, sulphate, phosphate, calcium, magnesium, potassium, and sodium) hypothesis across the ten location of Ntawogba creeks are analysed using the one way ANOVA.
Null Hypothesis One (Ho_1): There is no significant variation in the distribution of physico-chemical parameters in Ntawogba creek along the ten location points.
Alternate Hypothesis One (Ha_1): There is significant variation in the distribution of physico-chemical parameters in Ntawogba creek along the ten location points.
The ANOVA result displayed in Table 13 shows a between group of 1118.250 with 9 degrees of freedom and a mean square, value of 124.250; and a within group sum of square of 172293.530 with 110 degrees of freedom and a mean square value of 1566.305. Their total sum of square was 173411.780 with 119 degrees of freedom. Furthermore, the result revealed the F-cal value of 0.079 with a P-value of 1.000. Based on the decision rule of the study, since the P-value produced by the SPSS software is 1.000 and is greater than the chosen alpha level of 0.05 of significance, the null hypothesis was retained while the alternate hypothesis was rejected. Thus, we conclude that there is no significant variation in the mean distribution of physico-chemical parameters in Ntawogba creek among the ten locations ($F9, 110 = 0.79$ $P > 0.05$). This result implies that the mean distribution of the twelve physico-chemical parameters do not vary considerably across the ten sampling points along the Ntawogba creek.
Null Hypothesis Two (Ho_2): There is no significant variation in the mean value distribution of heavy metals parameters in Ntawogba creek along the ten location points.
Alternate Hypothesis Two (Ha_2) There is significant variation in the mean value distribution of heavy metals in Ntawogba creek along the ten location points.
The data below was used to compute the one-way Anova.

Table 12. Physico-chemical parameters

	PARAMETERS	METER	Oluobasanjo Point 1 GPS N4^0,48' 7.404" E6^0,59' 46.313"	Oluobasanjo Point 2 GPS N4^0,48' 11.559" E006^0,59' 45.258"	Railway/ Okija GPS N4^0,47' 49.731" E006^0,59 ' 55.668	Afam/Library Point 1 GPS N4^0,47' 48.006" E007^0,00' 58.212"	Afam/Library Point 2 GPS N4^0,47' 47.139" E007^0,05' 20.312"	Okija Point 1 GPS N4^0,47' 50.867" E006^0,59 ' 54.126"	Okija point 2 GPS N4^0,47' 50.292" E006^0,59 ' 55.061"	B/w Okija & Oluobasanjo Point 1 GPS N4^0,48' 6.228" E006^0,59' 46.223"	B/w Okija & Oluobasanjo Point 2 GPS N4^0,47' 59.685" E006^0,59' 49.362"	Behind Mile 3 Timber GPS N4^0,48' 34.099" E006^0,59 ' 35.531"	Total	%
1.	Temperature ^{0}c	Meter	26.5	24.2	27.2	26.1	24.3	28.2	27.1	26.6	25.3	24.3		
2.	PH	PH Meter	5.85	4.48	5.12	5.10	5.08	6.10	6.10	5.82	4.46	5.02		
3.	Electrical Conductivity,	Conductivity Meter	56.4	56.2	67.2	67.2	66.2	68.1	67.2	56.4	55.3	54.4		
4.	Salinity mg/kg	Meter	16.1	15.0	19.2	19.0	18.99	19.2	18.3	16.0	15.9	16.2		
5.	Moisture Content	Gravimetric Method	3.92	3.90	4.33	3.32	4.33	4.32	4.33	3.93	3.92	3.91		
6.	Nitrate, mg/kg	APHA 4500-N0^3	0.423	0.425	0.319	0.320	0.318	0.320	0.322	0.424	0.425	0.422		
7.	Sulphate, mg/kg	APHA 4500-S0^4	9.104	9.100	7.217	7.219	6.299	8.218	7.220	9.102	9.104	9.100		
8.	Phosphate, mg/kg	APHA 4500-P0^4	2.552	2.532	2.813	2.815	2.810	4.816	4.915	2.551	2.554	2.550		
9.	Ca, mg/kg		105.62	106.60	124.89	124.87	124.88	126.89	125.85	105.62	106.64	105.60		
10.	Mg,mg/kg		92.57	92.51	107.51	106.52	107.51	107.52	105.50	92.55	92.53	92.51		
11.	K, mg/kg	APHA 3111b	30.20	29.21	39.00	40.01	38.99	40.02	41.04	31.19	30.22	30.20		
12.	Na, Mg/Kg		50.60	50.44	63.90	63.90	62.91	66.80	65.79	52.62	50.46	50.59		

The result of the analysis is presented in Table 13

Table 13. A summary of ANOVA analysis on the mean distribution of physico-chemical parameter at the ten locations in Ntawogba creek. **Source:** Researchers' SPSS Computation (2022)

Sources of Variation	Sum of Square	Degree of Freedom	Mean Square	F-cal	P-Value	Alpha Level	Result	Decision
Between groups	1118.250	9	124.250	0.079	1.000	0.05	Not significant	Retained
Within Groups	172293.530	110	1566.305					
Total	173411.789	119						

Table 14. Heavy Metals

Parameters	Metod	Oluobasanjo Point 1 GPS N4^0,48' 7.404" E6^0,59' 46.313"	Oluobasanjo Point 2 GPS N4^0,48' 11.559" E006^0,59' 45.258"	Railway/ Okija GPS N4^0,47' 49.731" E006^0,59 ' 55.668	Afam/Library Point 1 GPS N4^0,47' 48.006" E007^0,00' 58.212"	Afam/Library Point 2 GPS N4^0,47' 47.139" E007^0,05' 20.312"	Okija Point 1 GPS N4^0,47' 50.867" E006^0,59 ' 54.126"	Okija point 2 GPS N4^0,47' 50.292" E006^0,59 ' 55.061"	B/w Okija & Oluobasanjo Point 1 GPS N4^0,48' 6.228" E006^0,59' 46.223"	B/w Okija & Oluobasanjo Point 2 GPS N4^0,47' 59.685" E006^0,59' 49.362"	Behind Mile 3 Timber GPS N4^0,48' 34.099" E006^0,59 ' 35.531"	Total	%
1 Mn, mg/kg		1.07	1.05	2.54	2.81	2.79	2.84	2.75	1.04	1.02	1.01		
2 Cr, mg/kg		0.11	0.10	0.19	0.22	0.20	0.20	0.23	0.13	0.09	0.10		
3 Zn,mg/kg		0.35	0.33	0.46	0.45	0.44	0.48	0.46	0.36	0.32	0.33		
4 Cd, mg/kg	APHA 3111b	0.18	0.19	0.21	0.24	0.22	0.24	0.22	0.19	0.20	0.17		
5 Fe, mg/kg		231.43	231.44	302.28	304.25	303.20	302.29	301.30	230.46	231.4	231.4		
6 Pb, mg/kg		0.33	0.31	0.36	0.33	0.34	0.36	0.34	0.35	0.33	0.32		

The result of the analysis is presented in Table 15.

Table 15. A summary of ANOVA analysis on the mean values distribution of heavy metals at the ten locations of Ntawogba creek. **Source:** Researchers' SPSS Computation (2022)

Sources of Variation	Sum of Square	Degree of Freedom	Mean Square	F-cal	P-Value	Alpha Level	Result	Decision
Between groups	2247.387	9	249.710					
Within Groups	601718.205	50	12034.364					
Total	603965.592	59		.021	1.000	0.05	Not significant	Retained

The result displayed in Table 15 show that in the ten locations where water sampled were taken, the between group had 2247.387 sum of squares with 9 degrees of freedom and a mean sum of square of 249.710; and within group sum of squares of 601718.205 and 50 degrees a freedom and a mean square value of 12034.364. Their total sum of squares was 603965.592 with 59 degrees of freedom. The F-cal value was .021 with a P-value of 1.000 which is greater than the chosen alpha value of 0.05 level of significance. Based on the decision rule, since the P-value obtained from the SPSS software is greater than the chosen alpha level of 0.05, the null hypothesis was retained while the alternate hypothesis was rejected. Therefore, the result revealed that there was no significant variation in the concentration level distribution of heavy metal in the ten locations along Ntawogba Creek ($F9, 50 = 0.21$, $P > 0.05$). The value of the heavy metals (Manganese, zinc, iron, lead, chromium and cadmium) do not vary considerably along the ten sampling points in Ntawogba creek. The alternate hypothesis was rejected at 0.05 alpha level of significance.

Null Hypothesis Three (Ho_3): There is no significant difference in the Concentration level of oil and grease in Ntawogba creek.

Alternate Hypothesis Three (Ha_3) There is significant difference in the Concentration level of oil and grease in Ntawogba creek.

Table 16. Oil and grease

	Parameters	Meter	Oluobasanjo Point 1 GPS $N4^0$,48' 7.404" $E6^0$,59' 46.313"	Oluobasanjo Point 2 GPS $N4^0$,48' 11.559" $E006^0$,59' 45.258"	Railway/ Okija GPS $N4^0$,47' 49.731" $E006^0$,59' 55.668	Afam/Library Point 1 GPS $N4^0$,47' 48.006" $E007^0$,00' 58.212"	Afam/Library Point 2 GPS $N4^0$,47' 47.139" $E007^0$,05' 20.312"	Okija Point 1 GPS $N4^0$,47' 50.867" $E006^0$,59' 54.126"	Okija point 2 GPS $N4^0$,47' 50.292" $E006^0$,59' 55.061"	B/w Okija & Oluobasanjo Point 1 GPS $N4^0$,48' 6.228" $E006^0$,59' 46.223"	B/w Okija & Oluobasanjo Point 2 GPS $N4^0$,47' 59.685" $E006^0$,59' 49.362"	Behind Mile 3 Timber GPS $N4^0$,48' 34.099" $E006^0$,59' 35.531"	Total %
21.	Oil & Grease	APR 45	0.45	0.43	0.55	0.52	0.51	0.54	0.53	0.51	0.52	0.50	

The result of the analysis is presented in Table 17.

Table 17. A summary of independent t-test analysis of difference in the concentration level of oil and grease in Ntawogba creek. **Source:** Researchers' SPSS Computation (2022)

Sources of Variation	N	Mean	SD	D.F.	T-Value	P-value	Alpha Level	Result	Decision
Oil and increase	10	.50600	.038064	9	42.037	.000	0.05	Significant	Rejected

The one sample t-test result displayed in Table 4.17 shows a sample size of 10, a mean value of 0.50600, a standard deviation value of 0.38064 and 9 degree of freedom. Furthermore, the result revealed a t-value of 42.037 with a P-value of 0.000 which is lower than the chosen alpha value of 0.05. Based on the above result obtained, from the SPSS software analysis, since the P-value produced by the SPSS is lower than the chosen alpha level ($P\ 0.000 <$ alpha level 0.05), the alternate hypothesis of significant difference in the concentration level of oil and grease in Ntawogba creek is upheld ($F9 = 42.037$, $P < 0.05$) while the null hypothesis, was rejected.

The result is significant at 0.05 alpha level. The result of the significant difference in the concentration level of oil and grease implies that the concentration level varies considerably along the ten sampling points investigated. This might be true because along the Diobu area of the Ntawogba creek, motor mechanic workshops and other artesian drops qualities of grease and other petroleum products at different points and drains into the creek and seeps into the soil.

Null Hypothesis Four (Ho_4): There is no significant variation in the distribution of Benthos in the ten stations of Ntawogba creek.

Alternate Hypothesis Four (Ha_4) There is significant variation in the distribution of Benthos in the ten stations of Ntawogba creek.

Table 18. Benthos

Taxonomic Group	Oluobasanjo Point 1	Oluobasanjo Point 2	Railway/ Okija	Afam/library point 1	Afam/library point 2	Okija point 1	Okija point 2	B/w Okija & Oluobasanjo point 1	B/w Okija & Oluobasanjo point 2	Behind mile 3 timber	Total %
POLYCHAETA	.		.	.	.						
Capitellidae											
1. Capitellacapitata	3	2	4	3	1	2	2	3	3	2	
2. Notomastus latreiceus	3	1	6	4	5	2	5	4	2	3	
Nephthyididae											
3. Nephthys hombergi	4	3	1	1	1	0	1	0	1	1	
Nereidae											
4. Nereis diversicolor	2	1	5	3	1	4	3	2	3	3	
5. Nereis pelagic	3	2	5	4	.2	3	1	1	3	2	
6. Nereis virens	2	1	3	2	2	3	2	3	1	2	
Spionidae											
7. Polydora capensis	2	2	4	2	3	1	3	2	2	1	
Eunicidae											
8. Epidiopatra gilchristi	2	1	3	3	2	3	3	2	2	1	
Total											
Crustacea											
Callianasspidae											
9 Pogebia deltaura	5	3	12	9	7	10	8	8	7	5	

The result of the analysis is presented in Table 19.

Table 19. A summary of anova analysis on the benthos distribution in the ten location stations of Ntawogba creek. **Source:** Researchers' SPSS Computation (2022)

Sources of Variation	Sum of Square	Degree of Freedom	Mean Square	F-cal	P-Value	Alpha Level	Result	Decision
Between Groups	51.611	9	5.735					
Within Groups	351.111	80	4.389					
Total	402.722	89		1.307	0.247	0.05	Not significant	Retained

Table 19 displayed the ANOVA analysis of Benthos distribution along the ten sampling points in Ntawogba creek. The result revealed a between groups sum of square of 51.611 with 9 degrees of freedom and a mean square value of 5.735 was 351.111 with 80 degrees of freedom and 9 mean square value of 4.389sum of squares was 402.722 with 89 degrees of freedom. The result further showed an F-value of 1.307 with a P-value of 0.247 which is higher than the chosen alpha level of 0.05. Based on the decision rule, since the P-value of 0.247 produced by the SPSS software is greater than the chosen alpha confidence level 0.05, the null hypothesis was retained while the alternate hypothesis was rejected. The result is that there is no significant variation in the distribution of benthos across the ten sampling locations (F 9.80 = 1.307, P> 0.05) at Ntawogba creek. The result is not significant.

Null Hypothesis Five (Ho_5): There is no significant variation in the distribution of phytoplankton in the ten stations along Ntawogba creek.

Alternate Hypothesis Five (Ha_5) There is significant variation in the distribution of phytoplankton in the ten stations along Ntawogba creek.

The result of the analysis is presented in Table 21.

As can be seen from the ANOVA result above, phytoplankton distribution across the ten sampling points along Ntawogba creek had a between group sum of squares of 171.700, 9 degrees of freedom with a mean square value of 19.078; while their within group sum of squares was 4218.308 with 120 degrees of freedom and a mean square value of 35.653. Their total sum of squares was 4,450. 008 with 129 degrees of freedom. In addition, the result displayed an F-value of 0.535 with a P-value of 0.847 which is higher than the chosen alpha level of the study. Based on this premise that the P-value of 0.847 that is higher than the chosen alpha level value of 0.05, the null hypothesis was retained that states that there is no significant variation in the distribution of phytoplankton across the ten sampled stations along Ntawogba creeks F(9.120) = 0.535, P>0.05). The alternate hypothesis was rejected at 0.05 alpha level of significance. The result is also not significant at 0.05 alpha level.

