

RESEARCH ARTICLE

EVALUATION OF NON-POINT SOURCE HEAVY METAL POLLUTION ON A DRAINAGE NETWORK OUTLET

Erewari Ukoha-Onuoha*, Charity Chisa Dike

Department of Agricultural and Environmental Engineering Rivers State University, Nkpolu-Oroworukwo Port-Harcourt, Rivers State, Nigeria

*Corresponding Author Email: erewari.ukoha@ust.edu.ng

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 23 September 2024

Revised 11 October 2024

Accepted 18 November 2024

Available online 26 November 2024

ABSTRACT

This study assessed the impact of road runoff on the ecological risk of heavy metals in the Eagle Island River. Runoff samples were collected from a drainage network of secondary and primary drains and an outlet. The drains were situated in the Rivers State University, Port Harcourt campus while the outlet is the Eagle Island River. Samples from the secondary drain, primary drain, upstream and downstream of outlet were labelled as SD, PD, US, and DS respectively. Samples were collected and analyzed using standard methods between the months of August and October, 2023. Heavy metals including Cd, Cr, Cu, Pb, and Zn were analyzed using Atomic Absorption Spectrophotometer Instrument (GBC XplorAA, Australia). Total pollution of heavy metals was determined using the degree of contamination (C_d) and the modified degree of contamination (mC_d) while the potential ecological risk was assessed by the Risk Index (RI). Results showed spatial variation of heavy metal concentration along the drainage network and Cd and Pb concentrations in all samples exceeded the WHO guideline. C_d and mC_d values ranged between 22.20 – 88.70 and 4.44 – 17.74 respectively while the RI values ranged between 217.72 – 609.53. This implies that the entire drainage network was polluted by heavy metals and Cd and Pb were largely responsible for the pollution load with Cd contributing a range of 7.75% - 26.46% while Pb contributed 66.88% - 90.14%. Cd and Pb are carcinogenic, therefore storm runoff treatment is recommended for environmental sustainability.

KEYWORDS

Runoff, Drainage network, Heavy Metals, Pollution indices, Ecological risk

1. INTRODUCTION

Of all the natural resources, water is the most essential for the sustenance of living things. Water's availability and quality, both seasonally and regionally, have a significant impact on human health, food production, and economic growth and development (Joshua and Islam, 2015). The two main sources of water include surface water including streams, rivers, lakes, etc and groundwater bodies like wells, boreholes, and springs. Rivers as water resources, are very important to man's health not only in terms of drinking water supply, but also in terms of their function in recreational and sport activities (Shanbehzadeh et al., 2014). Rivers also serve a set of economic, cultural, and ecological functions including transportation, ecotourism, aquaculture, ecological habitat, and ecological defense. However, the impact of human activities; urban and industrial waste disposal have significant negative effects on these water bodies which have resulted in water pollution and have caused serious ecosystem issues.

The two main sources of water pollution include point and nonpoint sources. Point sources are clearly defined distinct locations through which pollutants enter into water bodies and are therefore easy to control. On the other hand, nonpoint sources (NPS) also known as unidentifiable sources originates from everywhere including urban runoff, agricultural land runoff, eroding stream banks, and storm sewer. Runoff is the primary transport medium of pollutants in nonpoint source pollution. Pollutants from natural and anthropogenic activities are carried by runoff during and after precipitation which end up in adjacent lakes and rivers (Yoo and

Kang 2004; Jin-Ho et al., 2007). Also, the amount of non-point source pollutant entering a river varies greatly under different land uses (Zhang et al., 2022). The order of the contribution of total nitrogen and total phosphorus loads to Three Gorges Reservoir Area by different land use types (Tong et al., 2022).

Heavy metals have been identified as one of the common pollutants associated with nonpoint source pollution (Aziz et al., 2023; Briffa et al., 2020; Singh et al., 2024). They are toxic and persistent in the environment (Onyekuru et al., 2017; Temitope et al., 2016) and can bio-accumulate in the tissues of different biota (Melake et al., 2023; Zhang et al., 2023). The chief heavy metals noted in the environment include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), thallium (Ti), and zinc (Zn). Most of which are essential micronutrients for plants, animals, and humans, but at high concentrations, may cause toxicity and harm animals' health including humans. Of these, As, Cd, Cr, Hg, and Pb are recognized as health hazards. They accumulate in the food webs mainly in fishes and vegetables thereby threaten the living organisms that depend on these groups for their food (Temesgen and Shewamolto, 2022).

