**Mycoremediation of Heavy Metals from Wupa River Using *Aspergillus niger* and *Aspergillus fumigatus***

**Abstract**

Water pollution by heavy metals poses significant environmental and health risks, particularly in regions with high anthropogenic activities. This study evaluated the bioremediation potential of *Aspergillus niger* and *Aspergillus fumigatus* for heavy metal removal from water samples collected from the Wupa River in Abuja, Nigeria. The physicochemical parameters and heavy metal concentrations (lead, copper, and zinc) of the water samples were analyzed. The fungi were screened for their ability to remediate heavy metals, and their removal efficiency was assessed over an 8-day period. Results showed that *Aspergillus niger* achieved the highest removal efficiency for zinc (90%), while *Aspergillus fumigatus* was most effective for lead (83.77%). The consortium of both fungi demonstrated significant removal efficiency for all three metals, with lead removal reaching 83.77%. This study highlights the potential of fungal bioremediation as a sustainable and eco-friendly method for heavy metal removal from contaminated water bodies.

**Keywords**: Bioremediation, Heavy metals, *Aspergillus niger*, *Aspergillus fumigatus*, Wupa River,

**1.0 Introduction**

Water is a valuable [natural resource](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/natural-resource) that covers around 70% total earth's surface. Water bodies are crucial because they provide a significant portion of the water needed to sustain life on Earth, and their scarcity may have an impact on both domestic and agricultural activities (Mishra, 2023; Mohammed et al., 2024; Ibrahim et al., 2024a). Freshwater use has grown by 10% between 2000 and 2010 as a result of recent expansion in global population. The majority of freshwater worldwide is utilized for irrigation of farms (40%) and 20–40% is used for human use (Mohammed et al., 2020; Mohammed et al., 2021). [Water pollution](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/water-pollution) has a variety of distinct sources, including the discharge of industrial and field waste into nearest water bodies, [oil tanker](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/oil-tanker) leaks, the overuse of fertilizers and pesticides for crop protection, [sewage sludge](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sewage-sludge), and many others (Ibrahim et al., 2023). The major causes of aquatic pollution are prevalent in urban areas, activities like the direct release of polythene bags into rivers and streams (Mohammed et al., 2021), excessive chemical use, dirt, dust, and debris, and irrational use of chemicals. When introduced into aquatic habitats, contaminants including [petroleum hydrocarbons](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/petroleum-hydrocarbon), heavy metals, and pesticides can have a direct harmful effect (Adamu et al., 2022). Water pollution with heavy metals is one of the greatest consequences of industrialization in the area of mining, petroleum refining, automobiles and paints (Montase et al., 2022). Heavy metals have been defined and described as “naturally occurring metals having atomic number greater than 20 and an elemental density greater than 5 g cm−3. Heavy metals are prominent contaminants because they are toxic, non-biodegradable in the environment, and easily accumulated in living organisms (Montas et al., 2022; Ibrahim et al., 2024b).

Microbial bioremediation efforts benefit from the large natural diversity of microorganisms featuring a broad spectrum of pathways to metabolise or co-metabolise a wide range of compounds (Ibrahim et al., 2024 a&c). Furthermore, the adaptation of microorganisms to novel compounds is comparably higher than the typical short generation time of microbes is accompanied by high rates of evolutionary adaptation. Microbes may even utilize otherwise hazardous compounds for energy gain or as cellular building blocks. Furthermore, with the aid of genetic manipulation, microbial metabolisms can be “improved” or “designed” to target specific pollutants. With the aid of synthetic biology tools, microbial communities can even be assembled to target specific pollution scenarios (Borchert *et al.,* 2021; Xiang *et al.,* 2021). Bioremediation strategies are either in-situ, i.e., pollution is treated at the location where it occurs or ex-situ, where the polluted matrix is removed, or treatment is carried out elsewhere. Most common examples of microbial bioremediation are cleaning up industrial spills, such as oil spills (Patel et al., 2019). For oil spills, both bioaugmentation (i.e., the application of microbes to the pollution site) and bio stimulation (i.e., stimulation of the natural microbial community to perform faster and more efficiently) are used (Sharma *et al.,* 2020).