Null Hypothesis Six (Ho_6): There is no significant variation in the distribution of Zooplankton in the ten stations along Ntawogba creek.
Alternate Hypothesis Six (Ha_6) There is significant variation in the distribution of Zooplankton in the ten stations along Ntawogba creek.

Table 20. Phytoplankton

	Taxonomic Group	Oluobasanjo Point 1	Oluobasanjo Point 2	Railway/ Okija	Afam/Library Point 1	Afam/Library Point 2	Okija Point 1	Okija Point 2	B/w Okija & Oluobasanjo Point 1	B/w Okija & Oluobasanjo Point 2	Behind Mile 3 Timber	Total %
	Baccilariophyc EAE	.		.	.	.						
1	Melosira varians	12	10	13	11	9	12	11	8	8	6	
2.	Melosira distans	18	15	23	21	23	20	20	18	16	13	
3	Cosinodiscus lacustris	5	3	11	11	9	11	10	9	10	7	
4	Fragilaria vivenscens	10	7	20	20	20	17	17	15	13	11	
5	Synedra ulna	6	5	13	11	10	8	9	8	10	8	
6	Cyclotella operculata	22	19	8	8	6	7	6	5	7	6	
	TOTAL											
	Chlorophyceae											
7	Tetraodon sp.	1	1	0	0	0	0	0	0	0	0	
8	Netrium digitus	6	4	2	2	1	2	1	2	2	1	
	TOTAL											
	Cyanophyceae											
9	Anabaenopsos anoldic	2	2	8	7	5	7	5	4	4	2	
10	Rivularia planctonica	6	6	1	1	1	1	0	0	1	1	
	TOTAL											
	Phyrophyceae											
11	Ceratium hirudinella	3	2	7	6	7	5	7	6	5	4	
12	Peridium pusillium	8	8	3	3	2	3	2	4	1	1	
13	Peridinium cinatum	2	2	12	10	8	11	10	7	8	6	
	TOTAL											
	Total No: Individuals											
	Total number: Species.											

Table 21. A summary of anova analysis on the phytoplankton distribution in the ten location stations of Ntawogba creek. **Source:** Researchers' SPSS Computation (2022)

Sources of Variation	Sum of Square	Degree of Freedom	Mean Square	F-cal	P-Value	Alpha Level	Result	Decision
Between groups	171.700	9	19.078					
Within Groups	4218.308	120	35.653	0.535	0.847	0.05	Not significant	Retained
TOTAL	4450.008	129						

Table 22 Zooplankton

	Taxonomic Group	Oluobasanjo Point 1	Oluobasanjo Point 2	Railway/ Okija	Afam/Library Point 1	Afam/Library Point 2	Okija Point 1	Okija Point 2	B/w Okija & Oluobasanjo Point 1	B/w Okija & Oluobasanjo Point 2	Behind Mile 3 Timber	Total %
	COPEPODA	.		.	.	.						
	Temoridae											
1.	Temora Longicornis	23	20	17	14	13	15	14	10	13	8	
2.	Eurytemora hirundoides	14	10	18	12	11	16	11	15	14	9	
	Pontellidae											
3.	Anomalocera Patersoni	6	3	12	9	9	9	10	8	8	7	
	Euchaetidae											
4.	Parcuchaeta norvegica	5	4	10	10	7	9	7	8	8	6	
	Calanoidae											
5.	Calamus finmarchicus	7	5	5	3	5	4	4	3	3	2	
	Cyclopidae											

6.	Paracyclops affinis	8	8	10	10	8	8	6	5	4	3
	Total =										
	PROTOZOA										
7.	Tintinnopsis Sinensis	2	2	0	0	0	0	0	0	0	0
8	Tintinnopsis Wanji	6	4	2	2	1	2	2	2	2	1
	Total =										
	Total No: Individuals										

The result of the analysis is presented in Table 23.

Table 23. A summary of ANOVA analysis on the zooplankton distribution in the ten location stations of Ntawogba creek. **Source:** Researchers' SPSS Computation (2022)

Sources of Variation	Sum of Square	Degree of Freedom	Mean Square	F-cal	P-Value	Alpha Level	Result	Decision
Between groups	131.363	9	14.596					
Within Groups	2002.125	70	28.602	0.510	0.862	0.05	Not significant	Retained
Total	2133.488	79						

The ANOVA result displayed in Table 23 shows the distribution of zooplankton microorganism in the ten stations sampled along Ntawogba creek in Port Harcourt metropolis to have a between group sum of squares of 131.363, 9 degrees of freedom with a mean square value of 14.596; the within group sum of squares was 2,002.125 with 70 degrees of freedom and a mean square of 28.603, while 70 degrees of freedom and a mean square value of 28.602. Their total sum of squares was 2,133. 488 with 79 degrees of freedom. The result further revealed the F-calculated value of .510 with a P-value of 0.862. Since the P-value produced by the SPSS software is greater than the chosen alpha level of significance of 0.05. The null hypothesis was retained while the alternate hypothesis was rejected. Conclusively, the result implied that the nine Zooplankton identified in the study area does not vary in their distribution in ten stations along Ntawogba creeks in Port Harcourt metropolis $F(9,70)= 1510$, $P> 0.05$). The result is not statistically significant at 0.05 alpha level of significance.

Discussion of Findings

The discussion of findings is based on the parameters investigated which are;

- Physico-chemical parameters of the water samples
- Oil and grease concentration level
- Heavy metals concentration level
- Hydrobiological parameters
- Benthos identification and distribution
- Phytoplankton's identification and distribution
- Zooplanktons identification and distribution

Physico-chemical Parameters of Ntawogba River

The study examined twelve physico-chemical parameters (pH, temperature, electrical conductivity, salinity, moisture, nitrate, sulphate, phosphate, calcium, potassium, sodium and magnesium. Across the ten locations of Ntawogba river in Port Harcourt metropolis. The mean values of these parameters in the ten locations are as follows pH = 5.313, temperature = 25.93^{0}C; electrical conducitivity = 61.46µs/cm; salinity = 17.389ppt; moisture = 4.021%; NO_3 = 0.372mg/kg; SO_4 = 8.168mg/kg; PO_4 = 3.191mg/kg; Ca = 115.75mg/Kg; Mg = 99.72mg/kg; K= 35.01mg/kg and Na = 57.80mg/kg; mg/kg. These values are within the World Health Organization (WHO, 2017) permissible limits as shown in table 4. The physico-chemical parameter (temperature 27^{0}C; sulphate 4.0mg/l; phosphate 3.0mg/l, nitrate 2.0mg/l and electrical conductivity 520µs/cm) were also below the (WHO, 2017) permissible limits in a study of land use and surface water quality in an emerging urban city, Oshogbo, the capital of Osun State. With respect to electrical conductivity (EC), the high magnitude of EC within an urban area, especially in commercial and residential land use types is closely tied to the secretion of acidic substances such as sulphate, phosphate and nitrate, contained in solid wastes entering the water bodies as well effluent discharged from industries into water ways. The increasing levels of conductivity and cations are the products of decomposition and mineralization of organic materials. Electrical conductivity level increases with the existence of inorganic suspended solids in runoff as well as the presence of chloride and nitrate from sewage systems by extension reduces the purity of the surface water.

In a similar vein, the findings of this study are also in tandem with the findings of Osinbajo, et. al. (2011) that recorded a temperature of 27^0C a mean pH value of 7.5; a mean sulphate of 6.0mg/l; a mean nitrate value of 5.0mg/l which were below (WHO, 2017) permissible level in a study of the impact of industries on surface water quality of River Ona and River Alaro in Oluyole industrial estate, in Ibadan. The authors argued that industrial discharge had negative impact on the surface water qualities of both rivers. This would also be true for Ntawogba River which runs at the heart of Port Harcourt metropolis especially in the Diobu area around Ikoku and Gambia Street where there are lots of mechanic workshops.

Benthos Parameters Distribution

The study identified nine species of benthos (*Capitellacapitata, Notomastus latrieiceus, Nephthys hombergi, Nereis virens, Polydora capensis, Epidiopatra gilchristi, Pogebia deltaura, Nereis diversicolor* and *Nereis pelagic*) with different numbers distributed along the Ntawogba river channel. However, it differs with that of (Maham et al., 2012) that identified only three species of benthos (Ephermeroptera, Plecoptera and Trichopetra) (EPT) in Boardman River, Michigan in the United States of America (USA). The two studies also differ in statistical tool analysis as the present study analyzed the data with one-way analysis of variance (ANOVA) while that of Mahan, et. al. (2021) employed PERMANOVA, which is a multivariate analog of the more commonly used ANOVA. Another area of difference observed is while (Maham *et al*., 2012) investigated composition of benthos in upstream and downstream area, and as well as the total density of all macro vertebrates, overall data richness and functional feeding groups, the present study did not embark on such investigations. These differences observed in the study could be as a result of the objectives of the two studies.

The result revealed that nine species of benthos were identified and that there is no significant variation in the distribution of benthos in the ten locations of Ntawogba creek. On the contrary, the study involved mapping variations on algae density using remote sensing technique in Buffalo National River in Arkansas in USA. Their study also employed ariel photographs alongside multi spectral satellite images. The result revealed spectral distinctions among algae cover values ranging from 6 to 100% and concluded that blooms of benthic algae have become increasingly common in many parts of Buffalo River.

Phytoplankton Identification and Distribution

The findings of this study revealed that thirteen species of phytoplankton were identified across the ten locations of Ntawogba creek and that there is no significant variation in their distribution in the study area. These findings differ with others. The study involved the characterization of phytoplankton biomass, primary production and community structure. The results of index analysis revealed that the dominant species shifted from freshwater diatoms to saline water diatoms. The differences observed in the results of the two studies could be as a result of the objectives of the study.

The findings of this study revealed that a total of 97 species as gamma diversity; a connectivity difference between systems highlighted difference in phytoplankton abundance and biomass and a significant difference in phytoplankton species richness between the systems during the low water in a study of phytoplankton abundance and biomass directly within and between various wetland inhabitants in South America. The conclusion drawn from that study was that local factors may be responsible for changes on phytoplankton community.

The abundance of phytoplankton was highest in zone I out of the three zones and that phytoplankton biomass was influenced by change movement in the sampling stretches in River Gangu in India. The result also revealed that a significant effect was found at three locations along the river channel and that a “barge movement” influence phytoplankton abundance and biomass. The “barge movement” is an aquatic food chain linkage in Bhagirathi-Ituoghlya river.

Zooplankton Identification and Distribution

The results of the study revealed that a total of eight different species of zooplankton across the ten locations of Ntawogba creek in Port Harcourt metropolis in five families in two groups. The result also revealed that there is no significant variation in the distribution of zooplankton across the ten stations.

These findings revealed that species composition of zooplankton communities determined by metabarcoding was consistent with the results based on the traditional morphological approach in a study of zooplankton community profiling in a freshwater ecosystem in Tai basin in China. This difference between the two studies in also as a result of the objectives and methodology adopted in the two studies. The findings of this study also revealed spatial distribution of common species while there was no significant distribution in the present study. Metabarcoding is an advanced technology used in determining hydrobiology samples in an aquatic environment which is yet to be deployed in this part of the world.

Summary

This study investigated bed sediment characteristics in ten locations along Ntawogba river channel in Port Harcourt metropolis. The investigation involved seven environmental variables (physico-chemical parameters of the water) in the river channel, concentration level of heavy metals presence, the distribution of benthos, phytoplanktons, zooplanktons and soil particulate size (PSD) and identification of oil and grease in the river system. The study consisted of seven objectives and seven hypotheses based on the seven environmental variables.

The results of the study revealed that;

- The soil texture along the river channel consists mainly of sandy-clayey
- The majority mean values of the physico-chemical parameters were within the World Health Organisation (WHO) and Nigeria Industrial Standard (NIS) prescribed limit.
- The mean values of the five heavy metals (manganese, chromium, zinc, cadmium, iron and lead) (1.892mgkg, 0.157mg/kg, 0.398mg/kg; 0.206mg/kg; 266.945mgkg and 0.377mg/kg respectively, were below the World Health Organisation permissible limit and Nigeria Industrial Standard acceptable limit
- The mean value of the nine benthos samples identified in the river channel were *Capitellacapitata* (5.5) *Notomastus latrieiceus* (3.5); *Nephthys hombergi* (1.3); *Nereis virens* (1.9) *Polydora capensis* (202); *Epidiopatra gilchristi* (2.2); *Pogebia deltaura* (7.4), *Nereis diversicolor* (2.7); and *Nereis pelagic* (2.6).
- The mean values of the eight samples types of zooplankton identified in Ntawogba creek were *Temora longicornis* (28.1) *Eurytemora hirundoides* (13-0), *Anomalocera patersoni* (8:1); *Parcuchaeta norvegica* (7.0); *Tintinnopsis sinensis* (0.4); and *Tintinnopsis wanji* (2.4).
- The mean values of the thirteen phytoplankton swamp identified along Ntawogba river channel were: *Melosira varians* (10.0), *Melosira distans* (18.7); *Cosinodiscus lacustris* (18.6) *Fragilaria vivenscens* (15.0), *Synedra ulna* (8.8); *Cyclotella operculata* (9.4), *Tetraodon sp* (0.2); *Netrium digitus* (2.3); *Anabaenopsos anoldic* (4.6); *Rivularia planctonica* (1.8); *Ceratium hirudinella* (5.2); *Peridium pusillium* (3.5); and *Peridinium cinatum* (7.6).
- There is no significant variation in the mean distribution of physico-chemical parameters in Ntawogba creek along the ten locations (F 9, 110= 0.79, $P>0.05$).
- There is no significant variation in the mean distribution of heavy metals parameters in Ntawogba creek along the ten locations (F 9, 50= .021, $P > 0.05$).
- There is significant difference in the concentration level of oil and grease in Ntawogba creek (DF= T = 42.037, $P<0.05$).
- There is no significant variation in the distribution of benthos in the ten locations of Ntawogba creek (F 9, 80 = 1.307, $P>0.05$).
- There is no significant variation in the distribution of phytoplanktons in the ten locations of Ntawogba creek ($F(9,120) = 0.535$, P. > 0.05).
- There is no significant variation in the distribution of zooplankton in the ten locations of Ntawogba creek ($F(9,70)= .0510$, $P<0.05$).

