American Journal of Plant Sciences, 2023, 14, 191-201
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Environmental Impact of Bush Burning on the Physico-Chemistry of Mangrove Soil at Eagle Island, Niger Delta, Nigeria

Aroloye O. Numbere[1]*, Chinedu J. Obanye[2]

[1]Department of Animal and Environmental Biology, University of Port Harcourt, Port Harcourt, Nigeria
[2]Center for Molecular Biosciences and Biotechnology, Michael Okpara University of Agriculture, Nigeria
Email: *aroloyen@yahoo.com

How to cite this paper: Numbere, A.O. and Obanye, C.J. (2023) Environmental Impact of Bush Burning on the Physico-Chemistry of Mangrove Soil at Eagle Island, Niger Delta, Nigeria. *American Journal of Plant Sciences*, **14**, 191-201.
https://doi.org/10.4236/ajps.2023.142015

Received: December 14, 2022
Accepted: February 24, 2023
Published: February 27, 2023

Copyright © 2023 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

Abstract

Wetland soils derive their chemical composition from the sedimentary rock underneath. Among the metals produced are trace and nutrient elements which facilitate plant growth. Bush burning near mangrove forest is a common practice that has not been given much attention despite its negative impact on the environment. We thus hypothesize that the application of fire on wetland soil will negatively impact the soil chemistry. We collected soil samples from burnt and unburnt soilsat different distances from the point of burning to compare the concentration of nutrient elements (Calcium (Ca^{2+}), iron (Fe), Magnesium (Mg), Nitrate (NO_3^-), Phosphate (PO_4^{3-}) and Potassium (K). The result revealed that there was significant difference between metals ($P < 0.05$). Iron had the highest overall concentration in burnt (10743.75 ± 1508.39 mg/kg) and unburnt (8854.02 ± 1734.86 mg/kg) soils. In contrast, there was no significant difference in the concentration of metals in burnt and unburnt soils ($P = 0.07$). The order of metal concentration in the burnt soil is Fe > Mg > PO_4^{3-} > Ca^{2+} > K > NO_3^- while the order of metal concentration in the unburnt soil is Fe > Mg > Ca^{2+} > PO_4^{3-} > K > NO_3^-. There was also no correlation between distance and soil metal concentration ($r = -0.05$; $P > 0.05$). The result showed that burning does not negatively impact the wetland soil, rather it causes an increase in soil metal concentration probably due to the addition of ash from the burning process, which fertilizes the soil.

Keywords

Environmental Impact, Fire, Mangrove Forest, Physico-Chemistry, Soil

1. Introduction

Mangrove forest is one of the most productive ecosystems in the world [1] because of the presence of large amount of biodiversity, which includes micro to macro-organisms, as well as invertebrates and vertebrates. Mangroves play numerous ecological roles such as coastal protection, stabilization, climate regulation, carbon storage, water filtration and purification. Other supporting services of mangroves are nutrient cycling, soil formation and serving as habitat and nesting ground for fishes and birds. Mangroves are often found in swampy wetland environment that is rich in metals [2]. Different types of weeds inhabit the soil and serve as primary producers in the food chain [3]. The presence of weed around the mangrove forest makes it susceptible to bush fires especially during the dry season. In addition, anthropogenic activities such deforestation, sand mining, building of houses, reclamation, and oiling activities destroy the mangrove vegetation [4] and lead to sediment build up in the mangrove forest resulting in the conversion of swampy to sandy soil [5]. The sandy soil supports the proliferation of weeds and macrophytes. The growth of weeds on the degraded section of the forest attracts non-mangrove species such as arthropods (butterflies, bees, wasp and ants), rodents (bush rats), snakes and different bird species. The bushes around the forest are deliberately set on fire which endangers the entire ecosystem, this leads to an adverse effect of heat on the soil and vegetation [6] [7]. Burning activities occur during the dry season when the leaves of the plants are dry (October-March) and easily combustible. The burning has environmental impact on the forest soil [8] and by extension on other organisms in the mangrove forest [4]. The volatilized soil chemicals enter the atmosphere under high temperature and fall back as acid rain [9], furthermore, the liquified chemicals percolate through the ground water aquifer during rainfall to contaminate the ground water source and neighboring water body [10] [11]. The raging fire during burning kills the grasses and organisms that inhabit the soil. The problem is that bush burning destroys the soil structure [12] [13] and leads to erosion of chemicals into the swampy mangrove soil and surrounding water. The leaching of heavy metals down the soil profile results in the loss of soil nutrients, which negatively impacts the soil surface organisms. The topsoil becomes depleted of nutrients and soil improvements organisms such as earthworms and insects that burrow into the soil to facilitate decomposition and aeration. The heat from the bush fire also leads to the migration of mobile organisms while immobile organisms are killed [14]. The smoke and soot from the burning plants increase the atmospheric particulate matter, which is detrimental to health [15]. It also contributes to the increase in atmospheric carbon dioxide thereby increasing the global warming. Erosion transports chemical laden water in the river thereby increasing its chemical composition and concentration. This may be detrimental to aquatic organisms [16]. The heat from burning shrinks the mangrove leaves and impacts their photosynthetic capability. Specifically, we decided to determine the concentration of the following metals (Ca^{2+}, Fe, Mg,