Mycoremediation has the potential to be an economic and eco-friendly successful solution to any problems of soil and water pollution (Ibrahim et al., 2024d). Due to their robust growth, extensive hyphal network, production of adaptable extracellular ligninolytic enzymes, high surface area to volume ratio, resistance to heavy metals, ability to adapt to changing pH and temperature, and presence of metal-binding proteins, fungi are an excellent candidate for the remediation of various pollutants. (Khan *et al.,* 2019). It can be used to remediate numerous contaminants produced by different industries like dyes, herbicides, and pharmaceutical drugs in situ. As an alternative, it can be used in bioreactors. Bioreactors are systems that have their physicochemical properties constantly maintained to promote microbial growth (Aragão *et al.,* 2020). Various harmful compounds can be degraded by fungi. Changing local soil and water conditions can aid in fostering biological activity and, as a result, the degradation/removal of toxic substances via mycoremediation (Muzhda & Yahya, 2023). Fungi have also been proven to be effective in the removal of heavy metals such as lead (Pb) and cadmium (Cd). Fungi may accumulate these metals from water and store them in their tissues because they are already in their simplest condition and will not be degraded further (mycelia or fruiting mushroom bodies). After being utilized in mycoremediation, mushrooms used for this purpose must be treated as hazardous waste (Muzhda & Yahya, 2023). Because heavy metals cannot be decomposed or destroyed, they are stable and persistent environmental contaminants. As a result, their toxicity poses significant environmental and health risks, requiring a continual search for efficient, cost-effective technology for detoxification of metal-contaminated sites, so by using microorganisms such as fungi this can be solved. The study aims to evaluate the efficiency of two types of fungi.

**2. Materials and Methods**

**2.1 Study Area and Sample Collection**

Water samples were collected from Wupa River, Abuja, at locations influenced by anthropogenic activities. Samples were then transported to the laboratory in sterile plastic bottles for analysis.

**2.2 Physicochemical Analysis** Parameters including temperature, pH, electrical conductivity, turbidity, dissolved oxygen (DO), and biochemical oxygen demand (BOD) were measured using standard APHA (2012) methods as described by Oladeji, (2020).

**2.3 Heavy Metal Analysis** method described by Rashed & Muhammed, (2021) was used to anlyze the Lead (Pb), copper (Cu), and zinc (Zn) concentrations were determined using Atomic Absorption Spectrophotometry (AAS). Standard solutions were prepared for calibration, and results were compared to WHO permissible limits.

**2.4 Fungal Preparation and Bioremediation Experiment** Pure isolates of *A. niger* and *A. fumigatus* were obtained from the Nigerian Institute for Pharmaceutical Research and Development (NIPRD). Fungal inocula were prepared in potato dextrose broth and introduced into contaminated water samples. Bioremediation was monitored over 8 days, with residual metal concentrations analyzed post-treatment (Hassan et al., 2019).

**3. Results**

## 3.0 Physicochemical parameters of water samples collected from Wupa River;

The mean physicochemical parameters of water samples collected from Wupa River are presented in table 1. All the measured physicochemical parameters observed in water sample from Wupa River are within the world health organization maximum permissible limit for freshwater

**Table 1****: Physicochemical parameters of water samples collected from Wupa River**

|  |  |  |
| --- | --- | --- |
| Parameters  | Mean ± S.E | WHO permissible limit |
| Temperature  | 28.6 ± 0.11 | 40 |
| pH | 7.21 ± 0.07 | 7.0 – 8.5 |
| Conductivity  | 0.25 ± 0.00 | 600 |
| BOD | 4.45 ± 0.59 | 5 |
| DO | 5.09 ± 0.05 | 5 |
| Turbidity | 4.71 ± 0.14 | <40 |
| Chloride | 5.26 ± 1.12 |  |
| Sulphate  | 12.00 ± 1.90 | 250-400 |
| Nitrate  | 20.53 ± 0.50 | 50 |
| Total hardness | 10.43 ± 0.26 |  |
|  |  |  |

**3.2 Heavy metal concentration of water samples collected from Wupa River**

The heavy metal concentration of water samples collected from Wupa River are presented in Table 2. Lead record highest (11.09 ± 0.84 mg/L) in terms of mean concentration while zinc record lowest. All the heavy metal observed in water sample from Wupa River are within the world health organization maximum permissible limit for freshwater.