Conclusion

This study examined bed sediment characteristics of a river channel system and such characteristics in any ecosystem especially aquatic ecosystem are many and varied. It could be argued that anthropogenic activities along such river channel could alter the marine life especially microbial organisms such as benthos, phytoplankton and zooplankton. The study identified nine benthos organisms (*Capitellacapitata, Notomastus latrieiceus, Nephthys hombergi, Nereis virens, Polydora capensis, Pogebia deltaura, Epidiopatra gilchristi, Nereis diversicolor* and *Nereis pelagic*), eight zooplankton (*Temora longicornis, Eurytemora hirundoides, Anomalocera patersoni, Parcuchaeta norvegica; Calamus finmarchicus, Paracyclops affins, Tintinnopsis sinensis,* and *Tintinnopsis wanji*; thirteen phytoplankton organisms (*Melosira varians, Melosira distans, Cosinodiscus lacustris, Fragilaria vivenscens, Synedra ulna, Cyclotella operculata, Tetraodon sp, Netrium digitus, Anabaenopsos anoldic, Rivularia planctonica, Ceratium hirudinella, Peridium pusillium* and *Peridinium cinatum*); six heavy metal types (manganese (Mn), Chromium (Cr), Zinc (Zn), cadinium (Cd), iron (Fe), and lead Pb); three soil types (sand, silt and clay); and twelve physico-chemical parameters (pH, temperature, electrical conductivity, salinity, moisture, nitrate, sulphate, phosphate, calcium, magnesium, potassium, and sodium); and oil and grease along the ten locations of Ntawogba river channel in Port Harcourt metropolis.

The benthic invertebrate species as well as the phytoplanktons and zooplanktons function in different ways that are important to maintaining ecosystem functions such as energy flow in the food webs and is of very much concern to environmental managers that manage the environment, especially in an urban centre where this study was carried out. Many benthic and plankton species convert live plant and dead organic materials into prey items for larger consumers in complex food webs. In the process of maintaining energy flow, these benthic species simultaneously provide essential ecosystem services, such as nutrient cycling and aeration of sediments. Thus, different species comprise distinct functional groups that provide ecological integrity. In some cases, these functional groups may be represented by only a few species, so that any loss of species diversity could be detrimental to continued ecosystem functioning. Thus, it is increasingly important to protect the biodiversity of benthic and plankton communities to lower the risk of unexpected and unwanted consequences.

Sediments can be introduced into a river system either by natural and anthropogenic processes, but anthropogenic processes are very much common in urban areas where rivers and streams are located and residents of the urban centres find it very convenient to dispose of their wastes into the streams or rivers. In this respect, should be noted that streams and rivers have differing capacity to cope with suspended sediment depending upon (among other factors) their fauna, their gradient, and the nature of sediment. In many instances, especially at the lower end of any proposed standards, aesthetic considerations could well over-ride ecological ones. If there is sediment deposition, reduction in river productivity is likely to be greater than if the sediment remains in suspension. From all indications, it is likely that Ntawogba River is impacted by industrial, commercial and domestic activities and conscious efforts must be made to ensure that the river channel must be properly monitored to forestall further pollution. Thus, this study has shed in more light of bed sediment characteristics for proper environmental management in an urban centre.

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Review Paper

Air Pollution and the Food System: A Review and Recommendations for Sustainable Solutions

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Abstract Air pollution, a global concern, profoundly impacts the environment, human health, and ecosystems. Focusing on pollutants entering the food supply chain, their distinctive implications, and recommending sustainable mitigation techniques, this article examines the intricate interplay between air pollution and the food system. By exploring the less-discussed link between air pollution and food safety, evolving pollutant dispersion patterns in a changing climate, and emerging technological and policy interventions for food system resilience, the essay presents a fresh perspective. The primary objective is to elucidate the complex relationships between air pollution and the food chain, providing practical suggestions for stakeholders. We aim to assess the suitability of existing mitigation strategies in alleviating air pollution's adverse effects on food. Employing a mixed-method approach involving literature reviews, and case studies, we reviewed air pollution's diverse impacts on the food system. Pollutants directly affect livestock and crops, compromising food safety, exacerbated by climate change-altering pollutant distribution. Effective mitigation techniques, such as stringent emissions regulations and sustainable farming methods, yielded positive outcomes. Air pollution poses a serious threat to the food system's integrity, impacting sustainability, quality, and safety. Collaborative efforts involving industry, individuals, and governments are essential to minimize these negative effects and safeguard the food supply. Recommendations include enacting strict emission regulations, promoting sustainable farming, and fostering consumer education for positive change, emphasizing the need for continuous research to adapt and improve techniques in response to changing environmental conditions.

Keywords: *Agricultural Practices, Biochar, Climate Resilience, Emission Control, Mitigation, Sustainability.*

Introduction

Rapid industrialization and urbanization have resulted in widespread air pollution, which has become a major worldwide concern with far-reaching effects on environmental sustainability and human health. The unintentional consequence of rising industrial activity and vehicle emissions has become a major worry, looming large over many parts of daily life as societies strive for greater economic development. Its complex relationship with the food chain is one of the less-studied aspects of this problem. This research undertakes a thorough examination of the relationship between air pollution and the food chain, exploring the intricacies of pollutant infiltration, its innovative consequences, and the development of sustainable suggestions.

Many different types of pollutants have been released into the atmosphere because of the development of industrial operations and the increase in vehicle emissions. These contaminants, which can affect the food supply chain from soil to crops and cattle, can travel through ecosystems and include particulate matter, nitrogen oxides, and volatile organic compounds. To protect the integrity of the food system, solutions must take this dynamic interaction into account.

There is a clear study gap on the precise effects of air pollution on the food system, even while the body of existing literature (Kelly & Fussell, 2015; Manisalidis *et al*., 2020; Kewani *et al*., 2020; Tainio *et al*., 2021; EEA, 2023) recognizes the general effects of air pollution on health and the environment. There aren't many systematic studies that look at how pollution affects food quality,

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safety, and sustainability in general. By providing a thoughtful analysis of the complex relationships between air pollution and the complexities of the food system, this research aims to close this gap.

There are several issues when air pollution and the food chain come together. Pollutants can infect livestock and crops (Meyers et al., 2017), compromising food safety and nutritional value. This scenario is further complicated by shifting climatic trends, which have unknown effects on pollution dispersal. It is imperative to address these problems in order to guarantee a robust and sustainable global food supply. The nexus between air quality and food security is of paramount importance for sustainable development in Africa. The continent faces significant challenges in both domains, with air pollution and food insecurity posing serious threats to human health (Figure 1), agricultural productivity, and environmental sustainability. Air pollution, stemming from industrial emissions, vehicular exhaust, biomass burning, and natural sources, significantly impacts respiratory and cardiovascular health, especially in urban areas (Springmann et al., 2018; WHO, 2016; Smith et al., 2016; Lelieveld *et al*., 2015; Kampa and Castanas, 2008). Simultaneously, food security remains a pressing concern, with millions of Africans suffering from hunger, malnutrition, and food insecurity due to climate change, environmental degradation, poverty, and socio-economic inequalities (FAO, 2020; IFAD, 2019; WHO 2018).

Interactions between air quality and food security are complex and multifaceted. Air pollution can directly affect crop yields, soil fertility, and plant health through exposure to pollutants such as ozone, particulate matter, and nitrogen oxides, resulting in reduced agricultural productivity (Boman et al., 2005; Ainsworth et al., 2012; Pleijel *et al.*, 2018). Additionally, air pollutants can contaminate soil and water sources, further threatening food safety and quality (EPA, 2020). The health impacts of air pollution on agricultural workers also play a crucial role, as respiratory and cardiovascular diseases impair labor efficiency and productivity (Frumkin et al., 2002). Climate change exacerbates these issues by influencing weather patterns, atmospheric circulation, and pollutant transport mechanisms, leading to shifts in air quality and food security outcomes (Jacobson, 2008). Conversely, air pollution contributes to climate change by releasing greenhouse gases such as methane and black carbon, which exacerbate global warming (Bond et al., 2013). Addressing the intertwined challenges of air quality and food security requires integrated policy approaches, investments in research and innovation, and multi-stakeholder collaboration (UNDP, 2020; FAO, 2019; Giles et al., 2019; Giles et al., 2005).

Developing successful mitigation and adaptation methods requires an understanding of how air pollution affects the food chain. The findings of this study can help shape behaviors, policies, and technology that support the resilience and sustainability of our food systems as the world struggles to feed a growing population while reducing the effects of climate change. This essay takes a worldwide viewpoint, taking into account various geographic locations and farming methods. It is imperative to acknowledge that the precise effects of air pollution on the food chain may differ depending on local attributes and farming practices. The intricacy of pollutant interactions and the dynamic character of environmental conditions are among the study's limitations.

The primary aim of this work is to conduct a comprehensive review of the relationship between air pollution and the food system. The specific objectives include:

1. Investigating the pathways through which air pollutants affect the safety and quality of food.
2. Assessing the influence of changing climate patterns on the distribution and persistence of pollutants in the food supply chain.
3. Formulating sustainable recommendations and mitigation strategies to enhance the resilience of the food system in the face of air pollution challenges.

Data Collection

A comprehensive literature search was conducted in order to locate relevant research and data on methane emissions, their primary sources, their geographic distribution, and their impacts on air quality in order to conduct this review. Among other databases, publications from international organizations, official documents, and scholarly journals were examined. The search parameters ensured that the most recent findings were included by encompassing research conducted until September 2023. Searches frequently included the following terms: "food system," "air quality," "health effects," "sources," and "mitigation strategies." As part of the literature review, the

Environmental Protection Agency (EPA), the United Nations, and scholarly journals in the fields of atmospheric science, environmental science, and public health were consulted. There was also usage of scholarly resources such as PubMed and Google Scholar.

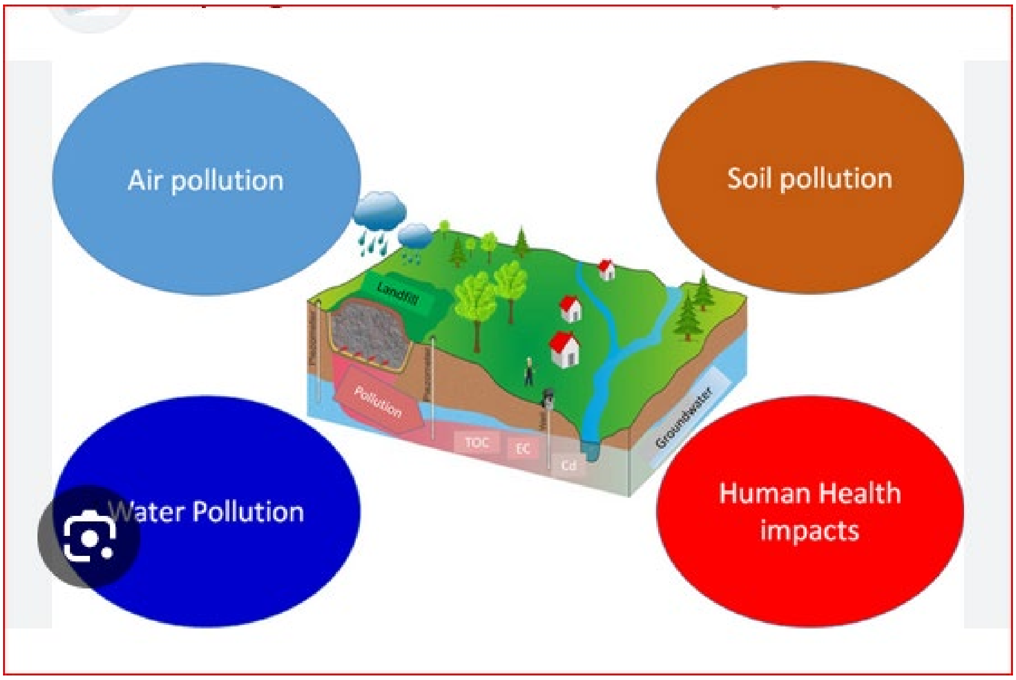

Figure 1: The Effect of Pollution on Food Impacts human health   Source: Siddiqua et al. (2022)

Air Pollution Impacts

1. **The infiltration and impact of different pollutants from air pollution on the various components of the food supply chain are complex and multifaceted.**

Here's an overview of how pollutants affect different stages of the food production process (Table 1):

Soil Contamination

A frequent pollutant that can settle on agricultural soils is airborne particulate matter. Heavy metals, polycyclic aromatic hydrocarbons (PAHs), and other hazardous materials might be present in these particles. Different phases of the food production process are impacted differently by particulate matter (PM) from air pollution. PM may contain heavy metals and other pollutants when it first settles on agricultural soils. PM can enter water bodies through air transport, affecting the quality of water used for irrigation. Plants absorb PM through their roots and leaves as they grow, which causes pollutants to build up in the tissues of the plants. Animal health may be impacted by livestock consumption of PM-contaminated feed, which is essential to the food chain.

PM settling on crops during food processing may continue, impacting the safety and quality of processed foods. Livestock may breathe in airborne PM, which can cause respiratory problems. and compromise the safety of products made from animals. In the end, tainted food products may expose consumers to PM, which raises questions about human health. To protect the integrity of the food supply chain, effective mitigation solutions must be developed after taking these implications into account.

Soil nitrogen deposition can result from air pollution's nitrogen oxides (NOx). Although nitrogen is an essential nutrient for plants, too much of it can change the chemistry of the soil and harm plants. Air pollution's nitrogen oxides (NOx) have a major influence on several steps in the food production process. Crop health and yield can be impacted by NOx because it can cause nutritional imbalances and soil acidification (Galloway et al., 2003). NOx can contaminate water supplies by air deposition, which affects the irrigation water's quality. Exposure to NOx in crops can modify metabolic pathways, impacting safety and nutritional value (Wang et al., 219). When livestock consume forage or water contaminated with NOx, negative health effects may occur (USEPA, 2021). NOx may have an impact on the development of unwanted chemicals during food processing, which could lower the quality of processed foods. Taken together, knowledge of the complex effects of NOx on the food chain is essential for both human health and sustainable agriculture.