The International Agency for Research on Cancer in 2012 has classified As, Cd, Cr, and Pb, as carcinogenic, while Co, Cu, Fe, Mn, Ni, and Zn, are classified as non-carcinogenic. The toxicity and carcinogenic potentials of heavy metals make heavy metals a major environmental and health concern and has led to the monitoring of the concentration of heavy metals in road runoff and in rivers receiving road runoff. Results of some of these

Quick Response Code



Access this article online

Website:

www.jcleanwas.com

DOI:

[10.26480/jcleanwas.02.2024.73.76](http://doi.org/10.26480/jcleanwas.02.2024.73.76)

studies have also shown that the extent of heavy metal concentrations in road runoff is site-specific and affected by the volume of traffic, road design, climate and surrounding land uses (Ukabiala et al., 2010; Nawrot et al., 2020; Gao et al., 2022). With urbanization and industrialization, there is a constant rise in heavy metal concentrations in urban runoffs which would affect the receiving environments, therefore heavy metal pollution assessment from nonpoint source should be given priority.

Researchers have developed heavy metal pollution load indices that give conclusive indication for the overall levels of heavy metals contamination

level in an environment (Hakanson, 1980; Abraham and Parker, 2008). Some commonly used pollution indices in ecological risk assessment include the contamination factor (CF), degree of contamination (C_d), modified degree of contamination (mC_d), ecological risk factor (Er), and risk index (RI). The mathematical representations of these indices and their categorization are displayed in Table 1. This study seeks to assess the impact of urban road runoff on the ecological risk of heavy metals in Eagle Island River, a drainage outlet for the River State University (RSU) Port Harcourt campus.

Table 1: Pollution Indices

Pollution indices	Formula	Values	Degree of pollution
Contamination Factor (CF_i)	$CF_i = \frac{C_i}{S_i}$	$CF_i < 1$ $1 < CF_i < 3$ $3 < CF_i < 6$ $CF_i > 6$	Low Moderate Considerate Very high
Degree of Contamination	$C_d = \sum CF_i$	$C_d < 6$ $6 \leq C_d < 12$ $12 \leq C_d < 24$ $C_d > 24$	Low Moderate Considerate Very high
Modified degree of contamination (CPI)	$mC_d = \frac{1}{n} \sum CF_i$	$mC_d < 1.5$ $1.5 \leq mC_d < 2$ $2 \leq mC_d < 4$ $4 \leq mC_d < 8$ $8 \leq mC_d < 16$ $16 \leq mC_d < 32$ $mC_d \geq 32$	Nil to very low low moderate high very high extremely high ultra-high
Ecological Risk Factor (E_r^i)	$E_r^i = T_i \times CF_i$	$E_r < 40$ $40 \leq E_r < 80$ $80 \leq E_r < 160$ $160 \leq E_r < 320$ $E_r \geq 320$	Low Moderate Considerate High Very high
Risk index (RI)	$RI = \sum E_r^i$	$RI < 150$ $150 \leq RI < 300$ $300 \leq RI < 600$ $RI \geq 600$	Low risk Moderate Considerate/severe Very high/serious

Where C_i is the measured concentration of the heavy metal, S_i is the standard permissible concentration of the contaminant and T_i is the toxic response factor for a given heavy metal. (Hakanson, 1980; Abraham and Parker, 2008)

2. MATERIALS AND METHOD

2.1 Description of study area

The study area is called Eagle Island in Port Harcourt City Local

Government Area of Rivers State. It is situated on projected coordinate of 528175.43mN & 275303.08mE – 529488.65mN, & 276709.19mE in (WGS-84) datum, (UTM) Zone 32N coordinate system. The layout covered a total area of 62.26 hectares consisting of 621 parcels of different parcel area (square meters) including parcels reserved for recreational and commercial purposes (Eze et al., 2022). It is bounded in the north by the RSU Port Harcourt campus, in the west by Diobu communities, in the east by the Nigerian Agip Company Limited, and in the south by rivers and wetlands that provide sites for many companies (Eze et al., 2022).