**Table 2** **Heavy metal concentration of water samples collected from Wupa River**

|  |  |  |
| --- | --- | --- |
| Heavy metal  | Mean ± S.E | WHO permissible limit |
| Lead (Pb)  | 11.09 ± 0.84 | 0.02 |
| Copper (Cu) | 5.49 ± 0.05 | 1.3 |
| Zinc (Zn) | 0.10 ± 0.00 | 0.12 |

**Table 3 Heavy metal bioremediation removal of *Aspergillus niger* and *Aspergillus fumigatus* in water samples collected from Wupa River**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameters  | Control | AN | AF | ANF |
| Temperature  | 28.6 ± 0.11 | 26.63 ± 0.37 | 26.9 ±0.52 | 26.73 ± 0.45 |
| pH | 7.21 ± 0.07 | 8.01 ± 0.00 | 8.02 ± 0.04 | 7.95 ± 0.10  |
| Conductivity  | 0.25 ± 0.00 | 0.19 ± 0.03 | 0.21 ± 0.02 | 0.22 ± 0.01 |
| BOD | 4.45 ± 0.59 | 2.88 ± 0.13 | 2.50 ± 0.49 | 2.65 ± 0.40 |
| DO | 5.09 ± 0.05 | 2.53 ± 0.54  | 2.62 ± 0.49 | 3.07 ± 0.09 |
| Turbidity | 4.71 ± 0.14 | 2.88 ± 0.32 | 3.04 ± 0.13 | 3.00 ± 0.91 |
| Chloride | 5.26 ± 1.12 | 2.41 ± 0.63 | 2.33 ± 0.58 | 2.30 ± 0.38  |
| Sulphate  | 12.00 ± 1.90 | 5.44 ± 2.31 | 4.54 ± 0.77 | 3.72 ± 0.44 |
| Nitrate  | 20.53 ± 0.50 | 8.39 ± 0.81 | 6.48 ± 0.85 | 6.13 ± 0.95 |
| Total hardness | 10.43 ± 0.26 | 8.44 ± 0.38 | 7.52 ± 0.52 | 7.02 ± 0.12 |
| Lead | 11.09 ± 0.84 | 3.63 ± 0.41 | 3.62 ± 0.73 | 1.80 ± 0.18  |
| Cupper | 5.49 ± 0.05 | 3.05 ± 0.05 | 1.91 ± 0.12 | 1.25 ± 0.42 |
| Zinc | 0.10 ± 0.00 | 0.009 ± 0.00 | 0.01 ± 0.00 | 0.003 ± 0.00 |

## 3.3 Screening of *Aspergillus niger* and *Aspergillus fumigatus* for heavy metal removal in water samples collected from Wupa River

The potentials of heavy metal removal of *Aspergillus niger*in water samples collected from Wupa River are shown in figure 1. The absorbance of *A niger* increases from day 1 in all the treated heavy metals and the control sample which record increase in absorption as sampling day increases (Figure 1).

Figure 2. The potentials of heavy metal removal of *Aspergillus* *niger* in prepared heavy metal stock solutions.

**3.4 Heavy metal removal efficacy of *Aspergillus niger* and *Aspergillus fumigatus* in water samples collected from Wupa River**

The potentials of heavy metal removal of *Aspergillus niger* and *Aspergillus fumigatus* in water samples collected from Wupa River are shown in figure 2 to 7. Water samples treated with *Aspergillus niger* (AN), *Aspergillus fumigatus* (AF) and combination of *Aspergillus niger* and *Aspergillus fumigatus* shows a good Bioremoval efficacy as there is significant reduction in all the heavy metals of the water samples.