Table 1. The infiltration and impact of Contaminants on the Various Components of the Food Supply Chain

Source	Pollutant	Medium of Exposure	Impact
Soil Contamination	Airborne particulate matter (Prescence of Heavy metals, polycyclic aromatic hydrocarbons (PAHs), and other hazardous materials). NOx	Agricultural soils, water bodies, plant roots and leaves, breathing by livestock, food processing	Respiratory problems of livestock, the quality of water used for irrigation, build up in the tissues of the plants, affects human health, soil acidification
Water Contamination Rain, Lakes, rivers, and irrigation systems	Pesticides and heavy metals	From contaminated air, agricultural soils and during food processing	Reducing the quality of the water suitable for irrigation, lower the produce's nutritional value, raise health risks of livestock. Affects quality of foods.
Crop Uptake	Contaminants (NOx, PM, CO, SO_2), Toxins, heavy metals	Leaves, roots	Altering growth and development of plants and animals, safety and quality of processed foods
Livestock Exposure	Contaminants (NOx, PM, CO, SO_2), Toxins, heavy metals	Through eating of the Contamination of feed and forage and by absorption by livestock	Contamination of Animal products, quality and safety of processed foods
Food Processing	Airborne contaminants	Left out in the open while drying or curing, processing technique	Quality and safety of processed foods are compromised
Food Safety and Quality	Chemical residues from air pollutants	Raw components, processing technique	Quality and safety of processed foods are compromised

Water Contamination

Pollutants in the air can be carried into bodies of water by rainfall. This runoff may influence the quality of water used for agriculture by introducing pollutants, such as pesticides and heavy metals, into lakes, rivers, and irrigation systems. The food production process can be greatly impacted at different stages by runoff from contaminated air. Pollutants from the atmosphere may be transferred into water bodies by runoff from agricultural soils, so reducing the quality of the water suitable for irrigation (Davidson et al., 2005). Contaminants added to irrigation water put crops' health and safety at risk and may also lower the produce's nutritional value (Lu et al., 2015). In addition, tainted feed and water might expose livestock indirectly and raise health risks (Huang et al., 2023). Pollutants delivered by runoff during food processing may linger and affect the safety and quality of processed foods. This complex interaction highlights the requirement for all-encompassing approaches to control runoff from contaminated air and safeguard the integrity of the food supply chain as a whole.

Crop Uptake

Through their leaves, plants can directly absorb contaminants. Toxins may build up in plant tissues as a result of this absorption. Pollutants have a substantial impact on several phases of the food production process, especially when absorbed by plant leaves. Airborne contaminants can impair crop health by altering growth and development when absorbed by leaves (Thimmegowda et al., (2020). The nutritional value and safety of crops may be impacted by the buildup of pollutants caused by this absorption (Díaz-Álvarez et al., 2018). Livestock might indirectly consume pollutants through polluted feed, which can impact their health and the safety of products obtained from animals (Hou, 2021). Pollutants absorbed by crops during food processing may linger and affect the safety and quality of processed foods. Comprehending these dynamics is vital in order to execute tactics aimed at alleviating the effects of leaf absorption on the complete food supply chain.

Plant roots could absorb pollutants from the soil. When it comes to heavy metals and persistent organic contaminants, this mechanism is very important. Pollutants that are ingested by roots have a substantial effect on several phases of the food production cycle. Pollutants may build up in plant tissues as a result of plants absorbing toxins from the soil, which could affect crop quality and safety (Zhang et al., 2017). This uptake by the roots may cause heavy metals to bioaccumulate, which could have an adverse effect on crops' nutritional value and endanger human health (Kabata-Pendias, 2011). When livestock eat polluted crops or fodder, they may absorb contaminants directly through their roots, which can lead to health problems (Kabata-Pendias, 2011). Pollutants absorbed by crops during food processing may not go away, which could have an effect on the safety and quality of processed foods. A thorough comprehension of root uptake patterns is essential for putting measures into action that guarantee the security and longevity of the food supply chain.

Livestock Exposure

When livestock eat tainted feed and forage, they may be inadvertently exposed to air pollution. Crop pollution builds up and enters the animal's diet. Pollution-induced contamination of feed and forage has a substantial effect on several phases of the food production process. Because they depend on tainted feed and pasture, livestock may directly consume contaminants, which could have a negative impact on their health and contaminate items made from animals (Yan et al., 2022). The safety and quality of meat and dairy products that people eat may be impacted by this contamination (Wang et al., 2007). Pollutants in feed and pasture can also interfere with an animal's capacity to develop and reproduce, which can make livestock farming less sustainable. Animal products that have been contaminated might therefore exacerbate problems with food processing, which can lower the general safety and quality of processed foods. Creating comprehensive methods that guarantee the sustainability and safety of livestock-based food systems requires an understanding of the complex relationships between forage/feed contamination and the whole food supply chain.

Additionally, livestock may directly absorb airborne contaminants, which could contaminate animal products and cause respiratory problems. Several phases of the food production process are significantly impacted by the inhalation of airborne contaminants. When livestock are directly exposed to airborne contaminants, they may experience respiratory problems, which could negatively affect their health and the safety of products obtained from animals (Wolffe, 202l). Furthermore, during agricultural growth, air pollution can deposit on crops and affect their quality and safety (Li et al., 2023). Crops that are exposed to contaminated air may accumulate contaminants, which could impact their safety and nutritional value. Persistent airborne contaminants have the potential to influence the overall quality and safety of processed foods by forming unwanted chemicals during the food processing process. For the purpose of creating mitigation methods for the effects of airborne contaminants on the entire food supply chain, it is imperative to comprehend these intricate relationships.

Food Processing

During manufacturing, food items may come into contact with airborne contaminants, particularly in open locations. This is especially important for products that are left out in the open while drying or curing. Pollutant contamination during food processing adds complexity to different steps in the food production process. The safety and quality of processed foods may be impacted by airborne contaminants that linger on raw components (Mirzaei et al., 2018). The nutritional value of finished goods may be impacted by processing techniques that concentrate or change the chemical makeup of pollutants (Llorente-Mirandes et al., 2017). Pollutants added during processing can also affect the food supply chain's overall safety and pose health concerns to consumers (Tindall et al., 2018). To guarantee the creation of safe and superior food products, effective risk management is crucial during the food processing process.

Food Safety and Quality

The safety and quality of the finished food items might be impacted by chemical residues from air pollutants on crops and in animal products. Pollutant chemical residues have a significant impact on many phases of the food production process. Crop safety and quality can be negatively impacted during cultivation by residues left by pesticides, heavy metals, and other pollutants (Wang et al., 2022). These residues might remain after harvest, which could endanger people's health if consumed (Qing et al., 2023). When livestock consume tainted feed or water, chemical residues can build up and compromise the safety of items generated from animals (Calatayud-Vernich et al., 2018). Remaining ingredients in food may concentrate during processing, impacting processed foods' safety and nutritional value (Chen et al., 2011). Ensuring the integrity of the food supply chain and reducing the amount of chemical residues present requires strict monitoring and compliance with safety rules.

The nutritional quality of food can be impacted by decreased crop nutrient content caused by elevated ozone levels, a common air contaminant. All phases of the food production process are greatly impacted by pollutants that alter nutrients. Reduced nutrient uptake and changed nutrient content in crops can be the result of air pollutants like ozone impairing plant physiological systems (Hatfield and Pruege, 2015; Maliba et al., 2019). The nutritional content of harvested crops may be impacted by these nutrient composition changes, which may have an effect on consumer health (Çakmakç & Çakmakç, 2023). The safety and quality of goods obtained from animals may be compromised by imbalances experienced by livestock that are fed nutrient-altered feed. Nutrient variations in raw components can affect processed foods' nutritional composition throughout food processing (Gui *et al*., 2023), so balanced diets must take this into account.

2. Novel Implications of Changing Climate Patterns on the Distribution and Persistence of Pollutants in the Food System

Altered Atmospheric Transport

The distribution and persistence of contaminants in the food chain are subject to new implications as a result of altered air transport brought about by shifting climatic patterns. Pollutant dispersal over wider geographic areas is influenced by changes in precipitation and wind patterns, which increases the distance that pollutants travel from their source (Seinfeld & Pandis, 2016). The quality and safety of crops may be impacted by increased pollutant deposition on agricultural soils as a result of these changed transport dynamics.

Furthermore, the persistence of contaminants in the atmosphere may be impacted by shifting climatic trends. Certain pollutants may become more volatile in response to temperature changes and changed atmospheric conditions, which would extend their length of residence in the atmosphere (Jacob and Winner, 2009). Consequently, there is a greater chance that contaminants will travel farther before depositing.

The intricate relationship between pollution distribution and climate-induced changes in air transport has significant effects on the food chain. Comprehending these innovative consequences is crucial for formulating adaptable tactics in agriculture, including as enhanced monitoring and precision farming, to lessen the adverse effects of contaminants on crops and guarantee the security and longevity of the world's food chain.

Increased Volatility of Organic Compounds

Changes in climate patterns have led to an increase in the volatility of organic molecules, which has new consequences for the persistence and spread of contaminants in the food chain. Certain organic pollutants become more volatile with rising global temperatures, which may result in larger atmospheric concentrations and longer-range transport. This increased volatility has an impact on pollution dispersion patterns, which in turn impacts the distribution of pollutants over various geographic regions (Jacob & Winner, 2009).

Warm temperatures have the potential to accelerate the evaporation of organic substances, allowing them to be transported over greater distances prior to deposition. The safety and quality of crops are impacted by the difficulties in anticipating and controlling pollution exposure in agricultural areas caused by this increasing mobility.

Reevaluating current models for determining pollutant behavior in the atmosphere is necessary due to the impact of shifting climate patterns on organic compound volatility. Mitigating the possible dangers to the food chain requires adjusting agricultural practices and regulatory measures to account for the changed dynamics of the pollution movement. To fully understand these unexpected consequences and create solutions that work for resilient and sustainable food production, cross-disciplinary research and collaboration are crucial.

Changes in Precipitation Patterns

As a result of changing climatic conditions, changes in precipitation patterns have unique consequences for the persistence and dispersion of contaminants in the food chain. Changes in precipitation can affect the path that pollutants take, from the point of emission to the food chain. Variations in the amount of precipitation can cause more runoff, which can introduce contaminants into water bodies from a variety of sources. Crop quality and safety may be impacted by this runoff's potential to pollute irrigation water (Davidson *et al.,* 2005). Modified precipitation patterns have the potential to exacerbate soil erosion and introduce contaminants into streams. Water quality and aquatic ecosystems may be impacted by sediment-bound pollutants that endure in aquatic environments (Wu et al., 2020).

The availability of contaminants in the soil is impacted by variations in moisture levels. This can therefore affect how pollutants are absorbed by plants, changing the chemical makeup and safety of crops (Li et al., 2017). Modified precipitation can have an impact on atmospheric parameters, which can impact the long-range transportation of pollutants. This could cause pollutants to spread across wider geographic areas and affect areas that are not directly affected by them (Jacob & Winne, 2009). Food security may be impacted by changes in precipitation patterns that impair agricultural output. The susceptibility of food systems to climate variability may be made worse by problems brought on by pollutants (IPCC, 2014).

Impact on Soil-Water Dynamics

The distribution and persistence of contaminants in the food chain are subject to new consequences brought about by changing climatic patterns, particularly as they relate to soil-water dynamics. Variations in evapotranspiration rates and precipitation patterns affect the dynamics between soil and water, which affects the amount of water available for agricultural use. Pollutant mobility and transport in the soil may be impacted by this change in water availability (IPCC, 2014). Pollutant leaching into groundwater may rise because of variations in soil-water dynamics. This puts crops that are irrigated with such water at danger of contamination as well as the quality of available water resources (Schlesinger, 2009).

Erosion processes are influenced by modifications in the soil-water dynamics. Pollutants that are bonded to sediment can be transported via soil erosion, which may have an influence on aquatic ecosystems and neighboring bodies of water by lowering water quality (Wu et al., 2020). The dynamics between soil and water affect how bioavailable contaminants are in the soil. This could therefore have an impact on how pollutants are absorbed by plants, which could have an impact on the safety and caliber of agricultural products (Li et al., 2017). Modified soil-water dynamics have the potential to impact agricultural systems' overall production. Crop yield variations and crops' vulnerability to pollution exposure may be caused by changes in water availability and quality (IPCC, 2014).

Shifts in Soil Microbial Activity

Novel implications for the distribution and persistence of contaminants in the food chain are presented by changing climatic patterns, specifically in relation to their effects on changes in soil microbial activity. Soil microbial populations are subject to changes in temperature, precipitation, and other climate-related phenomena. Certain contaminants may undergo metamorphosis as a result of altered microbial activity, which could impact their destiny in the soil ecosystem (Bardgett and van der Putten, 2014). Changes in the microbial activity of soil can influence how pollutants degrade and get detoxified. Several bacteria are essential for decomposing and neutralizing pollutants, which affects how long they remain in the environment (Bardgett & van der Putten, 2014).

Certain contaminants can have their mobility influenced by soil bacteria. Variations in microbial activity can impact the transportation, sorption, and desorption of pollutants in the soil, hence affecting the distribution of those contaminants (Lehmann & Joseph, 2009). Changes in the microbial populations can impact soil health in a cumulative manner. Pollutant dynamics may be impacted by changes in soil microbial activity, which may also have an impact on soil structure, nutrient cycling, and overall ecosystem functioning (Bardgett & van der Putten, 2014).

Microbes in the soil have an impact on the nutrients and contaminants that are available to plants. Variations in microbial activity can impact a contaminant's bioavailability and crop absorption (Lehmann & Joseph, 2009).

Increased Frequency of Extreme Weather Events

Climate change is causing an increase in the frequency of extreme weather events, which has new implications for the persistence and spread of contaminants in the food chain. Storms and periods of heavy rain can worsen soil erosion and runoff, which can introduce contaminants from agricultural fields into water bodies. This discharge adds to water contamination, which compromises irrigation water safety and may have an effect on crops (Davidson *et al.*, 2005). Floods in particular are extreme weather phenomena that have the ability to move contaminants bonded to sediment over great distances. Water bodies may get contaminated as a result, which may have an influence on aquatic ecosystems and agricultural areas downstream (Wu et al., 2020).

Severe weather conditions, including hurricanes or floods, can harm agricultural chemical storage installations. Pollutants may be released as a result, compromising the quality of the soil and water. Pollutant distribution in the atmosphere during extreme weather events may be impacted by changes in wind patterns. This may result in the long-distance movement of pollutants, impacting areas distant from the immediate source (Seinfeld & Pandis, 2016).

Unpredictable occurrences have the potential to destroy infrastructure and release toxins kept in commercial or industrial settings. This may lead to localized pollution and present environmental problems.

Impacts on Crop Physiology

The distribution and persistence of contaminants in the food chain are subject to new consequences brought about by shifting climatic patterns and their effects on crop physiology. Temperature, precipitation, and atmospheric changes can all have an impact on plant physiology, which may change how pollutants are absorbed by crops. This could affect the distribution and concentration of pollutants in plant sections that are edible (Zhang et al., 2017). Changes in crop physiology and soil microbial activity brought on by climate change may have an impact on how toxins in the soil are broken down and transformed. This in turn may have an effect on the persistence and destiny of pollutants (Bardgett and van der Putten, 2014).