NO_3^-, PO_4^{3-} and K) because they are useful to plant growth [17] [18].

The aim of this study is to compare the concentration of selected metals between burnt and unburnt soil in the wetland environment. Thus, the objectives of the study are 1) to determine the concentration of each metal in the study area, 2) to compare the concentration of soil metals in burnt and unburnt sites, and 3) to determine the correlation between distance and soil metal concentration.

2. Materials and Methods

2.1. Description of Study Area

The study was carried out in Eagle Island (N04˚47.525; E006˚58.593; Figure 1), a coastal community rich in mangrove forest, at the fringes of Port Harcourt, which is an oil producing city, in the Niger Delta, Nigeria. The specific location is situated behind the Rivers State University. The site was formerly used for sand mining operations but was later abandoned and left to lie fallow. The patch of land at this site before being used for sand mining was cleared of its mangrove trees and made bare and having few weeds still growing. The population of the weed aggressively increases in size and is burnt in October each year to reduce the foliage. The burning scorches the soil and wipes out a large population of soil-and plant-based organisms. Thus, this study was carried out to investigate the impact of the burning on the soil chemical concentration.

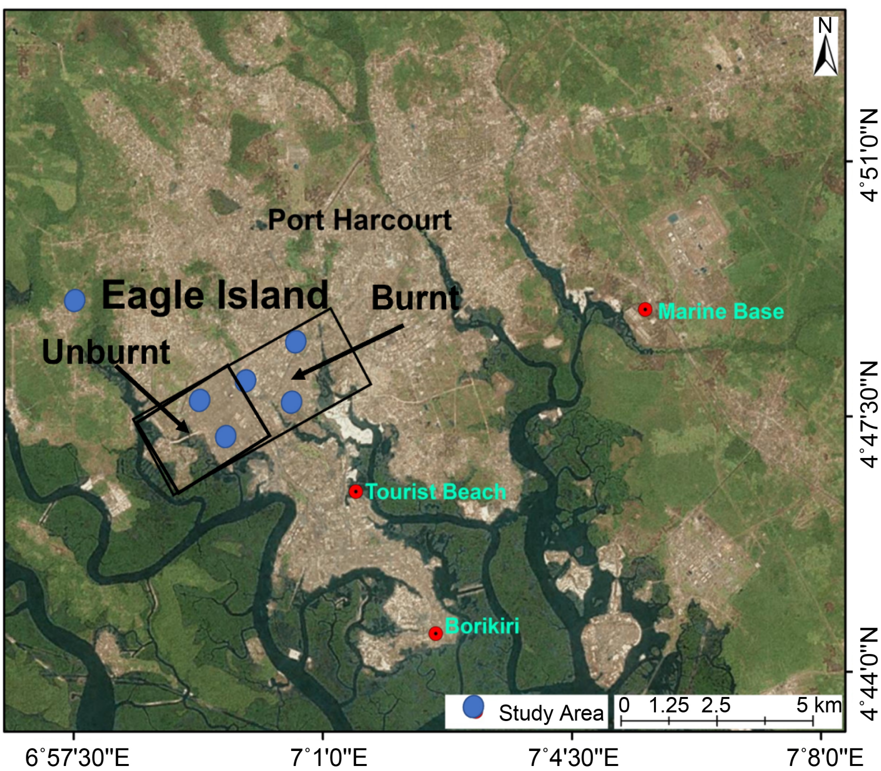

Figure 1. Map of study area showing burnt and unburnt areas at Eagle Island, Niger Delta, Nigeria.