Figure 3: Bioremoval efficiency of *A.niger* and *A. fumigatus* for lead
Key: *Aspergillus niger*(AN), *Aspergillus fumigatus*(AF), *Aspergillus niger*+ *Aspergillus fumigatus(*ANF*)*

Figure 4: Bioremoval efficiency of *A.niger* and *A.fumigatus* for copper
Key: *Aspergillus niger*(AN), *Aspergillus fumigatus*(AF), *Aspergillus niger*+ *Aspergillus fumigatus(*ANF*)*

Figure 5: Bioremoval efficiency of *A. niger* and *A. fumigatus* for zinc
Key: *Aspergillus niger*(AN), *Aspergillus fumigatus*(AF), *Aspergillus niger*+ *Aspergillus fumigatus(*ANF*)*

Figure 6: Bioremoval efficiency of heavy metals for *Aspergillus niger*key:Lead(pb), Copper(Cu), Zinc(Zn)

Figure 7: Bioremoval efficiency of heavy metals for *Aspergillus fumigatus*key:Lead(pb), Copper(Cu), Zinc(Zn)

Figure 8: Bioremoval efficiency of heavy metals for *A. niger* and *A. fumigatus* consortia
key:Lead(pb), Copper(Cu), Zinc(Zn)

##

The mean percentage removal of heavy metals from wastewater by *Aspergillus niger* was presented in Figure 6. *A.niger* recorded the highest metal removal efficiency in Zn (90), whereas the lowest metal removal was observed in Cu (44.26).

The mean percentage removal of heavy metals from wastewater by *Aspergillus fumigatus* was presented in Figure 7. *A.fumigatus* recorded the highest metal removal efficiency in Zn (90), whereas the lowest metal removal was observed in Cu (65.21).

The mean percentage removal of heavy metals from wastewater by *A. Niger and A. fumigatus* consortiawas presented in Figure8. *A. Niger and A. fumigatus* consortiarecorded the highest metal removal efficiency in Pb (83.77), whereas the lowest metal removal was observed in Zn (70).

Bioremoval efficiency of *Aspergillus niger* and *Aspergillus fumigatus* for Pb was presented in Fig 3. The highest value was recorded in *A.niger* and *A.fumigatus* consortia (83.77) for treatment water. whereas the lowest was in A. niger (67.18).

Bioremoval efficiency of *Aspergillus niger* and *Aspergillus fumigatus* for Cu was presented in Fig 4. The highest value was recorded in *A.niger* and *A.fumigatus* consortia (77.05) for treatment water. whereas the lowest was in *A. niger* (44.26).

Bioremoval efficiency of Aspergillus niger and Aspergillus fumigatus for Zn was presented in Fig 5. The highest values were recorded in *A.niger* and *A.fumigatus* (90) for treatment water. whereas the lowest was in *A. niger* and *A.fumigatus* consortia (70).

**4. Discussion**

The presence of heavy metals in water bodies poses significant risks to both human health and aquatic ecosystems. Heavy metals such as lead (Pb), copper (Cu), and zinc (Zn) are persistent pollutants that do not degrade naturally and can accumulate in biological systems over time (Ibrahim et al., 2023; Ibrahim et al., 2024a,b&c). In this study, water samples collected from Wupa River exhibited heavy metal concentrations exceeding WHO permissible limits, highlighting the severity of contamination in the region. The high levels of Pb and Cu observed in the study are likely due to effluent discharge from industrial activities and wastewater treatment plants.

Bioremediation using fungi, particularly *Aspergillus niger* and *Aspergillus fumigatus*, has shown great promise in mitigating heavy metal contamination by producing organic acids (such as citric and oxalic acids) that enhance the solubilization and bioavailability of heavy metals, facilitating their removal from contaminated environments (Ibrahim et al., 2024a). These fungi possess metal-binding proteins and enzymatic systems that enable them to bioaccumulate, transform, or degrade toxic pollutants, making them effective agents for soil and water remediation (Dwivedi, 2023). The findings of this study demonstrate that both fungal species significantly reduced Pb, Cu, and Zn concentrations in water samples, with the highest removal efficiency recorded for Zn (90%) this is in accordance with previous studies in Wupa wastewater who recorded 98% reduction of zinc by *Aspergillus niger* (Ibrahim et al.,2024b) and a 99% removal of zinc was seen by *Bacillus subtillis* (Ibrahim et al., 2024b&C). The ability of these fungi to sequester heavy metals can be attributed to their cell wall composition, which contains functional groups such as carboxyl, amino, and hydroxyl groups that facilitate metal binding (Priyadarshini et al., 2021). Furthermore, the extracellular enzymes produced by these fungi enhance metal chelation, thereby increasing their bioremediation potential (Dinakarkumar et al., 2024).