Crop growth patterns may change because of climatic changes, which could have an impact on the length and timing of various growth stages. These changes have the potential to affect when and how much pollution builds up in crops (Hatfield and Prueger, 2015). Crop resilience can be weakened by climatic stressors, increasing their vulnerability to harm from pollutants. This could lead to heightened susceptibility to stress caused by climate change as well as exposure to pollutants (Lobell and Gourdji, 2012). Changes in climate could have an effect on how soil bacteria and plants interact. The availability and mobility of pollutants in the rhizosphere are influenced by these interactions, which are important for pollutant dynamics (Lehmann and Joseph, 2009).

Relationship between Air Pollution and the Food Chain: Scientific Data

Air pollution affects the food chain through multiple pathways, including direct impacts on crop growth and productivity, contamination of food products, and adverse effects on livestock health. Below is a detailed examination of these relationships supported by scientific data:

Impact on Crop Growth and Productivity

Ozone is a potent phytotoxic pollutant that can reduce crop yields significantly. Studies have shown that ambient ozone concentrations can reduce yields of staple crops. For instance, wheat yields can decline by 7-12% and soybean yields by 6-16% due to ozone exposure (Avnery *et al.*, 2011). In India, it is estimated that wheat and rice losses due to ozone exposure amount to approximately 3.5 million tons annually, translating to significant economic losses and food insecurity (Ghude *et al.*, 2014). Particulate matter can physically damage plant surfaces and interfere with photosynthesis. Studies in China have shown that PM can reduce the photosynthetic rate in crops like wheat by 20-30%, leading to lower yields (Guo *et al.,* 2010).

Contamination of Food Products:

Airborne heavy metals, such as lead (Pb), cadmium (Cd), and mercury (Hg), can deposit on soil and plants, leading to bioaccumulation in food crops. A study in Ghana found elevated levels of Pb and Cd in vegetables grown near industrial areas, posing health risks to consumers (Bempah et al., 2012). In Nigeria, significant contamination of leafy vegetables with heavy metals was observed due to proximity to traffic and industrial activities, highlighting the risks to food safety (Nwankwoala, 2015). POPs such as dioxins and polychlorinated biphenyls (PCBs) can be transported through air and deposit on agricultural fields, contaminating crops and livestock. These pollutants can bioaccumulate through the food chain, posing long-term health risks. Research indicates that areas with high atmospheric POPs concentrations also show elevated levels of these contaminants in locally produced food (Batterman *et al.*, 2009).

Effects on Livestock:

Livestock exposed to air pollutants such as ammonia (NH_3) and hydrogen sulfide (H_2S) from intensive farming operations often suffer from respiratory problems. Studies have shown that chronic exposure to these pollutants can reduce growth rates and milk production in cattle (Gould, 2005). In poultry, high levels of ammonia in confinement houses can lead to respiratory distress, reduced feed intake, and lower egg production (David et al., 2015). Additionally, heavy metals like lead and cadmium, deposited through air pollution, can accumulate in animal tissues, posing health risks to both livestock and humans consuming animal products (Swarup et al., 2005). These impacts highlight the need for mitigating air pollution to safeguard livestock health and ensure the sustainability of animal farming practices.

Climate Change Interactions:

While increased CO_2 levels can enhance photosynthesis and crop yields, this benefit is often offset by the detrimental effects of air pollutants and climate change. Higher temperatures and altered precipitation patterns can exacerbate the impact of air pollution on crops, as seen in studies indicating that combined stressors can reduce wheat yields by up to 18% (Porter, 2005). Air pollution can also influence the frequency and severity of extreme weather events such as droughts and storms, further stressing agricultural systems. For example, particulate matter can affect cloud formation and precipitation, leading to altered water availability for crops (Ramanathan et al., 2001).

Existing and Emerging Mitigation Strategies for Minimizing Adverse Effects of Air Pollution on Food Safety and Sustainability

Sustainable Agricultural Practices:

Mitigation measures, both established and new, are critical in reducing the detrimental impacts of air pollution on food safety and sustainability, especially about sustainable agriculture practices. By creating green spaces and planting trees, you may use nature's filters to lessen the amount of airborne contaminants that land on crops. Pollutants can be absorbed and captured by trees, reducing their direct effects on crops and soil. Crop rotation and cover cropping improve the microbial diversity and soil structure. By doing this, contaminants are better able to be absorbed by the soil and broken down, which lessens their persistence and any negative effects on crop quality (Pretty and Bharucha, 2014). By using precision agricultural technology, nutrient utilization efficiency is maximized and resource waste is reduced. Examples of these technologies include precision irrigation and fertilization. This strategy can lessen the requirement for overapplying fertilizers, which will lessen the amount of air pollution that contaminates the soil. By focusing on natural pest management techniques and fertilizers, organic farming lessens its dependency on artificial chemicals. This method encourages better soil and safer food production by reducing the amount of pollutants introduced into the environment (Reganold & Wachter, 2016).

Applying biochar, a type of charcoal made from organic matter to soils can increase fertility and decrease the amount of contaminants that are bioavailable. By improving nutrient retention and reducing the negative effects of pollutants on crops, biochar serves as a soil amendment (Hou, 2021). Using low-emission farming machinery and equipment reduces the amount of air pollutants released during farming activities. This helps to lessen agriculture's overall environmental impact (Bittman, 2013). Reducing greenhouse gas emissions is frequently the first step in combating air pollution. Methane emissions can be decreased by using techniques such as as methane collection from waste management systems and improving livestock diets, which lessens the negative environmental effects of livestock production (Rotz et al., 2011). Reduced soil disturbance, no-till farming, and soil conservation are techniques that support soil structure and reduce air pollution. Stable soils promote strong crop growth and reduce environmental hazards, which are important components of sustainable agriculture (Six *et al.,* 2004).

Green Infrastructure and Urban Planning

In urban areas, reducing the negative impact of air pollution on food safety and sustainability requires the implementation of green infrastructure and urban planning measures. Increasing the amount of green space in urban areas-such as parks and gardens-helps absorb and filter air pollutants, lowering the concentrations of those pollutants (McPhearso *et al*., 2016; Nowak et al., 2018). By collecting pollutants and fostering biodiversity, installing green walls and roofs on buildings improves the quality of the air. Both overall food safety and sustainable urban agriculture are enhanced by these buildings. Planting trees strategically in urban areas improves air quality and increases the safety of urban food production by acting as a natural barrier against airborne pollution. Urban forests that are developed serve as pollution sinks and offer a number of advantages, including better air quality, temperature regulation, and assistance for local food production projects. The development of healthier habitats for both people and crops is supported by the coordination of land use planning to incorporate green spaces with urban infrastructure.

These strategies support resilience against the detrimental effects of air pollution on food safety and general environmental health, and they are consistent with the ideas of sustainable urban development. Building more sustainable and livable urban environments requires ongoing study and teamwork in implementing green infrastructure concepts.

Emission Control Technologies:

In order to lessen the detrimental impacts of air pollution on food safety and sustainability, emission control technologies are essential. By reducing emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs), catalytic converters in automobiles and industrial facilities restrict the amount of these pollutants that end up on crops. Particulate matter (PM) from combustion processes is captured by particulate filters in exhaust systems, which stops it from dispersing into the atmosphere and landing on farmland. By accelerating the conversion of nitrogen oxides (NOx) into harmless nitrogen and water vapor, SCR technology minimizes the impact on air and soil quality by reducing the amount of NOx in emissions (EEA, 2019).

Encouraging the use of electric and low-emission vehicles contributes to a reduction in the amount of pollutants discharged into the environment, improving air quality and lowering the possibility of harming food crops. The implementation of sophisticated combustion technologies in industrial operations reduces air pollution emissions, hence mitigating the issue of contaminant deposition on crops (Zhang et al., 2017). By helping to regulate air quality sustainably, these technologies protect the environment and the security of food production systems. Building a robust and sustainable food supply chain in the face of air pollution concerns requires ongoing research and broad application of these emission control techniques.

Air Quality Monitoring and Early Warning Systems

The mitigation of air pollution's detrimental impacts on food safety and sustainability is largely dependent on-air quality monitoring and early warning systems.

Continuous monitoring of air quality makes it possible to identify pollution levels in a timely manner, allowing for quick action to safeguard food safety and protect crops (Monks et al., 2015; Kelly and Fussell, 2015). The development of sensor technology has made it possible to monitor air quality on-site in a portable and affordable manner, providing real-time data for agricultural decision-making. Proactive measures are made easier by the development of integrated data systems that integrate meteorological, agricultural, and air quality data (Huang *et al*., 2023). This improves our understanding of the interactions between pollutants and crops. Farmers can take preventive measures, such modifying planting schedules or putting protective measures for crops in place, by putting early warning systems based on predictive models and data monitoring into place (Wang et al., 2019). Engaging citizens in citizen science programs to monitor air quality improves data collecting and raises community awareness, which promotes working together to address the impact of pollution on food safety (Calatayud-Vernich *et al.*, 2018).

By enabling stakeholders to act quickly in response to air quality issues, these initiatives protect the integrity of the food supply chain. To effectively and sustainably control air quality in agriculture, research, governments, and communities must continue to invest in monitoring technologies and work together.

Climate-Resilient Crop Varieties:

Climate-resilient crop varieties represent a pivotal mitigation strategy for minimizing the adverse effects of air pollution on food safety and sustainability. Developing crop varieties with enhanced tolerance to air pollutants, such as ozone and particulate matter, ensures sustained productivity under challenging environmental conditions (Lobell & Gourdji., 2012; Ainsworth *et al*., 2008). Genetic modification and trait-specific engineering enable the creation of crops with heightened resistance to pollutants, mitigating the impact of contaminants on crop quality and safety (Maliba *et al.*, 2019). Integrating climate-resilient traits with precision agriculture practices optimizes resource use and minimizes the impact of air pollution on crop yields, contributing to sustainable and efficient food production (Timsina & Connor, 2001). Promoting diverse crop varieties that exhibit resilience to varying environmental stresses, including those induced by air pollution, enhances overall food system robustness (Challinor *et al.*, 2014).

Establishing community seed banks with diverse, climate-resilient crop varieties supports local adaptation efforts and ensures a more secure and sustainable food supply (Padulosi et al., 2019). Implementing these strategies is vital for building climate-resilient agricultural systems that can withstand the challenges posed by air pollution, ultimately contributing to food safety and long-term sustainability. Ongoing research and collaboration in crop breeding and biotechnology are essential for the successful deployment of these mitigation measures.

Biochar Application

Applying biochar is a useful mitigating technique to reduce the harmful impacts of air pollution on sustainability and food safety. As a sorbent, biochar reduces the bioavailability of contaminants to crops by adsorbing them from the air and soil (Stanford et al., 2019). By improving soil structure and encouraging aeration and water retention, it lessens the negative effects of air pollution on the health of the soil (Hou, 2021; Nowak et al., 2018). Additionally, using it can restrict the amount of certain pollutants that are released into the atmosphere by reducing their volatilization (Inyang *et al*., 2016). Enhancing soil nutrient retention by the use of biochar promotes crop health and productivity in general, particularly when air pollution is present. It promotes advantageous microbial activity, which helps the soil ecosystem become more resilient overall and breaks down contaminants (Mukherjee et al., 2013). A viable strategy to lessen the effect of air pollution on food safety is to apply biochar as a soil amendment, which fosters agricultural and environmental resilience.

Public Education and Awareness

Mitigation techniques such as public awareness and education are crucial in reducing the detrimental impact of air pollution on food safety and sustainability (Whitmarsh & O'Neill, 2020). Public awareness of the connections between food safety and air quality promotes community involvement and teamwork in the fight against pollution (Calatayud-Vernich *et al*., 2018). Growing public knowledge enables consumers to demand produce free of pollutants and to support sustainable practices. Incorporating environmental education and air quality into school curricula fosters awareness at a young age and instills in the next generation a sense of responsibility for sustainable food systems. By using media channels for educational efforts, people can become more aware of how air pollution affects food safety and are encouraged to adopt eco-friendly practices (Kaur & Pandey, 2021). Workplace training programs that include instruction on food safety and air quality inform employees about possible hazards and promote actions that reduce pollution consequences. These tactics, which place a strong emphasis on public awareness and education, help create a more knowledgeable and involved society by encouraging sustainable behaviors that protect food safety and improve environmental sustainability as a whole.

Regulatory Measures and Policy Interventions

The implementation of regulatory measures and policy initiatives is crucial in reducing the detrimental impact of air pollution on food safety and sustainability. Stricter emission regulations for motor vehicles and industrial sources limit the amount of pollutants released, protecting the quality of the air and lessening their effects on crops (Li *et al.*, 2023). Creating integrated regulations that take agricultural practices and air quality into account guarantees a thorough strategy to reduce pollution's effects on the food supply chain (Calatayud-Vernich et al., 2018). The implementation of zoning restrictions serves to mitigate the direct exposure of crops and soil to pollutants by controlling the establishment of industrial operations in close proximity to agricultural regions (Wu et al., 2020). Providing financial incentives to farmers that embrace environmentally friendly farming methods, such organic farming or agroforestry, promotes agricultural pollution reduction initiatives (Piñeiro *et al*., 2020).

Enforcing laws and strengthening monitoring systems are essential for guaranteeing adherence to air quality requirements and reducing the adverse effects of pollution on food safety (Sofia et al., 2020). A resilient and sustainable food system in the face of air pollution concerns requires effective regulatory and policy frameworks that promote a balance between industrial growth and environmental protection. When used in concert and with flexibility, these mitigation techniques provide a comprehensive way to reduce the harmful effects of air pollution on food sustainability and safety. Policymakers, scientists, and practitioners must continue their research and work together to develop and improve these tactics to meet the changing difficulties brought on by air pollution.

Conclusion

The assessment concludes by highlighting the complex interactions that exist between air pollution and the food chain and emphasizing the urgent need for all-encompassing mitigation measures. From crop cultivation to processing and consumption, there are several phases in the food supply chain when air pollution has a negative impact on food safety and sustainability. The intricate nature of this interaction is further highlighted by new implications brought forth by shifting climatic patterns.

Both established and new mitigation techniques present viable solutions to these problems. A multifaceted strategy is necessary for everything from the application of biochar to the promotion of crop varieties that are adaptable to climate change and the execution of regulatory measures. Building a resilient and sustainable food system involves incorporating cutting-edge technologies like air quality monitoring along with public awareness and education.

The increasing severity of air pollution problems caused by climate change underscores the importance of cooperation between policymakers, researchers, communities, and agricultural stakeholders. In order to ensure the resilience of the food supply chain, reduce the negative effects of air pollution on food safety, and promote a healthier, more sustainable future, it is imperative that sustainable practices, well-informed decision-making, and proactive policy interventions be implemented.

Recommendations

Several recommendations can be made to strengthen efforts to minimize the negative effects of air pollution on food safety and sustainability based on the review's findings:

Allocate resources towards ongoing investigations to enhance our comprehension of the interplay between atmospheric pollution and the food chain. To tracking pollution levels and their effects on crops, strengthen air quality monitoring systems.