2.2. Experimental Design

Involves the delineation of the sampling site into burnt and unburnt (control) areas. In all, ten ($n = 10 \times 5 = 50$) soil samples were collected at different distances from the actual burnt site. Four (n = 4) soil samples were collected from the burnt area while six (n = 6) soil samples were collected at the unburnt area (**Figure 2**).

2.3. Sample Collection

Surface soils were collected at a depth of 20 cm with a soil augur. Five composite samples at different distances in the burnt and unburnt areas were collected as mixed. A representative sample of about 1 kg soil was placed in a cellophane bag and sent to the laboratory for further analysis.

2.4. Laboratory Procedure

The soil samples were air-dried for 12 days and ground to pass through a sieve of 2 mm mesh size. The pH, soil moisture and temperature were measured with a soil tester called AgraTronix (USA). It is a 4 in 1 tester to determine best soil conditions. The concentrations of K, PO_4^{3-}, NO_3^-, Ca^{2+}, Mg and Fe was analyzed with the Buck scientific atomic absorption spectrophotometer 205 in mg/kg of soil.

2.5. AAS Analysis of Soil Sample

The procedure of soil analysis involves the placement of 2.0 g of soil in a beaker with the addition of 10 ml of HNO_3 (nitric acid). The mixture is thoroughly stirred and heated at 120˚C. The HNO_3 breaks down and vaporizes the soil

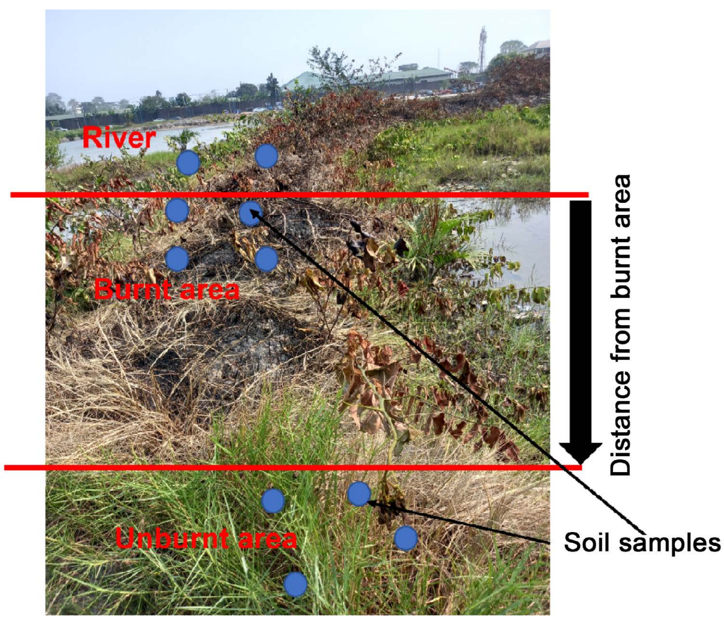

Figure 2. Experimental design of the soil and distance of collection at Eagle Island, Niger Delta, Nigeria.

organic components leaving only the inorganic components. Distilled water (10 ml) is then added to rinse the beaker to recover sample. The next stage is the analysis of the sample in the atomic absorption spectrophotometric machine.

2.6. Statistical Analysis

An analysis of variance (ANOVA) was conducted since there was multiple samples *i.e.*, >2 per block (n = 50) to test whether there was any significant difference in soil metal concentration between the burnt and unburnt areas [19]. Logarithmic transformation of the data was performed to meet assumptions of normality and homoscedasticity [20]. Furthermore, Pearson's product–moment correlation was done to compare whether there was any significant difference between distance of soil collection and concentration of metals. All analysis was done in R statistical environment 4.2.2 [21].

3. Results

3.1. The General Physico-Chemistry of the Study Area

In situ testing shows that the soil is sandy and slightly acidic (~pH = 6.6 - 7.2) (**Table 1**). The temperature range is 29.6˚C - 33.9˚C and the soil moisture is below 1.0 because of the dryness. The soil color ranges from brown, dark brown to black. The burnt area is dark brown to black because of the charcoal while the unburnt area is brown in color. The distance of sample collection ranges from 30 - 150 m from the point of burning.