The efficiency of *A. niger* and *A. fumigatus* in heavy metal removal is also influenced by environmental factors such as pH, temperature, and dissolved oxygen levels. The observed increase in pH after fungal treatment suggests that the metabolic activities of the fungi contribute to the neutralization of acidic contaminants, thereby creating a more favorable environment for metal precipitation and removal (Ibrahim et al., 2024).

One of the significant advantages of fungal bioremediation is its cost-effectiveness and environmental sustainability compared to conventional methods such as chemical precipitation and ion exchange (Ibrahim et al., 2024b). Unlike traditional approaches, fungal bioremediation does not generate secondary waste and is capable of treating large volumes of contaminated water with minimal energy input (Kapahi & Sachdeva, 2019). The ability of *A. niger* and *A. fumigatus* to thrive in diverse environmental conditions makes them suitable candidates for large-scale bioremediation applications (Borchert et al., 2021). Despite the promising results observed in this study, several challenges must be addressed to optimize fungal bioremediation processes. The efficiency of heavy metal removal can be influenced by the presence of competing ions and organic matter, which may interfere with metal-binding sites on fungal cell walls (Dhanushree & Hina Kousar, 2017; Dell’Anno et al., 2022).

**5. Conclusion and Recommendations**: The findings of this study underscore the potential of *A. niger* and *A. fumigatus* as effective agents for heavy metal bioremediation. Their ability to reduce Pb, Cu, and Zn concentrations, coupled with their production of bioactive secondary metabolites, highlights their significance in sustainable water treatment strategies. Future research should focus on optimizing fungal growth conditions and exploring the potential of fungal consortia to enhance bioremediation efficiency. Additionally, genetic modifications and metabolic engineering approaches could be explored to improve fungal resistance to high metal concentrations and increase biosorption capacity

**Reference**

Adamu, K.M., Mohammed, Y.M., Ibrahim, U.F., Abdullahi, I.L., & Jimoh, Y.O. (2022). Assessment of some physical, chemical and biological parameters of Lake Dangana, Niger State, Nigeria. *The Zoologist,* 20. 133-140*.* http://dx.doi.org/10.4314/tzool.v20i1.17.

Ali-Shtayeh, M.S., Jamous, R.M.F. & Abu-Ghdeib, S.I. (1999). Ecology of cycloheximide-resistant fungi in field soils receiving raw city wastewater or normal irrigation water, *Mycopathologia*, 144: 39 – 54

Aragão, M. S., Menezes, D. B., Ramos, L. C., Oliveira, H. S., Bharagava, R. N., Ferreira, L. F. R., Teixeira, J. A., Ruzene, D. S. & Silva, D. P. (2020). Mycoremediation of vinasse by surface response methodology and preliminary studies in air-lift bioreactors. *Chemosphere,* 244, 125432.

Borchert, E., Hammerschmidt, K., Hentschel, U. & Deines, P. (2021). Enhancing microbial pollutant degradation by integrating eco-evolutionary principles with environmental biotechnology. *Trends in Microbiology*, 29, 908–918. doi: 10.1016/ j.tim.2021.03.002

Borchert, E., Hammerschmidt, K., Hentschel, U. & Deines, P. (2021). Enhancing microbial pollutant degradation by integrating eco-evolutionary principles with environmental biotechnology. *Trends in Microbiology*, 29, 908–918. doi: 10.1016/ j.tim.2021.03.002

Dell’Anno, F., Rastelli, E., Buschi, E., Barone, G., Beolchini, F. & Dell’Anno, A. (2022). Fungi Can Be More Effective than Bacteria for the Bioremediation of Marine Sediments Highly Contaminated with Heavy Metals. *Microorganisms*, 10, 993. https://doi.org/10.3390/ microorganisms10050993

Dhanushree, M.S. & Hina, K. (2017). A Study on Bioremediation Potency of *Aspergillus Niger* in Treatment of Pulp and Paper Mill Effluent and Evaluation of Phytotoxicity Effect of Treated Effluent on Vigna Radiata. *SSRG Int. J. Agric. Env. Sci (SSRG – IJAES).* 4(4): 97-99.