Encourage the fusion of agricultural and air quality initiatives. To lessen the effects of pollution, strict emission limits, zoning laws, and incentives for sustainable agricultural practices should be developed and enforced.

Start extensive public education initiatives to inform people about the connection between food safety and air pollution. Give customers the information they need to make decisions that will promote environmentally friendly, sustainable farming.

Encourage the use of sustainable farming methods and crop varieties that are adaptable to climate change. To reduce the negative effects of pollution on soil and crops, promote the use of biochar and precision farming.

Encourage international cooperation to solve problems with transboundary air pollution. Exchange research results, best practices, and approaches to policy to build a global framework for resilient and sustainable food systems.

Engage local populations in citizen science projects to monitor the quality of the air. Promote community involvement in initiatives to reduce pollution and practice sustainable farming.

Encourage the creation and application of cutting-edge technology to improve agricultural sustainability and minimize pollution, such as sophisticated emission control systems and precision farming implements.

Create adaptable plans that take into consideration the unique effects of shifting climatic patterns on the dispersion of pollutants. Encourage agriculture's resilience by using a variety of climate-smart strategies.

Invest in enhancing the ability of communities, legislators, and farmers to adopt and adjust to sustainable practices. Make sure all parties involved have the information and tools required for efficient pollution mitigation.

Promote cooperation between governmental, non-governmental, academic, and private sectors. Provide forums for information exchange and cooperative projects to tackle the intricate problems at the nexus of air pollution and the food chain.

Putting these suggestions into practice calls for a multifaceted, coordinated strategy. Through tackling the intricate and interrelated problems outlined in the assessment, interested parties can collaborate to construct a food system that is more resilient, sustainable, and environmentally sensitive.

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Research Paper

Effect of Domestic Sewage Sludge on the Botanical Composition of Eroded Pastures

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Abstract: This research to evaluate the use possibilities of sewage sludge in eroded pasture areas, the effects of stabilized treatment sludge (biosolid) from the Konya domestic wastewater treatment plant on soil and plants were monitored in marginal and eroded pasture areas in field trials for 3 years period. In this study, analysis processes of soil fertility parameters, micro and macro elements, and toxic heavy metals were examined. The enrichment factors of heavy metals in soil and plants, their effects on heavy metal accumulation and leaching in the soil profile, and their effects on erosion parameters were examined. In addition, biomass yield, protein ratio, botanical composition parameters, heavy metal contents and heavy metal risks in terms of animal health in pasture plants were investigated. In this article, the effects of sewage sludge on the development parameters of plant species that grow predominantly under natural conditions were evaluated. In the experiment, an increase in plant coverage area, height and especially the number and diversity of species were observed in the plots. Provided the necessary precautions are taken, it turns out that the D application has a feasible result of 1 ton da^{-1} (dry matter) in the method of mixing into the soil to a depth of 0-5 cm, once every 3 years. This recommended dose is valid for the ecological conditions in this region where the research was conducted, and similar studies are needed to recommend it in different ecological regions of Turkey.

Keywords: *Sewage sludge, biosolid, erosion, degraded pasture, botanical composition, heavy metal.*

Introduction

Development of urbanization and the growth of the population, significant increases are observed in the amount of stabilized treatment sludge generated from domestic wastewater treatment plants. The most economical method of disposal of sewage sludge for cost is land disposal. Serious problems may arise in the disposal of sewage sludge on land due to the salinity and heavy metals contains. However, if sewage sludge is used in a controlled and conscious manner in accordance with national standards, its useful part can be used as biosolids (fertilizer) for soil improvement (Mücevher *et al.*, 2020).

Pastures are important for animal husbandry, and they provide great benefits to the country's economy by preventing wind and water erosion and soil loss. For this purpose, legal regulations must be made to implement the necessary plans, including pasture improvement (Çepel, 2008). Compared to forests and other ecosystems, relatively little is known about the ecological status of grasslands. The crisis in global soil health is also closely related to the management of natural and semi-natural grasslands around the world. Both the destruction and creation, composition, and renewal of natural and semi-natural grasslands have been greatly affected by human management (Johnson *et al*., 2017). One of the measures to be taken against wind erosion in dry places with sparse vegetation is to protect the vegetation, and another is to enrich the soil in terms of organic matter. Organic matter is useful in resisting erosion because it has a high-water retention power (Eyce, 1995). Although rangelands are an important carbon sink with great potential to achieve environmental and development goals, they are often neglected in the land restoration agenda (Johnson *et al*., 2017).

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The Central Anatolia Region is a region with the least productive pastures, annual rainfall is between 250-500 mm, pastures dry quickly, and grazing pressure is very high (Sutie et al., 2005). In the south of this region, the altitude generally varies between 700-1050 mm in the places including Çumra, Cihanbeyli, Karapınar and Konya Ereğli. In these places, natural steppe areas have been destroyed in the last 15-20 years (66-80% has disappeared) and a radical change has occurred (Akman *et al*., 2014). In these pastures, where vegetation has been degraded on a large scale, production is attempted at the expense of erosion. In some cases, although improvements are tried to be made through controlled grazing, additional measures (furrowing, shaping, fertilizing, seeding, *etc*.) are needed (Akyürek, 1986). It is known that sewage sludge (biosolid) is also used with good control in special areas with different methods to fertilize or increase organic matter in the soil. However, it should not be forgotten that it must be dried and processed, and this is important for health and the environment. It has been stated that the main values in the use of biosolids as fertilizer are due to the slowly absorbable nitrogen and phosphorus from the nutrients therein (Ignatieff & Page, 1965). It has been stated that treatment sludge is used in Spain and that productivity increases and soil properties improve with the application (Altın *et al*., 2005). It has a positive effect on the establishment of vegetation and the productivity of pasture vegetation, especially in pastures degraded by erosion. However, it has also been stated that it should be used in a way and to an extent that does not harm the environment (Altın *et al*., 2005).

In arid and semi-arid regions, the inadequacy of crop production negatively affects animal husbandry. In addition to the lack of precipitation in arid (25-200 mm precipitation) and semi-arid (200-800 mm precipitation) places, evaporation caused by high temperatures is an important problem. All of these create harsh environmental conditions for humans, animals and plants. Water deficiency is very evident in arid areas and rainfall is irregular. It is typical for these regions to have low precipitation, low air humidity and high evapotranspiration. In addition, the organic matter content of the soil is low. Even if the soil depth is high, the amount of usable water stored in the soil is low because rainfall is insufficient. In arid areas, there are flora and fauna that have adapted to the ecological conditions described. As a result of this information, this research was conducted to see the effects of the application of sewage sludge in a pasture that is eroded, marginal and fragile, and classified as weak.

Material and Method

Climate Condition

The climate of the region is defined as semi-arid continental, with dry and hot summers and cold and rainy winters. Most of the snowfall falls in January and February. The average precipitation is 275 mm, and 40% of it falls during the winter months. The average rainfall from July to September is 15 mm (Şimşekli, 2012). In the project area, high temperatures in summer and low humidity in the soil profile throughout the year negatively affect the amount of organic matter in the soil and ultimately the physical and chemical quality of the soil (Bot & Benites, 2005). These decreases in vegetation due to temperature differences play a role in increasing degradation, desertification and ultimately wind erosion due to the decrease in the organic matter cycle to the soil. The distribution and amount of precipitation throughout the year is of great importance in terms of soil moisture, plant productivity and the amount of soil organic matter. The values of the 10-year average rainfall data of the research area are given below (Table 1; MGM, 2018). When Karapınar precipitation data is examined, excluding snowfall in December in 2016, there is 132.6 mm of precipitation, especially in terms of water year. 2016 was a very dry year has happened.

Location and Soil Condition

In this research, as a trial site was established by surrounding the Karapınar Desertification and Erosion Research Center land with wire fences in the eroded, weak, fragile and degraded Yenice Pastureland right next to it. The area where the project will be implemented was surrounded by a concrete wire fence and parcelization work was carried out. As a result of the preliminary survey land determination of the area where the trial site will be established, Yenice Pasture with its soil structure, degraded pasture, flat and sandy loam soil was chosen as the most suitable place (Table 2). Especially in our country, a sandy loam soil structure was chosen in accordance with the regulation on the use of sewage sludge in soil.

Table 1. Karapınar rainfall data –last 10 years mm

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total (mm)
2008	17,9	9,7	29,2	26,5	20,4	5,7	0	0	20,2	30,8	22,5	49,2	232,1
2009	63,8	47,8	26,1	43,8	25,8	5,9	59	0	10,9	14,7	44,8	52,3	394,9
2010	37,4	18,9	7,5	28,4	10	46,8	0	3,4	1,2	52,8	1,2	69,8	277,4
2011	34,9	52,6	35,3	28,8	73,3	26,4	0	0	7	16,5	13,3	25,7	313,8
2012	51	25	24	6,6	12	18,4	2,8	7,8	1	32,6	26,6	70,7	278,5
2013	21,2	43,4	9,4	57,4	33,4	24,4	2,4	0,6	12,8	15,2	12	7,6	239,8
2014	40,4	18,4	47,2	3,2	18,4	26	0	9,8	17,2	48,2	33,8	29,8	292,4
2015	13,2	24,9	45,4	16,6	28	46,4	0	5,2	0,8	3,6	1,6	0,6	186,3
2016	25,8	0,4	28	4,6	27,6	19,2	0,4	0,2	20,6	0,2	13	100	240,0
2017	12,2	2,2	11,8	39,8	33	15,6	0	29,4	0	26	63,8	15,8	249,6
Mean	31,8	24,3	26,4	25,5	28,1	23,4	6,4	5,64	9,17	24,0	23,2	42,15	270,5

Table 2. Constitution classification of soil samples taken from pastures

Region	Coordinates	% Sand	% Clay	% Silt	Class
Yenice Pasture	N 37.6512304, E 33.4628130	68,45	13,55	18,00	Sandy loam (SL)

Table 3. Konya KOSKİ Wastewater Treatment Plant, 1 and 2 treatment sludge samples analysis results, limit values and analysis methods

Parameter / Example	Sewage Sludge		Limits	Analysis Methods
	1 no.	2 no.		
Lead (Pb mg/kg furnace dry matter)	56,2	47,06	750	EPA 6020 A (ICP-MS)
Cadmium (Cd mg/kg)	8,13	8,52	10	
Chromium (Cr mg/kg)	500	598	1000	
Cupper (Cu mg/kg)	298	261	1000	
Nikel (Ni mg/kg)	175	165	300	
Zink (Zn mg/kg)	1735	1534	2500	
Mercury (Hg mg/kg)	0,617	0,596	10	TS 2537 EN 1483
Nitrogen (TKN mg/kg)	27669	25483		SM-4500-$N_{org.}$ B
Phosphorus (P mg/kg)	10297	9834		Method ofburning(Olsen et al.)
PCB (mg/kg)	<0,1	<0,1	0,8	EN 12766
PCDD/F (ng TE/kg furnace dry matter)	0,183	0,44	100	TS EN 1948/2-3
pH	6,71	6,73		TS 8332 ISO 10390
C/N (%)	7,12	7,23		D.13.Y.04.24 (İnternal method)
Moisture (%)	72,57	38,29		TS 9546 EN 12280
dry matter(DM) (%)	27,43	61,71		
Loss on Combustion (glow), Organic Matter (at770 ºC) (%)	51,1	43,27	> 40	TS EN 12879
Conductivity (dS/m)	2,63	3,8		ISO 11265
E. coli (EMS/g)	1,8E+05 kob/g	1,9E+06 kob/g	least 2 Log10 (%99)	ISO 16649-2

Properties of Sewage Sludge

The sewage sludge from the dewatered domestic wastewater treatment plant unit used as material in the project was sent to the TÜBİTAK MAM Environment Institute Laboratory in accordance with the protocol with Konya KOSKİ General Directorate, one of the project partners, for the analysis of the sewage sludge. The analysis results of these samples were found to comply with Türkiye Regulation on the Use of Sewage Sludge in Soil (Table 3).

Method

The stabilized treatment sludge (biosolid) coming out of the sludge dewatering unit at the Konya Domestic Wastewater Treatment Plant was laid in a thin layer on the surrounded U-shaped concrete lagoons. Samples were taken from different points of the pile and sent to TÜBİTAK MAM Environmental Research Institute for analysis. As a result of the analysis processes, the stabilized domestic sewage sludge pile, which was following the regulation, was periodically turned upside down with a mixer scoop machine, crushed with a cylinder, and dried in an open pile in the sun, continued for 2 months. With this drying method, the dry matter ratio of sewage sludge was increased from 25% DM to 80% DM. The sewage sludge material was transported from Konya Center to the project area in Karapınar, Konya.

Ready-to-use biosolid material piles were created by grinding / shredding the sewage sludge with a rotary machine and sifting through a 10 mm sieve range. On 03-07 November 2014, the dose application in each parcel was carried out on 100% dry matter (DM) according to the moisture content of the sewage sludge, as stated in the project's pasture trial pattern plan. Protective gloves, masks and boots were used during the application of sewage sludge in the field experiment on eroded pasture soil.

A trial design plan was applied in a total of 40 plots in 2 main subjects, with 4 replications and 5 doses. The doses of treatment sludge are 0 (Control), 1, 2, 4 and 8 tons/da (DM) (Arvas et al., 2007). The trial parcel dimensions were set in an area of 8m in the parcels with the surface scattering process (subject S), the biosolid was distributed homogeneously. In the parcels with the mixing process (subject D), after it was distributed homogeneously with a rake, the soil was mixed to a depth of 0-5 cm.

1) Mixing process with a rake into the 0-5 cm layer of the soil (main topic D),
2) Sprinkling on the soil surface, (Main subject S),

The experiment was carried out according to the "Random blocks divided plots trial design" with 4 replications and gravel. In the project, before the application of sewage sludge (biosolid) to the pasture, natural plant survey study was carried out in the plots in June 2014, and physical and chemical analysis and soil sampling were carried out from the raw soil in October. 2014 (control year) is the natural data of the eroded and degraded pasture.

Sewage sludge (biosolid) application was applied once in November 2014. Subsequently, the effects of the sewage sludge were observed for 3 years (in June 2015, 2016 and 2017) after its application. In the project implemented in natural pasture, pasture plant vegetation survey studies were carried out in the parcels according to the Quatrat method in June 2014-2015-2016-2017.

The following procedures were followed in making measurements regarding pasture vegetation. Determination of botanical composition; a- Based on weight, samples are taken from the vegetation, divided into species, and species are weighed separately (Avcıoğlu, 1983). b- It is done in two ways, according to the coverage area. These are expressed as %. These measurements were made before and after treatment sludge application every year in June.

Result and Discussion

Before the treatment sludge application, a natural plant vegetation study was carried out in the eroded pasture in June 2014, and after the treatment sludge application was made in November 2014, the observations and sampling of the plants continued every year for 3 years, in June 2015, 2016 and 2017. (Özyazıcı & Özyazıcı, 2012).