3.2. Comparison between Concentration of Metals

The ANOVA result indicates that there is a significant difference ($F_{6, 54} = 62.07$, $P < 0.001$, **Table 2**) between the metals analyzed. In the burnt region Fe concentration is the highest (10743.75 ± 1508.39 mg/kg) followed by Mg (650.18 ± 145.74 mg/kg) and PO_4^{2+} (284.75 ± 42.73 mg/kg). Nitrate has the least overall concentration (85.06 ± 22.63 mg/kg). The order of metal concentration in the burnt soil is Fe > Mg > PO_4^{3-} > Ca^{2+} > K > NO_3^-. Similarly, in the unburnt area Fe has the highest concentration (8854.02 ± 1734.86 mg/kg) followed by Mg (497.12 ± 116.22 mg/kg) and Ca (234.22 ± 86.02 mg/kg). Nitrate has the least concentration (60.93 ± 10.35 mg/kg). The order of metal concentration in the unburnt soil is Fe > Mg > Ca^{2+} > PO_4^{3-} > K > NO_3^-.

Table 1. General soil physico-chemistry of study area at Eagle Island, Niger Delta, Nigeria (±SE).

Study Site	Coordinates	pH	Pore water salinity (ppt)	Temperature (˚C)	Soil moisture	TOC (%)	Mean Distance
Burnt	N04˚47.525; E006˚58.593	6.6 ± 0.1	1.34 ± 0.01	33.9 ± 0.2	0.01 ± 0.001	1.11 ± 0.01	90.00 ± 21.21
Unburnt	N04˚47.317; E006˚58.593	7.2 ± 0.2	1.16 ± 0.01	29.6 ± 0.1	0.01 ± 0.002	1.02 ± 0.01	

Table 2. Mean concentration of metals in burnt and unburnt soils at Eagle Island, Niger Delta, Nigeria (±SE).

Soil type	Metals (mg/kg)					
	Ca^{2+}	Fe	Mg	NO_3^-	PO_4^{3-}	K
Burnt	241.69 ± 55.96	10743.75 ± 1508.39	650.18 ± 145.74	85.06 ± 22.63	284.75 ± 42.73	171.54 ± 27.40
Unburnt	234.22 ± 86.02	8854.02 ± 1734.86	497.12 ± 116.22	60.93 ± 10.35	193.38 ± 50.49	135.95 ± 14.80

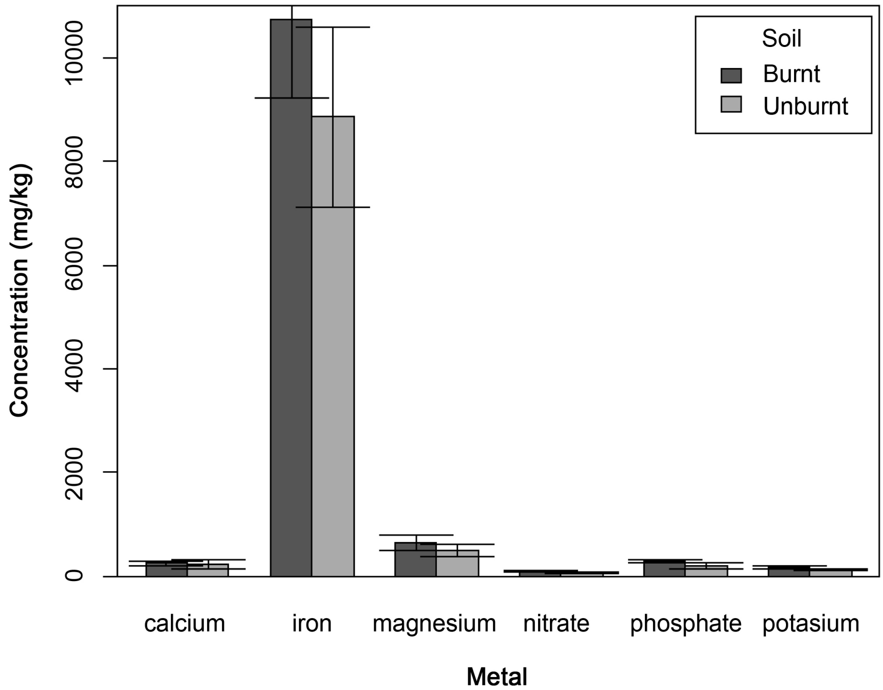

Figure 3. Metal concentration in burnt and unburnt soil at Eagle Island, Niger Delta, Nigeria (±SE).