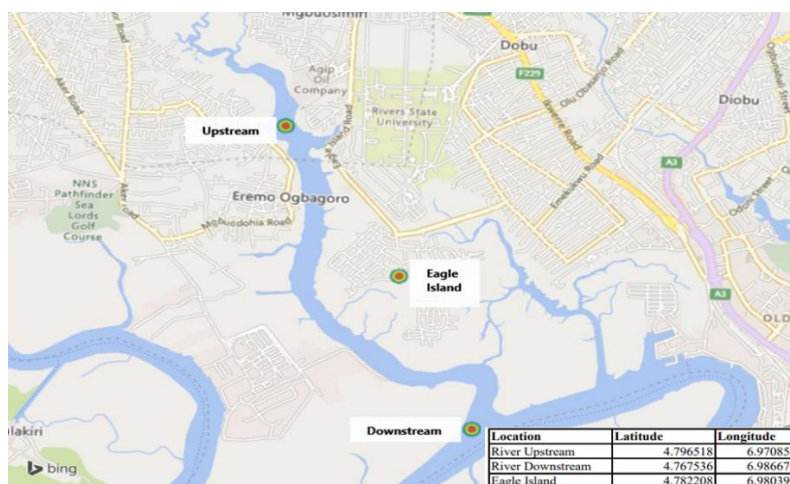


Figure 1: Map of the Study Area and its coordinates. Source: (Adopted from Google Map)

2.2 Sample collection and analysis

Runoff samples were collected from secondary and primary drains. The secondary drain is a drain along the tarred road connecting the

Engineering Faculty, Information Technology Center (ITC), Education, Science, and Law Faculties in the RSU, Port Harcourt campus. This drain collects road runoff and discharges into the primary drain which discharges into the outlet (Eagle Island River). The primary drain is

located around one of the female hostels and a shopping complex. Water samples were also collected at the upstream and downstream sections of the outlet. Samples from secondary drain, primary drain, upstream and downstream of outlet were labelled as SD, PD, US and DS respectively. All samples were collected between the months of August and October, 2023. Samples collection and analyses were done using standard methods. Heavy metals including Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), and Zinc (Zn) were analyzed using Atomic Absorption Spectrophotometer (ASS) Instrument (GBC XplorAA, Australia) by direct aspiration method as described by APHA in 2017. Total pollution level and Ecological risk assessment of heavy metals from road runoff were determined using the C_d , mC_d , and RI as shown in Table 1.

3. RESULTS AND DISCUSSION

3.1 Physiochemical properties of runoff and Eagle Island River

As shown in Table 2, the average pH of the secondary drain (SD) for the 3 months ranged between 5.85 to 6.89, while that of the primary drain (PD) ranged between 5.91 to 6.31 suggesting that both samples were slightly acidic. Similarly, upstream (US) and downstream (DS) average pH within

the study period was slightly acidic with pH values ranging from 6.06 to 6.53 and 6.09 to 6.53 respectively. The acidity of the drainage network was within range for normal unpolluted rainwater of about 5.6-7. Rainwater maybe slightly acidic due to the formation of carbonic acid as rainwater reacts with atmospheric CO_2 (Efe and Mogborukor, 2012). The salinities of the secondary and primary drains were much lower than that of the river water samples at both the upstream and downstream sections. Salinity readings showed that, runoff at secondary and primary drains were fresh water while the Eagle Island River water was brackish and the salinity values at the downstream were higher than at the upstream (Table 2). The variation in the salinity of the River water samples for the various months, is an indication of an external influence such as runoff. However, such runoff could not have been from the university campus road runoff. The high values of salinity of the upstream and downstream sections of the River in the month of September corroborate this fact. Table 3 shows that there was 28 days of rainfall in the month of September with an average monthly rainfall of 441.94 mm which was the highest amount of rainfall within the study duration. The high rainfall depth would have transported more dissolved solids from other land use sources that resulted in the higher salinity of the river water samples this is similar to the work of Tong et al., in 2022.