Botanical composition of the pasture

The botanical composition of the pasture was determined in the plots before the application of sewage sludge, and then it was followed at the same time for three years (in June of 2015, 2016 and 2017) and the changes after the application of sewage sludge were determined. Data obtained before and after treatment sludge application; It is stated in Tables 4 -11.

The plant distribution in the natural pasture that was eroded before the application of sewage sludge (biosolid) in 2014 (control year) in the project is shown in Tables 4 and 5 below. The dominant plant species are generally *Salvia absconditiflora*, *Acantho limonulicinum* var. *ulicinum*, *Astragalus onobrychis*, *Noaea mucronate* and other species. The average plant coverage area of the parcels is 42.5%; The average plant height was found to be 7 cm. The plant distribution in the pasture in the parcels in the 1st year (2015) after the application of sewage sludge in the project is shown in Tables 6 and 7 below. The dominant plant species are *Salvia absconditiflora*, *Acantho limonulicinum* var. *ulicinum*, *Astragalus onobrychis, Noaea mucronata*, *Alyssum linifolium* var. *teheranicum*, *Alopecurus arundinaceus*, *Bromus tectorum*, *Stipa ehrenbergiana*, *Panicum* sp., have also emerged. The average plant coverage area of the parcels is 73%; The average plant height was found to be 15 cm. An increase in the plant coverage area, height, and number and diversity of species was observed in the parcels. The plant distribution in the pasture in the parcels in the second year (2016) after the application of sewage sludge in the project is shown in Tables 8 and 9 below. The dominant plant species are *Salvia absconditiflora*, *Acantho limonulicinum* var. *ulicinum*, *Astragalus onobrychis*, *Noaea mucronata*, *Alyssum linifolium* var *teheranicum*, *Bromus tectorum*, *Stipa ehrenbergiana*have also emerged. Since 2016 was a dry year, decreases in the plant population with rainfall are noteworthy. The average plant coverage area of the parcels is 48%; The average plant height was found to be 7 cm. There were decreases in plant coverage area, height, and number and diversity of species in the parcels compared to 2015. On the other hand, the number of plant diversity is higher compared to Control 2014. The plant distribution in the pasture in the parcels in the 3rd year (2017) after the application of sewage sludge in the project is shown in Tables 10, 11 below. The dominant plant species are *Salvia absconditiflora*, *Acantho limonulicinum* var. *ulicinum*, *Astragalus onobrychis*, *Noaea mucronata*, *Alyssum linifolium* var. *teheranicum*, *Alopecurus arundinaceus*, *Bromus tectorum*, *Eremopyrum bonaepartis* var. *sinaicum*, *Stipa ehrenbergiana*other species of the grass family that sheep like for grazing have also emerged. The average plant coverage area of the parcels is 52%; The average plant height was found to be 18 cm. There was an increase in the plant coverage area, height and especially the number and diversity of species in the plots.

Table 4. Botanical composition of 2014 (before application of sewage sludge)

Natural botanical composition-quatrate method in the parcels before the application of sewage sludge (biosolid) in the eroded pasture in June 2014																
Application method of the parcel			Vegetated area of the parcel -%					Average plant height in the plot -cm					Plant species in the plots***			
Subject	Dose	Block	1.Block	2.Block	3.Block	4.Block	Avg.	1.Block	2.Block	3.Block	4.Block	Avg.	1.Block	2.Block	3.Block	4.Block
S.s.Before mixing into the soil 0-5 cm with a rake	D0-Control	D0	40	40	45	40	41	7	7	7	7	7	1,3,4	1,3,4	1,2,3,4	1,2,3,4,5
	D1-1 tonda^{-1}	D1	50	45	50	50	49	7	7	7	7	7	1,2,4	1,2,5,9	1,2,3,4,6	1,2,4,5,10
	D2-2 tonda^{-1}	D2	40	50	40	35	41	7	7	7	7	7	1,2,3,4,7	1,2,4,5	1,2,4	1,2,4,10
	D4-4 tonda^{-1}	D4	35	50	40	45	43	6	7	7	7	6	1,2,4,5,6	1,2,3,4,9	1,2,4	1,3,4
	D8-8 tonda^{-1}	D8	50	50	40	40	45	7	7	7	7	7	1,2,3	1,2,3,4,8	1,2,3,4	1,2,4,6
S.s.Before spreading on the soil surface	S0-Control	S0	30	40	45	50	41	7	7	7	7	7	1,2,4	1,2,3,9	1,2,3,4,5	1,2,3,4,10
	S1-1 tonda^{-1}	S1	45	35	50	40	43	7	7	7	9	7	1,2,3,4	1,2,3,4	1,3,4,5,6	1,2,3,5
	S2-2 tonda^{-1}	S2	30	35	40	50	39	7	7	7	7	7	1,3,4,5,8	1,3,4,5	1,2,3,4,9	1,2,3,4
	S4-4 tonda^{-1}	S4	30	50	55	40	44	7	7	6	7	6	1,2,5,6	1,2,4,6	1,2,3,4,5	1,3,4
	S8-8 tonda^{-1}	S8	30	40	40	50	40	7	6	7	7	7	1,2,3,4	1,2,4	1,2,3,4	1,2,3,4
Cumulative		Average vegetated area of the parcels -%					42,5	Average plant height of the parcels-cm				7				

***The plant species in the table are listed below in numbers.

1	*Salvia absconditiflora*	6	*Thymus leucostomus*, endemic
2	*Acantho limonulicinum var. ulicinum*	7	cereals (50 %*agropyroncristatum*,50 %*stipa*)
3	*Astragalus onobrychis*	8	cereals (%one hundred*cynodondactylon*)
4	*Noaea mucronata*	9	cereals (% one hundred*stipa*)
5	*Alhagi maurorum subsp. maurorum*	10	*Onopordu macanthium*

Table 5. Areal distribution of plants in 2014

Types of plants	Cumulative number	%
Salvia absconditiflora	2220,5	55,51
Acantho limonulicinum var. ulicinum	627,5	15,69
Astragalus onobrychis	320	8,00
Noaea mucronata	426	10,65
Alhagi maurorumsubsp. maurorum	152	3,80
Thymus leucostomus, endemic	144	3,60
Onopordu macanthium	15	0,38
Cereals (other)	67	1,68
%one hundred *Cynodon dactylon*	5	0,13
Stipa	15	0,38
50 % *Agropyron cristatum*,50 % *Stipa*	8	0,20
Cumulative % one hundred	4000	100

Table 6. Botanical composition of 2015

Botanical composition-quatrate method in the parcels during the 1st year observation after the application of sewage sludge (biosolid) in the eroded pasture in June 2015.																
Application method of the parcel			Vegetated area of the parcel -%					Average plant height in the plot -cm					Plant species in the parcel ***			
Subject	Dose	Bl	1.Bl	2.Bl	3.Bl	4.Bl	Avg	1.Bl	2.Bl	3.Bl	4.Bl	Avg	1.Bl	2.Bl	3.Bl	4.Bl
S.s.After mixing 0-5 cm into the soil with a rake	D0-Control	D0	55	50	70	60	59	9	8	8	14	10	1,3,4,5,9,13	1,2,3,4,8	1,2,3,4,8,16	1,2,3,4,5,6,8,9
	D1-1 tonda^{-1}	D1	65	70	75	70	70	16	11	13	17	14	1,2,4,5,9,16	1,2,3,4,6,7,14	1,2,4,5,8,9,14,18	1,2,3,4,5,6,8,14
	D2-2tonda^{-1}	D2	90	80	80	75	81	13	11	18	19	15	1,2,3,5,9	1,2,4,5,8,9	1,2,3,4,5,8,9,14,15	1,2,3,4,5,8,14
	D4-4 ton da^{-1}	D4	70	80	75	85	78	18	13	20	21	18	1,2,4,5,6,9,17	1,2,3,4,7,9,12,15,20	1,2,3,4,7,9,14,16	1,2,3,4,5,6,8,9,12
	D8-8 ton da^{-1}	D8	60	75	70	70	69	18	18	20	21	19	1,2,3,5,9,15	1,2,3,4,5,6,7,9,16	1,3,4,5,9,11,14,15	1,2,3,4,5,9,14,15,17
S.s.After sprinkling on the soil surface	S0-Control	S0	55	70	60	65	63	11	9	9	9	10	1,2,4,9,13	1,2,3,4,8,9	1,2,3,6,8,12,14	1,2,3,4,7,8,9,13,17
	S1-1 ton da^{-1}	S1	70	85	70	90	79	13	9	17	19	14	1,2,3,4,5,9,14	1,2,3,4,5,7,8,9,14	1,4,6,7,8,9,17	1,2,3,4,5,6,8,9,14
	S2-2 ton da^{-1}	S2	85	85	70	80	80	13	13	13	19	14	1,3,4,5,6,10,13,14	1,3,4,5,6,8,9,19	1,2,3,4,5,8,9,14	1,2,3,4,5,14,21
	S4-4 tonda^{-1}	S4	90	80	70	75	79	13	13	18	19	16	1,2,3,4,5,7,8,9	1,2,4,5,7,9,13,14,17	1,2,3,4,5,9,14,15	1,3,4,5,8,9
	S8-8 tonda^{-1}	S8	90	70	65	70	74	17	18	20	20	19	1,2,3,4,5,9,13,15,18	1,2,4,9,13,14,15,16	1,2,3,4,9,10,14	1,3,4,5,9,14,15,21
Cumulative		Average vegetated area of the parcels -%					73	Average plant height of the parcels -cm				15				

***The plant species in the table are listed below in numbers.

1	*Salvia absconditiflora*	12	*Eremopyrum bonaepartis* var.*sinaicum*
2	*Acantho limonulicinum var. ulicinum*	13	*Stipa ehrenbergiana*
3	*Astragalus onobrychis*	14	*Panicum sp.*
4	*Noaea mucronata*	15	*Polygonum arenastrum*
5	*Alyssum linifolium*var.*teheranicum*	16	*Onopordu macanthium*
6	*Alhagi maurorum subsp. maurorum*	17	*Thymus leucostomus*, endemic
7	*Alopecurus arundinaceus*	18	*Bromus erectus*
8	*Androsace maxima*	19	*Onobrychis sativa* lam
9	*Bromus tectorum*	20	*Lepidum sp.*
10	*Cynodon dactylon*var.*villosus*	21	*Scabiosa argentea* L.
11	*Chenopodium album* L.		

It has been stated that the effects of fertilizers on the botanical composition of pastures can be explained by the fact that the nutrient needs of pasture plants are different from each other and the ability or ease of plant species to absorb nutrients from the soil, and that it gives the opportunity to change the botanical composition due to their effects on plant species (Bakır, 1985). Çetik (1985) stated that there are many plants that are resistant to drought and salinity around Karapınar, and that there are differences depending on whether the soil is barren or sandy. While these plants include the species, we detected in the pasture we worked on (*Noaeamucronata, Bromus tectorum*, *etc*.), the existence of many perennial and annual plants of the same genus but different species has also been reported. In another study conducted in Karapınar (Akköz and Bayram, 2012), 82 families and their 378 genera and 616 species were identified, and 102 of the taxa were stated to be endemic. Among the species detected: *Noaea mucronata*, *Alopecurus arundinaceus*, *Bromus tectorum*, *Cynodon dactylon*, *Chenopodium album*, *Thymus leucostomus*, *Bromus erectus*. It has been stated that plants such as *Stipa ebrenbergiana* and *Polygonum arenastrum*, which are the same in terms of genus but different in terms of species, were also detected in the pastures we researched (6 pastures) in Konya's problematic pastures (6 pastures) (salty, alkaline, stony, etc.). In the study (Yılmaz, 1977), it was stated that while species such as *Cynodon dactylon*, *Bromus erectus, Androsace maxima* were encountered in these places, there were also many other species. In this research, it was also stated that the most species in the botanical composition were from other families (except the Wheat and Legume families).

Table 7. Areal distribution of plants in 2015

Average % of areal distribution of plant species in cumulative parcel doses in 2015 Quatrat method.										
Plant Types in Different Dosing Applications	Application of mixing sewage sludge into 0-5 cm soil D dosage issues					Application of scattering sewage sludge on the soil surface S dosage issues				
	D0	D1	D2	D4	D8	S0	S1	S2	S4	S8
Salvia absconditiflora	52,5	35	32,5	22,5	30	45	36,25	32,5	27,5	33,75
*Acantho limonulicinum*var.*ulicinum*	7,5	12,5	15	6,25	6,25	18,75	6,25	2,5	10	8,75
Astragalus onobrychis	12,5	2,5	8,75	7,5	7,5	8,75	10	8,75	8,75	5,5
Noaea mucronata	15	13,75	8,75	11,25	8,75	8,75	10	12,5	13,75	8,75
Alyssum linifolium var. teheranicum	1,25	7,5	8,25	4	11,25		5	7,5	8,75	3,75
Alhagi maurorumsubsp. maurorum	1,25	4		4	1,25	2,5	2,5	6,25		
Alopecurus arundinaceus		1,25		3,75	1,25		1,75		2,5	
Androsace maxima	4	6,25	8,25	1,25		3,75	8,75	6,25	6,25	
Bromus tectorum	2,5	6,25	10,75	14	17,5	4,5	7,5	3,75	8,75	19,5
Cynodon dactylon var.*villosus*								1,25		2,5
Eremopyrum bonaepartis var. *sinaicum*				4		1,25				
Stipa ehrenbergiana	1,25					2,5		2,5	2,5	3,75
Panicum sp.		5,75	4,5	3,75	7,5	1,25	3,25	6,25	2,5	3,75
Polygonum arenastrum				0,75	5				1,25	5
Onopordu macanthium	1,25	1,25		0,75	1,25					1,25
Thymus leucostomus, endemic				7,5	1,25	2,5	8,75		3,75	
Bromus erectus		1,25								1,25
Scabiosa argentea L.								3,75		2,5
Chenopodium album L.					1,25					
Other	1	2,75	3,25	8,75		0,5		6,25	3,75	
Cumulative-% one hundred	100	100	100	100	100	100	100	100	100	100