3.3. Comparison of Metal Concentration between Burnt and Unburnt Soil

The ANOVA result reveal that there is no significant difference in the concentration of metal between burnt and unburnt soil ($P_{1, 58} = 0.13$, P = 0.72, Figure 3).

3.4. Correlation between Soil Metal Concentration and Distance

There was little or no correlation between soil metal concentration and distance ($t = -0.36542$, $df = 58$, p-value = 0.7161; cor = −0.04792637, Figure 4). However, the negative correlation sign means that there is a tendency for the metal concentration to reduce with increasing distance away from the burnt area.

4. Discussion

4.1. Comparison between Metal Concentration

The physico-chemistry of mangrove and wetland soils is significant towards the stability of soil living organisms [22] and plays key role in the soil-plant trophic

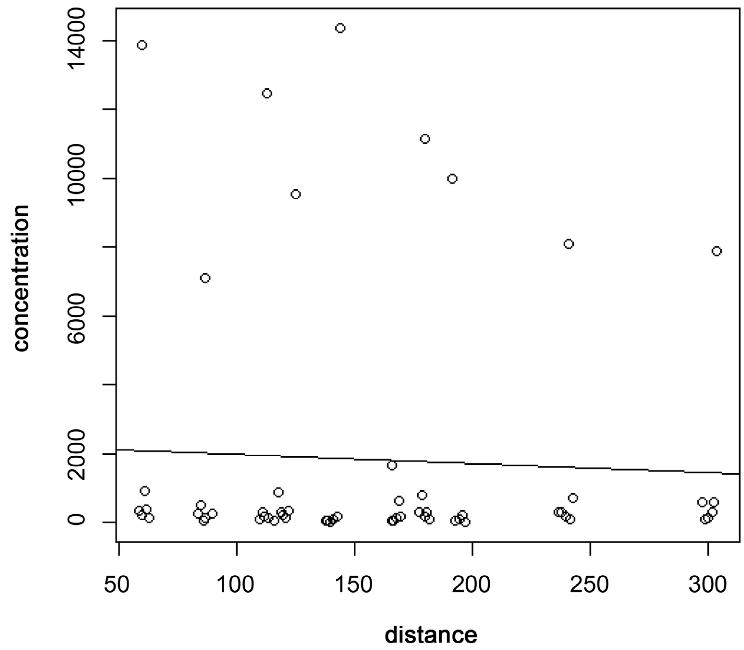

Figure 4. Correlation of soil metal concentration (mg/kg) versus distance (m) at Eagle Island, Niger Delta, Nigeria.

pathway. Thus, the degradation of soil chemical composition through the application of fire can impact revealed that the concentration of iron was the highest because of the sedimentary makeup of the base rock of the coastal environment as shown by previous studies in that location [3] [23]. Iron exudes from the base soil to the topsoil after every ebb tide, which mostly occur because of an earlier sand filling activity that brought sandy soil from sea bottom onto the land surface in the study area [24]. Magnesium too was the next dominant metal in the study sites and had originated from silicates in the base rock. Magnesium is a decomposition product that comes from weathering. Magnesium is taken up by plants in the form of Mg^{2+} ion. Phosphorus is also a micronutrient that is absorbed by the plant root through [25] [26]. It is found in small quantity, and, mainly available in the form of orthophosphates which also originates from primary and secondary minerals available in the soil. Nitrates have the least concentration and are the primary source of nitrogen used for plant growth. Previous study had also reported low nitrate concentration in the same site [24]. The sandy soil in the study area has low organic composition, which has caused the overall nitrate concentration to be low compared to the swampy mangrove soil that is rich in litter. Metal-laden soil influences the growth of mangrove by acting as trace elements that provide nutrients for the growth and development of the leaves, stems and roots of mangroves. They metals are products of litter decomposition and enrich mangrove soils to facilitate tree growth.