Dinakarkumar, Y., Gnanasekaran, R., Reddy, G. K., Vasu, V., Balamurugan, P., & Murali, G. (2024). Fungal bioremediation: An overview of the mechanisms, applications and future perspectives. *Environmental Chemistry and Ecotoxicology*.

Dubey, S., Shri, M., Gupta, A., Rani, V., & Chakrabarty, D. (2018). Toxicity and detoxification of heavy metals during plant growth and metabolism. *Environmental Chemistry Letters*, *16*, 1169-1192.

Dwivedi, S. K. (2023). Fungi mediated detoxification of heavy metals: Insights on mechanisms, influencing factors and recent developments. *Journal of Water Process Engineering*, *53*, 103800.

Hassan, A., Pariatamby, A., Ahmed, A., Auta, H. S., & Hamid, F. S. (2019). Enhanced bioremediation of heavy metal contaminated landfill soil using filamentous fungi consortia: a demonstration of bioaugmentation potential. *Water, Air, & Soil Pollution*, *230*, 1-20.

Ibrahim, U.F, Adamu, K.M, Mohammed, S.S.D., Chukwu, M.N., & Mabekoje, O.O. (2024a). Bioremediation of Selected Heavy Metals from Industrial Influent Collected at Wupa Wastewater Treatment Plant, Abuja. *Nile Journal of Engineering and Applied Science*, 2 (1), 212-223. <http://dx.doi.org/10.5455/NJEAS.193825>

Ibrahim, U.F., Adamu, K.M., Mohammed, S.S.D., Chukwu, M.N, & Mabekoje, O.O. (2024b). Bioremediation Potentials of *Bacillus subtillis* and *Aspergillus* niger on Selected Heavy Metals from Wupa Wastewater. *Nigerian Journal of Biotechnology*. 41(1), 25-31. <https://doi.org/10.4314/njb.v41i1.4>

Ibrahim, U.F., Adamu, K.M., Mohammed, S.S.D., Chukwu, M.N. & Umar H.F. (2023). Utilization of *Bacillus subtilis and Aspergillus niger* for the Bioremediation of Heavy Metals in the WUPA Wastewater Treatment Plant, Abuja. *The 2nd International Conference on Multidisciplinary Engineering and Applied Sciences* (ICMEAS-2023).

Ibrahim, U.F., Mohammed, Y. M., Ndanusa, A.H., & Badamasi, A. (2024c). Application of *Pseudomonas aeruginosa* and *Bacillus subtilis* for Heavy Metal Bioremediation in Wastewater from Wupa Wastewater Treatment Plant, Abuja, Nigeria. *Nile Journal of Engineering and Applied Science*, 2(1), 1-10. http://dx.doi.org/10.5455/NJEAS.147823

Ibrahim, U.F., Ndanusa, A.H., Ibrahim, A.A., Ibrahim, M.I., Shuaibu S., Olokpo S.O. & Mohammed, Y.M. (2024d). Physicochemicasl characteristic, molecular characterization of bacteria and fungi isolates found in the Nile Stream, Abuja Nigeria. *Dutse Journal of pure and applied Sciences ,*10 (4c), 63-73. <https://doi.org/10.4314/dujopas.v10i4c.6>

Jimenez-Bonilla, P. (2019). *Enhancing the robustness of Clostridium saccharoperbutylacetonicum N1-4 for butanol production through metabolic engineering and cell immobilization strategies* (Doctoral dissertation, Auburn University).