Table 2: Physiochemical Characteristics of Runoff and River Water in Time and Space

Parameters	Samples											
	August				September				October			
	SD	PD	US	DS	SD	PD	US	DS	SD	DP	US	DS
pH	5.85	5.91	6.06	6.09	6.49	5.90	6.11	6.08	6.89	6.31	6.53	6.74
Temperature (°C)	28.7	29.2	28.3	28.3	28.8	29.8	30.5	29.1	27.0	26.7	26.7	26.9
Salinity (ppm)	25	124	2280	5210	28	129	5190	5270	25	38	2700	2980
EC (μS/cm)	50	249	4550	10,440	56	256	10,380	10,570	51	77	5550	5880

Table 3: Characteristics of the rain events monitored in Port Harcourt city between August and October 2023

Event	Average Temp. °C	Rain days in a month	Average monthly rainfall (mm)
August	28	25	397.44
September	25	28	441.94
October	26	29	402.42

3.2 Mean concentration of heavy metals along drainage network

As shown in Table 4, the mean concentrations of Cd and Pb for all samples exceeded the maximum allowable limits (MAL) of 0.005 mg/l and 0.015 mg/l respectively in surface water by the World Health Organization (WHO). On the other hand, the mean concentrations of Cu and Zn for all samples and Cr for SD and US samples were below the WHO MAL of 2 mg/l, 5 mg/l, and 0.1 mg/l respectively. The low mean concentrations of Cu and Zn implies that these heavy metals may not pose any environmental risk along the drainage network especially the outlet. Moreover, the International Agency for Research on Cancer in 2012 has classified them as non-carcinogens. However, the carcinogens (Cd, Cr, and Pb) that exceeded the WHO guidelines have potential pollution and ecological risk.

Table 4: Mean concentration of heavy metals at various sampling points

Sampling point	Cd mg/l	Cr mg/l	Cu mg/l	Pd mg/l	Zn mg/l
SD	0.034	0.068	0.015	0.276	0.050
PD	0.023	0.274	0.003	0.223	0.082
US	0.016	0.049	0.007	0.459	0.067
DS	0.034	0.186	0.007	1.199	0.065

3.3 Potential Ecological risk assessment of heavy metals

Results of total pollution level and ecological risk assessment of heavy metals along the drainage network as determined by C_d , mC_d , and RI are presented in Table 5. The C_d values described sampling points SD, US and DS as very highly polluted ($C_d > 24$) and sampling point PD as considerably polluted ($12 \leq C_d < 24$). Similarly, the mC_d values described sampling points SD, PD, and US as highly polluted with $4 \leq mC_d < 8$ while sampling point DS was described as extremely highly polluted ($16 \leq mC_d < 32$). The difference in the total pollution description between the C_d and mC_d is attributable to the fact that both indices may not be

comparable (Gao and Chen, 2012) since there are 4 and 6 different categories for C_d and mC_d respectively. The potential ecological risk index (RI) values as shown in Table 5 explains that sampling points SD, PD, and US had moderate risk potential with values ranging from 217.72-299.41 while sampling point DS had very high-risk potential with a value greater than 600 (Table 1). The RI value description were different from C_d and mC_d for all sampling points except sampling point DS. This is because RI has low similarity with other indices.

Table 5: Pollution Levels At Various Sampling Points

Sampling points	C_{deg}	mC_d	RI
SD	25.96	5.19	299.41
PD	22.20	4.44	217.72
US	34.37	6.87	252.01
DS	88.7	17.74	609.53

3.4 Effect of individual heavy metal on potential ecological risk

Table 6 showed that Cd and Pb contributed the most pollution load at all sampling points with Cd contributing a range of 7.75% - 26.46% while Pb contributed 66.88% - 90.14%. Cd pollution load contribution was highest at the SD and least at the DS sampling points ($SD > PD > US > DS$). The high level of pollution at the SD was associated with traffic activities along the road (Gao et al., 2022). The pollution pattern of Cd ($SD > PD > US > DS$) along the drainage network implies that the major source of Cd in the Eagle Island River was largely the road runoff from the university campus. Similarly, the high level of Pb pollution across the entire drainage network was associated with traffic activities for SD and PD sampling points and a combination of traffic and industrial activities for US and DS sampling points. This is similar to the work of Gao et al. (2022). The pollution load patterns of Pb along the drainage network is $DS > US > SD > PD$. This explains that the source of Pb in the Eagle Island River was largely contributed by the activities around the downstream section of the river rather than from the road runoff in the university campus.