Table 8. Botanical composition of 2016

Botanical composition-quatrate method in the parcels during the 2nd year observation after the application of sewage sludge (biosolid) in the eroded pasture in June 2016.																	
Application method of the parcel			Vegetated area of the parcel-%					Average plant height in the plot-cm					Plant species in the parcel***				
Subj.	Dose	Bl	1.Bl	2.Bl	3.Bl	4.Bl	Avg	1.Bl	2.Bl	3.Bl	4.Bl	Avg	1.Bl	2.Bl	3.Bl	4.Bl
S.s.After mixing 0-5 cm into the soil with a rake	D0-Control	D0	40	40	40	40	40	5	6	7	6	6	1,3,4,9	1,3,4,5,9	1,2,3,4,22	1,2,3,4,5,6,9,13
	D1-1 tonda^{-1}	D1	40	40	60	60	50	5	6	6	7	6	1,2,4,5,9	1,2,4,5,6,9,13	1,2,3,4,9,17	1,2,4,9,22
	D2-2 tonda^{-1}	D2	50	50	50	55	51	9	9	9	9	9	1,2,3,4,9,13	1,2,4,5,6,9,12,13	1,2,3,4,5,9	1,2,4,5,6,9,10,22
	D4-4 tonda^{-1}	D4	50	60	60	55	56	9	9	9	9	9	1,4,5,6,7,9,12, 17	1,2,3,4,5,9,13	1,2,3,4,5,9	1,3,4,5,6,9
	D8-8 tonda^{-1}	D8	40	50	50	55	49	8	9	8	9	8	1,2,3,9,13	1,2,3,5,6,9,10,13	1,2,3,4,5,9	1,2,3,4,5,9
S.s.After sprinkling on the soil surface	S0-Control	S0	40	40	40	50	43	6	6	7	6	6	1,2,4,5,9	1,2,3,5,9,16,22	1,2,3,4,5,6,9	1,2,3,4,9,13,17
	S1-1tonda^{-1}	S1	50	40	50	40	45	6	6	7	7	6	1,2,3,4,5,9,13	1,2,3,4,9	1,4,5,6,10,17	1,2,3,4,6,9
	S2-2 tonda^{-1}	S2	50	50	40	50	48	9	6	9	9	8	1,2,3,4,5,9	1,3,4,5,6,9	1,2,4,5,9,13	1,2,3,4,9,17,23
	S4-4 tonda^{-1}	S4	40	60	50	60	53	6	6	6	9	7	1,2,4,5,6,9	1,2,4,9,17	1,2,3,4,9	1,3,4,9
	S8-8 tonda^{-1}	S8	30	40	60	60	48	7	7	9	9	8	1,2,3,4,9	1,2,4,9	1,2,3,4,5,9,10	1,2,3,4,9
Cumulative			Average vegetated area of the parcels-%				48	Average plant height of the parcels-cm				7				

***The plant species in the table are listed below in numbers.

1	*Salvia absconditiflora*	12	*Eremopyrum bonaepartis* var.*sinaicum*
2	*Acantho limonulicinum*var. *ulicinum*	13	*Stipa ehrenbergiana*
3	*Astragalus onobrychis*	14	*Panicum sp.*
4	*Noaea mucronata*	15	*Polygonum arenastrum*
5	*Alyssum linifolium*var.*teheranicum*	16	*Onopordumacanthium*
6	*Alhagi maurorum subsp. maurorum*	17	*Thymus leucostomus*, endemic
7	*Alopecurus arundinaceus*	18	*Bromus erectus*
8	*Androsace maxima*	19	*Onobrychis sativa lam*
9	*Bromus tectorum*	20	*Lepidum sp.*
10	*Cynodon dactylon*var.*villosus*	21	*Scabiosa argentea* L.
11	*Chenopodium album* L.	22	*Xeranthemum annuum*
		23	*Phlomis armeniaca*

In another study covering different parts of Konya (pastures of Sağlık, Yapalı, Alibeyhüyüğü, İnli, Karadona villages), the Lup-Transect method was applied, and in the findings, the areas covered with vegetation were found to be between 13.75-38.56%, and 67.72% of this vegetation was covered by other plants. It has been reported that 28.21% consists of plants from the family of wheat and 4.17% consists of plants from the legume family (Özmen, 1983). While some of the species detected in the study conducted in Polatlı Acıkır natural pastures on the border of Konya, which are the continuation of steppe pastures (such as *Tyhmus leucostomus* var. *gypsaceus*, *Alyssum linifolium*, *Bromus tectorum*, *Noaea mucronata*), were the same as the species we found, some of them were found to have the same genus and different species. (Akman et al., 1990). In another study conducted in the pasture in Haymana-Yuvacık village, with fertilization at the end of 6 years of use, the rate of wild thyme (*Thymus squarrosus Fisch.*) in the vegetation decreased to less than 1% at the end of six years, while the rate of grasses increased from 20.5% to 73%. Here, the effect of fertilization was seen in terms of the ratios in the botanical composition (Tan, 1989). Since these results are under the same step conditions, they support the results determined in our research.

Table 9. Areal distribution of plants in 2016

Average % of areal distribution of plant species in cumulative parcel doses in the Quatrat method in 2016.										
Plant Types in Different Dosing Applications	Application of mixing sewage sludge into 0-5 cm soil D dosage issues					Application of scattering sewage sludge on the soil surface S dosage issues				
	D0	D1	D2	D4	D8	S0	S1	S2	S4	S8
Salvia absconditiflora	55	53,25	35	28,75	18,25	45	47	33,75	22,5	20
*Acantho limonulicinum*var.*ulicinum*	10	15	12,5	3,75	13	18,75	8,75	6,25	9,25	8,75
Astragalus onobrychis	10,75	1,75	5,5	3,75	7,5	8,75	8	10	5,5	3,75
Noaea mucronata	15	13,75	12	12,5	3,75	11,75	10,75	17,5	10,75	13,75
Alyssum linifolium var. teheranicum	1,25	1,75	8	12,5	7,5	2,75	2,5	8,75	2,5	1,25
Alhagi maurorumsubsp. Maurorum	1,25	1,25	3,75	2,5	1,25	2,5	3	2,5	2,5	
Alopecurus arundinaceus				1,25						
Androsace maxima										
Bromus tectorum	3,75	6,25	13	23,75	39,25	4,75	8,75	16,25	43,25	50
Cynodon dactylon var. *Villosus*			3,25		0,75		1,25			2,5
Chenopodium album L.										
Eremopyrum bonaepartis var.*sinaicum*			1,25	5						
Stipa ehrenbergiana	2,5	2,5	5	2,5	8,75	1,25	2,5	1,25		
Panicum sp.										
Polygonum arenastrum										
Onopordu macanthium						0,75				
Thymus leucostomus, endemic		3,75		3,75		2,5	7,5	1,25	3,75	
Bromus erectus,										
Onobrychis sativa lam										
Lepidum sp.										
Scabiosa argentea L.										
Xeranthemum annuum		0,75	0,75			1,25				
Phlomis armeniaca								2,5		
other	0,5									
Cumulative-% one hundred	100	100	100	100	100	100	100	100	100	100

Table 10. Botanical composition of 2017

Botanical composition-quatrate method in the parcels during the 3rd year observation after the application of sewage sludge (biosolid) in the eroded pasture in June 2017																
Application method of the parcel			Vegetated area of the parcel -%					Average plant height in the parcel - cm					Plant species in the parcel ***			
Subj.	Dose	Bl	1.Bl	2.Bl	3.Bl	4.Bl	Avg	1.Bl	2.Bl	3.Bl	4.Bl	Avg	1.Bl	2.Bl	3.Bl	4.Bl
S.s.After mixing 0-5 cm into the soil with a rake	D0-Control	D0	50	45	50	45	48	15	15	15	15	15	1,2,3,4,17	1,2,3,4,5,9,13	1,3,4,12,18	1,2,3,4,6,9,12,13
	D1-1 tonda^{-1}	D1	50	50	45	50	49	15	17	17	20	17	1,2,3,4,5,20	1,2,3,4,5,6,12,13	1,2,3,4,5,9,12,13,17	1,2,4,5,6,8,9,13
	D2-2 tonda^{-1}	D2	50	45	60	50	51	17	17	20	18	18	1,2,3,4,5,7,9,10,12	1,2,4,5,6,12,20	1,2,3,4,5,9,12,14,15,20	1,2,4,5,6,9
	D4-4 tonda^{-1}	D4	60	55	55	60	58	20	20	20	20	20	1,2,4,5,9,12,13,17,20	1,2,3,4,5,7,9,12	1,2,3,4,5,7,11,12,15	1,3,4,5,9,12,20
	D8-8 tonda^{-1}	D8	60	55	60	60	59	20	20	22	22	21	1,2,4,5,9,12,13,20	1,2,3,4,5,6,9,12,13	1,3,4,5,9,11,12,16	1,2,3,4,5,9,12,13,14
S.s.After sprinkling on the soil surface	S0-Control	S0	45	45	45	40	44	13	15	15	15	15	1,2,4,21	1,2,3,4,12,13,18,20	1,2,3,4,6,14,18,19	1,2,3,4,17
	S1-1 tonda^{-1}	S1	50	50	45	45	48	17	17	15	20	17	1,2,3,4,5,9,12,13,20	1,2,3,4,5,14,22	1,2,3,4,5,6,9,12,17	1,2,3,4,5,6,9,12
	S2-2 tonda^{-1}	S2	50	55	45	50	50	17	18	17	18	18	1,3,4,5,6,10,11,13	1,2,3,4,5,6,9,12	1,2,3,4,5,20	1,2,3,4,5,7,9,11,12,20
	S4-4 tonda^{-1}	S4	55	60	55	55	56	20	22	20	20	21	1,2,4,5,12,13,17,20	1,2,4,5,7,9,11,12,14,17	1,2,3,4,5,6,12,16	1,3,4,5,9,12,15
	S8-8 tonda^{-1}	S8	60	70	55	60	61	20	24	20	26	23	1,2,3,4,6,9,11,12,13,16,18,20	1,2,3,4,5,7,9,11,20	1,2,3,4,5,9,12,13,15	1,2,3,4,5,9,11,13,14,20
Cumulative			Average vegetated area of the parcels -%				52	Average plant height of the parcels - cm				18				

***The plant species in the table are listed below in numbers.

1	*Salvia absconditiflora*	12	*Eremopyrum bonaepartis var. sinaicum*

2	*Acantho limonulicinum* var. *ulicinum*	13	*Stipa ehrenbergiana*
3	*Astragalus onobrychis*	14	*Nigella arvensis* var. *glauca*
4	*Noaeamucronata*	15	*Papaver hybridum*
5	*Alyssum linifolium* var.*teheranicum*	16	*Onopor dumacanthium*
6	*Alhagi maurorum subsp. Maurorum*	17	*Thymus leucostomus*, endemic
7	*Alopecurus arundinaceus*	18	*Bromus erectus*
8	*Agropyron elongatum*	19	*Centaurea carduiformis subsp*. var.
9	*Bromus tectorum*	20	*Scabiosa argentea* L.
10	*Cynodon dactylon* var. *Villosus*	21	*Xeranthemum annuum*
11	*Descurainia sophia subsp. sophia*	22	*Phlomis armeniaca*

Table 11. Areal distribution of plants in 2017

Average % of areal distribution of plant species in cumulative parcel doses in the Quatrat method in 2017.										
Plant Types in Different Dosing Applications	Application of mixing sewage sludge into 0-5 cm soil D dosage issues					Application of scattering sewage sludge on the soil surface S dosage issues				
	D0	D1	D2	D4	D8	S0	S1	S2	S4	S8
Salvia absconditiflora	49,25	29,25	21,25	13,75	6,25	43	27,5	32,5	17,5	9,38
*Acantho limonulicinum*var. *ulicinum*	6,25	12,5	7,5	10	5	11,25	12,5	8,75	6,25	8,75
Astragalus onobrychis	12	6,25	3,75	10	5	7,5	10	10	5,5	6,25
Noaea mucronata	16,25	22	21,75	14,5	16,25	16,25	15	13,75	18,75	14,38
Alyssum linifolium var. *teheranicum*	1,75	5,5	16,25	18,75	16,25		7,25	12,5	13,75	9,5
Alhagi maurorumsubsp. Maurorum	2,5	4,25	3,75		1,25	1,25	5	3,75	2,5	1,25
Alopecurus arundinaceus			0,75	1				0,75	2,5	0,75
Agropyron elongatum		3								
Bromus tectorum	1,75	2	9,25	6,25	21,25		6,25	6,25	11,25	16,13
Cynodon dactylon var.*Villosus*			2,5					1,25		
Descurainia sophia subsp. sophia				1,25	8,25			3,75	1,25	6,88
Eremopyrum bonaepartis var. *sinaicum*	1,5	1,25	6,25	11,25	8,75	1,25	2,75	2,5	7	6,38
Stipa ehrenbergiana	5	9		5	7,5	3,75	2,5	1,25	2,5	8,75
Nigella arvensis var. *glauca*			1,25		1,25	1,75	2,5		1,25	1,75
Papaver hybridum			0,75	0,75					1,25	0,5
Onopordu macanthium					0,5				1,25	1,25
Thymus leucostomus, endemic	1,25	3,75		1,25		7,5	5		5	
Bromus erectus	2,5			1,25		2				1,25
Centaurea carduiformis subsp. var.						1,25				
Scabiosa argentea L.		1,25	5	5	2,5	2,5	1,25	3	2,5	6,88
Xeranthemum annuum						0,75				
Phlomis armeniaca							2,5			
Cumulative-% one hundred	100	100	100	100	100	100	100	100	100	100,00

Conclusion

Unlike soil texture, soil structure can be changed by appropriate agricultural regulations. Stable forms of soil organic carbon, such as humus, within the soil aggregate can retain up to seven times its own weight in water. Efficient management of water and nutrients is achieved by adding organic matter to sandy soils (Corsi, 2018). Benefits of organic matter to the soil and plants in the pasture; It helps retain moisture, provides a good environment for young plants, space and food for microorganisms, and helps loosen and enrich the soil. Organic fertilizer also plays an important role in the establishment of new pastures in poor, erosion-prone areas (Thompson, 1950). Degradation of pastures is a faster process in arid and semi-arid regions. Here, it is not possible to rehabilitate the vegetation without first stabilizing the soil, that is, keeping the soil in place and correcting the deteriorated physical and chemical properties of the soil (Bakır, 1987).

Considering the evaluations in the final report of this project, in regions with a rainfall regime where rainfall is at least 250-300 mm, in marginal, eroded, weak pasture lands, human health can be used in our country, if it complies with all the criteria of the "Regulation on the Use of Sewage Sludge in Soil". Provided that the necessary precautions are taken, it turns out that the D application has a feasible result of 1 ton/da (DM) in the method of mixing into the soil to a depth of 0-5 cm, once every 3 years. This recommended dose is valid for the ecological conditions in this region where the research was conducted, and similar studies are needed to recommend it in different ecological regions of Turkey (Mücevher *et al.,* 2020). As stated by different researchers and the results of this research show, Sustainable Pasture in Our Country In management (SPM), it is expected to improve the eroded, degraded and weak pasture areas with the optimum dose of stabilized, suitable domestic treatment sludge specified in this study, in accordance with the criteria specified in the regulation on the use of sewage sludge in soil, and the data obtained will contribute to the relevant institutions and organizations at the point of implementation is considered.

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