4.2. Comparison of Metal Concentration between Burnt and Unburnt Soils

There were no significant differences in the concentration of metals between burnt and unburnt soil. This situation is probably caused by the dissolution and distribution of metals by rainfall [27] between the surface and sub-surface soil three months after the burning of the grasses in October. Another reason is because of the harmattan wind, which causes dryness across the site. The wind energy carries and deposits sediment-laden air across the site, including the burnt and unburnt areas. However, despite the non-significance of the statistical test ($P > 0.05$), the concentration of all metals in burnt soil was higher than the concentration of metals in unburnt soil (**Table 1**, **Figure 3**). This study reveals that burning of the bush increases soil metal concentration rather than depleting it. This might be attributed to the addition of burnt plant ash to soil, which creates a plant-soil pathway for the enrichment of soil chemicals. Agriculturally, bush burning is used to supplement soil fertility [28]. Therefore, the black charcoal and ash from the burnt plants increases the organic content of the soil [29], which had elevated the nitrate concentration in the burnt soil [30] compared to the unburnt soil. The result shows that controlled bush burning can be used to enrich soil nutrients. The negative implication of burning is the destruction of soil-based organisms such as earth worms and crickets that burrow into the soil to increase aeration and soil fertility. The metals investigated are relevant for plant growth and development. The grasses are often burnt during the dry season when the vegetation is dry and can easily be incinerated. Furthermore, plant ash deposited on the surface of the soil becomes liquified and percolate into the sub-soil and move down the soil profile during the raining season. Movement of nutrient chemicals in the sandy soil can help transport metals to the neighboring mangrove swamp [31]. However, the effect of this metal migration into the mangrove forest is not determined in the study. The burning also destroys disease-causing organism that inhabit the burnt areas of the wetland. The elimination of these organisms will prevent them from migrating to the mangrove forest to cause disease and stress to the trees. Moreover, there are other current risk mangroves face in the study area such as sand mining leading to deforestation, hydrocarbon pollution from marine transportation, accumulation of plastic waste and urban development projects [32], which all contribute to the elimination of mangroves in the coastal areas of the Niger Delta.

Bush burning has side effect on volatile organic elements that disappear from the soil through vaporization. The burn areas also are deprived of soil-based organisms (e.g., earthworm and insects) that die under the heat of the fire. Despite the negative effect of bush burning it can also have a positive role on the mangrove by eliminating disease causing organisms that hibernate in the bushes and later migrate to infect the mangroves.

4.3. Correlation between Distance and Metal Concentration

The correlation result shows that the metal concentration was higher nearer the burnt site compared to the site far away from the point of burning, which signifies that burning increases the metal concentration of the soil [33]. The time of burning and sample collection is spaced apart by three months, which might have influenced the outcome of the soil physico-chemistry.

5. Conclusion

There are few studies on bush burning near mangrove forest in the Niger Delta. This study thus, reveals that burning has a positive impact chemically, but may nevertheless, have adverse effects on the soil structure and profile. We thus, recommend regulated and controlled burning of weed around mangrove forest as a means of preventing disease-causing organisms from migrating to the mangrove forest. Another finding of this study is the chemical enrichment of the soil, which in the long run may have a positive impact on the overall well-being of the mangrove forest. Future studies will consider temporal variation of the soil physico-chemistry by collecting samples during the time of burning and some months away from the time of burning.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ahmed, S., Sarker, S.K., Freiss, D.A., Kamruzzaman, M., Jacobs, M., Islam, M.A., Alam, M.A., Suvo, M.J., sani, M.N.H., Dey, T. and Naabeh, C.S.S. (2022) Salinity Reduces Site Quality and Mangrove Forests Functions. From Monitoring to Understanding. *Science of the Total Environment*, **853**, Article ID: 158662. https://doi.org/10.1016/j.scitotenv.2022.158662

[2] Dey, g., Banerjee, P., Maity, J.P., Sharma, R.K., Gnanachandrasamy, G., Huang, Y.H., Huang, H.B. and Chen, C.Y. (2022) Heavy Metals Distribution and Ecological Risk Assessment Including Arsenic Resistant PGPR in Tidal Mangrove Ecosystem. *Marine Pollution Bulletin*, **181**, Article ID: 113905. https://doi.org/10.1016/j.marpolbul.2022.113905

[3] Numbere, A.O. (2020) Diversity and Chemical Composition of Weeds in Sand-Filled Mangrove Forest at Eagle Island, Niger Delta, Nigeria. *American Journal of Plant Sciences*, **11**, 994. https://doi.org/10.4236/ajps.2020.117071

[4] Numbere, A.O. (2022) Application of GIS and Remote Sensing towards Forest Resource Management in Mangrove Forest of Niger Delta. In: Jhariya, M.K., *et al*., Eds., *Natural Resources Conservation and Advances for Sustainability*, Elsevier, Amsterdam, 433-459. https://doi.org/10.1016/B978-0-12-822976-7.00024-7

[5] Maghsodian, Z., Sanati, A.M., Tahmasebi, S., Shahriari, M.H. and Ramavandi, B. (2022) Study of Microplastics Pollution in Sediments and Organisms in Mangrove Forests: A Review. *Environmental Research*, **208**, Article ID: 112725. https://doi.org/10.1016/j.envres.2022.112725

[6] Mack, R.N., Simberloff, D., Mark Lonsdale, W., Evans, H., Clout, M. and Bazzaz, F.A. (2000) Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. *Ecological Applications*, **10**, 689-710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

[7] Gill, N.S., Stallman, J.K., Pratt, L., Lewicki, J., Elias, T., Nadeau, P.A. and Yelenik, S.