Kapahi, M. & Sachdeva, S. (2019). Bioremediation options for heavy metal pollution. *Journal of Health and Pollution*, 9, 1-20. https://doi.org/10.5696/2156-9614-9.24.191203

Khan, I., Aftab, M., Shakir, S., Ali, M., Qayyum, S., Rehman, M. U., Haleem, K. S. & Touseef, I. (2019). Mycoremediation of heavy metal (Cd and Cr)–polluted soil through indigenous metallotolerant fungal isolates. *Environmental monitoring assessment,* 191, 1-11.

Liu, J., & Liu, G. (2018). Analysis of secondary metabolites from plant endophytic fungi. *Plant pathogenic fungi and oomycetes: methods and protocols*, 25-38.

Mishra, R. K. (2023). Fresh water availability and its global challenge. *British Journal of Multidisciplinary and Advanced Studies*, *4*(3), 1-78.

Mohammed, Y. M., Arimoro, F. O., Ayanwale, A. V., Adamu, K. M., Ismail, A. and Umar M. and Kanki, H. (2020). Assessment of some physicochemical parameters of Moussa stream, Bida, Niger State Nigeria. *Journal of Public Health and Environmental Pollution,* 4(2), 020-024, November, 2020

Mohammed, Y.M., Adamu,K.M., Edegbene, Ovie T.T., Ibrahim, B.U., Danjuma S., and Edegbene, A.O., (2024). Development of macroinvertebrates‑based multimetric index to assess the ecological health of a rural river in North‑central Nigeria. Biologia https://doi.org/10.1007/s11756-024-01824-0

Mohammed, Y.M., Arimoro, F. O. Ayanwale, A.V. Adamu, K.M., Keke, U. N., Abubakar, M. D. & Achebe. A.C. (2021). The current state of water quality and benthic invertebrate fauna in Chikke Stream (North-Central Nigeria)*. Ukranian Journal of Ecology*, 11(3), 26-34.DOI: 10.15421/2021\_136

Montaser, D.A., Easa, S.M., Mansour, M.M.A. & Mohamed, S.S. (2022). The Efficiency of some Locally Isolated Fungi on Removing Pb, Cd, Cr and Ni and their Mixture from Wastewater

Muzhda, Q.Q. & Yahya, A.S. (2023). Bioremediation of Heavy Metals by using *Aspergillus niger* and *Candida albicans*. *ZANCO Journal of Pure and Applied Sciences,* 35(3), 180-186.

Oladeji, S. O. (2020). Evaluation of physicochemical parameters in wastewater from Muhammad Ayuba dam in Kazaure, Jigawa state, Nigeria. *Archives of Agriculture and Environmental Science*, *5*(4), 482-488.

Patel, S., Homaei, A., Patil, S., & Daverey, A. (2019). Microbial biosurfactants for oil spill remediation: pitfalls and potentials. *Applied microbiology and biotechnology*, *103*(1), 27-37.

Priyadarshini, E., Priyadarshini, S. S., Cousins, B. G., & Pradhan, N. (2021). Metal-Fungus interaction: Review on cellular processes underlying heavy metal detoxification and synthesis of metal nanoparticles. *Chemosphere*, *274*, 129976.

Raji, Z., Karim, A., Karam, A. & Khalloufi, S. (2023). Adsorption of Heavy Metals: Mechanisms, Kinetics, and Applications of Various Adsorbents in Wastewater Remediation—A Review. *Waste*, 1, 775–805. https://doi.org/10.3390/ waste103004

RASHED, R. O., & MUHAMMED, S. M. (2021). Evaluation of heavy metal content in water and removal of metals using native isolated bacterial strains. *Biodiversitas Journal of Biological Diversity*, *22*(8).

Sharma, R., Singh, N. S., Dhingra, N. & Parween, T. (2020). *Bioremediation of oilspills from ShoreLine environment,” in Modern age waste water problems*: Solutions using applied nanotechnology. Eds. M. Oves, M. O. Ansari, M. Zain Khan, M. Shahadat and I. M. I. Ismail (Cham: Springer International Publishing), 275–291

Xiang, L., Li, G., Wen, L., Su, C., Liu, Y. & Tang, H. (2021). Biodegradation of aromatic pollutants meets synthetic biology. *Synthetic & Systematic Biotechnology*. 6, 153–162. doi: 10.1016/j.synbio.2021.06.001