(2023) Out of the Frying Pan and into the Fire: Effects of Volcanic Heat and Other Stressors on the Conservation of a Critically Endangered Plant in Hawai'i. *Environmental Conservation*, 1-8. https://doi.org/10.1017/S0376892922000480

[8] Ajikah, L.B., Adekanmbi, O.H., Oyebanji, O.O., Agboola, O.O., Akomaye, F.A., Adeonipekun, P.A. and Ogundipe, O.T. (2022) Floral Composition and Diversity of the Lagos Coastal Environment, South-Western, Nigeria. *African Journal of Ecology*. https://doi.org/10.1111/aje.13080

[9] Zhou, Z., Lu, J., Feng, Q. and Liu, W. (2022) Review on Occurrence, Speciation, Transition and Fate of Sulfur in Typical Ultra-Low Emission Coal-Fired Power Plants. *Journal of the Energy Institute*, **100**, 259-276. https://doi.org/10.1016/j.joei.2021.12.004

[10] Lee, T.H., Chuah, J. and Snyder, S.A. (2022) Occurrence of Emerging Contaminants in Southeast Asian Environments: Present Status, Challenges, and Future Prospects. *ACS ES&T Water*, **2**, 907-931. https://doi.org/10.1021/acsestwater.1c00453

[11] Ramos, E., Padilla-Reyes, D., Mora, A., Barrios-Piña, H., Kant, S. and Mahlknecht, J. (2022) Assessment of Artificial Sweeteners as Wastewater Co-Tracers in an Urban Groundwater System of Mexico (Monterrey Metropolitan Area). *Water*, **14**, 3210. https://doi.org/10.3390/w14203210

[12] Filkov, A.I., Cawson, J., Swan, M.H. and Penman, T.D. (2023) Wildland Fire. In: Meacham, B.J. and McNamee, M., Eds., *Handbook of Fire and the Environment*: *Impacts and Mitigation*, Springer, Cham, 235-271. https://doi.org/10.1007/978-3-030-94356-1_7

[13] Karthik, V., Bhaskar, B.V., Ramachandran, S. and Kumar, P. (2023) Black Carbon Flux in Terrestrial and Aquatic Environments of Kodaikanal in the Western Ghats, South India: Estimation, Source Identification, and Implication. *Science of the Total Environment*, **854**, Article ID: 158647. https://doi.org/10.1016/j.scitotenv.2022.158647

[14] Anderson, J. and Prosser, R.S. (2023) Potential Risk to Aquatic Biota from Aerial Application of Firefighting Water Additives. *Environmental Pollution*, **316**, Article ID: 120651. https://doi.org/10.1016/j.envpol.2022.120651

[15] Ramirez, C.E., Quinete, N., de Astudillo, L.R., Arroyo-Mora, L.E., Seba, D. and Gardinali, P. (2022) Elemental Composition of Airborne Particulate Matter from Coastal South Florida Area Influenced by African Dust Events. *Aeolian Research*, **54**, Article ID: 100774. https://doi.org/10.1016/j.aeolia.2022.100774

[16] Qaiser, N., Sidra, S., Javid, A., Iqbal, A., Amjad, M., Azmat, H. and Ali, Z. (2023) Microplastics Abundance in Abiotic and Biotic Components along Aquatic Food Chain in Two Freshwater Ecosystems of Pakistan. *Chemosphere*, **313**, Article ID: 137177. https://doi.org/10.1016/j.chemosphere.2022.137177

[17] Jose, J.V. (2023) Physiological and Molecular Aspects of Macronutrient Uptake by Higher Plants. In: Aftab, T. and Hakeem, K.R., Eds., *Sustainable Plant Nutrition*: *Molecular Interventions and Advancements for Crop Improvement*, Academic Press, Cambridge, 1-21. https://doi.org/10.1016/B978-0-443-18675-2.00010-9

[18] Sparks, D.L., Singh, B. and Siebecker, M.G. (2023) Environmental Soil Chemistry. Elsevier, Amsterdam.

[19] Quinn, G.P. and Keough, M.J. (2002) Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511806384

[20] Logan, M. (2010) Biostatistical Design and Analysis Using R: A Practical Guide. John Wiley and Sons, London. https://doi.org/10.1002/9781444319620

[21] R Development Core Team (2013) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.

[22] Sharma, S. and Singh, D.N. (2015) Characterization of Sediments for Sustainable Development: State of the Art. *Marine Georesources & Geotechnology*, **33**, 447-465. https://doi.org/10.1080/1064119X.2014.953232

[23] Numbere, A.O. (2017) Concentrations of Iron and Other Physico-Chemical Parameters in Ground and Surface Water in Some Mangrove Forest Areas in the Niger Delta, Nigeria. *African Journal of Applied Zoology and Environmental Biology*, **19**, 1-12.

[24] Numbere, A.O. (2021) Natural Seedling Recruitment and Regeneration in Deforested and Sand-Filled Mangrove Forest at Eagle Island, Niger Delta, Nigeria. *Ecology and Evolution*, **11**, 3148-3158. https://doi.org/10.1002/ece3.7262

[25] Marschner, P. and Rengel, Z. (2023) Nutrient Availability in Soils. In: Rengel, Z., Cakmak, I. and White, P.J., Eds., *Marschner's Mineral Nutrition of Plants*, Academic Press, Cambridge, 499-522. https://doi.org/10.1016/B978-0-12-819773-8.00003-4

[26] Penn, C.J., Camberato, J.J. and Wiethorn, M.A. (2023) How Much Phosphorus Uptake Is Required for Achieving Maximum Maize Grain Yield? Part 1: Luxury Consumption and Implications for Yield. *Agronomy*, **13**, 95. https://doi.org/10.3390/agronomy13010095

[27] Zhang, Z., Li, J., Wang, H., Li, Y. and Duan, X. (2023) Impact of Co-Contamination by PAHs and Heavy Metals on Micro-Ecosystem in Bioretention Systems with Soil, Sand, and Water Treatment Residuals. *Journal of Cleaner Production*, **383**, Article ID: 135417. https://doi.org/10.1016/j.jclepro.2022.135417

[28] Guo, Y., Boughton, E.H., Liao, H.L., Sonnier, G. and Qiu, J. (2023) Direct and Indirect Pathways of Land Management Effects on Wetland Plant Litter Decomposition. *Science of the Total Environment*, **854**, Article ID: 158789. https://doi.org/10.1016/j.scitotenv.2022.158789

[29] Jamir, T.I., Sharma, Y.K. and Sharma, S.K. (2022) Changes in Soil Properties and Fertility Status Caused by Slash-and-Burn Fires in Nagaland. *Journal of the Indian Society of Soil Science*, **70**, 355-363. https://doi.org/10.5958/0974-0228.2022.00029.9

[30] Zeng, J., Han, G., Zhang, S. and Qu, R. (2023) Nitrate Dynamics and Source Identification of Rainwater in Beijing during Rainy Season: Insight from Dual Isotopes and Bayesian Model. *Science of the Total Environment*, **856**, Article ID: 159234. https://doi.org/10.1016/j.scitotenv.2022.159234

[31] Guo, Z., Liu, J., Zeng, H., Xiao, X., Liu, M., Hong, H. and Yan, C. (2023b) Variation of Glomalin-Metal Binding Capacity in 1 m Soil Profiles from Mangrove Forests to Mudflat and Affected Factor Analysis. *Science of the Total Environment*, **863**, Article ID: 160890. https://doi.org/10.1016/j.scitotenv.2022.160890

[32] Numbere, A.O. and Aigberua, A.O. (2022) Characterization of Tidally Accumulated Plastic Waste and the Effect on Mangrove Ecosystems at Eagle Island, Niger Delta, Nigeria. *Journal of Coastal Research*. https://doi.org/10.22541/au.164960114.47164275/v1

[33] Cheung, D.J. and Giardino, J.R. (2023) Debris Flow Occurrence under Changing Climate and Wildfire Regimes: A Southern California Perspective. *Geomorphology*, **422**, Article ID: 108538. https://doi.org/10.1016/j.geomorph.2022.108538