Table 6: Percentage pollution contribution of individual heavy metal at various sampling points

Sampling points	Cd, %	Cr, %	Cu, %	Pb, %	Zn, %
SD	26.46	2.62	0.03	70.86	0.04
PD	20.73	12.30	0.009	66.88	0.07
US	9.51	1.43	0.009	89.02	0.04
DS	7.75	2.10	0.003	90.14	0.01

4. CONCLUSION

In the assessment of heavy metals in a drainage network in Rivers State University, Port Harcourt campus, the concentrations of non-carcinogenic heavy metals (Cu and Zn) were below while the carcinogenic heavy metals (Cd, Cr, and Pb) exceeded the WHO guidelines in surface water. Cd, Cr, and Pb were responsible for 99.9% of the pollution load in the secondary and primary drains as well as the upstream and downstream section of the Eagle Island river. C_d and mC_d values described the total pollution along the drainage network to range from significantly polluted to extremely highly polluted while the RI values described the potential ecological risk as moderately to very high risk. Sources of Cd, Cr, and Pb were attributed to traffic activities in the campus and other anthropogenic activities around the downstream section of the Eagle Island River. Storm runoff treatment in the study area is recommended for sustainable environment.

REFERENCES

- Abraham, G.M.S. and Parker, R.J., 2008. Assessment Of Heavy Metal Enrichment Factors And The Degree Of Contamination In Marine Sediments From Tamaki Estuary, Auckland, New Zealand. *Environ Monit Assess*, 136, Pp. 227–238.
- American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF), 2017. Standard Method of Examination of Water and Wastewater (23rd ed.). APHA Washington DC
- Aziz, K. H. H., Mustafa, F. S., Omer, K. M., Hama, S., Hamarawf, R. F. & Rahman, K. O., 2023. Heavy Metal Pollution in The Aquatic Environment: Efficient and Low-Cost Removal Approaches to Eliminate Their Toxicity: A Review. *RSC Advances*, 13, Pp. 17595–17610.
- Briffa, J., Sinagra, E. and Blundell, R., 2020. Heavy Metal Pollution in The Environment And Their Toxicological Effects On Humans. *Heliyon*, 6, Pp. 1-26.
- Efe, S. I. and Mogborukor, J. O. A., 2012. Acid Rain in Niger Delta Region: Implication on Water Resources Quality and Crisis. *An International Journal of Science and Technology*, 1(1), Pp. 17-46.
- Ekpo, P. B., Umoyen, A. J., Akpan, N. G., Ekpo, I. P., Abu, G. and Sunday, C. J., 2021. Evaluation of Pollution Load: Heavy Metal Contents and Physiochemical Properties of the Great Kwa River, Calabar, Cross River State, Nigeria. *International Journal of Environment and Climate Change* 11(2), Pp. 19-31. <https://doi.org/10.9734/ijeccc/2021/v11i230356>
- Eze, P. I. and Godswill, P. T., 2022. A As-Built Assessment Mapping of Eagle Island
- Gao, S., Wang, X., Hua, L., Kong, Y., Chen, J., and Chen, Z., 2022. Heavy metals in road-deposited sediment and runoff in urban and intercity expressways. *Transport safety and Environment*, 4(1), Pp. 1-9
- Gao, X., and Chen, C. T. A., 2012. Heavy metal pollution status in surface sediments of the coastal Bohai Bay. *Water Research*, 46, Pp. 1901-1911.
- Hakanson, L., 1980. An Ecological Risk Index for Aquatic Pollution Control – A Sedimentological Approach. *Water*, 14(8), Pp. 975-1001. [http://dx.doi.org/10.1016/0043-1354\(80\)90143-8](http://dx.doi.org/10.1016/0043-1354(80)90143-8)
- International Agency for Research on Cancer, 2012. *IARC Monographs Arsenic, Metal, Fibres, and Dusts: A Review of Human Carcinogens*. 100C. IARC Lyon.
- Jin-Ho K., Jong-Sik L., Won-Il K., Goo-Bok J., Kuk-Heon H., Jong-Su R., Suk-Cheol K., Sun-Gang Y., Jeong-Taek L., and Soon-Kuk K., 2007. Estimation of Nonpoint Source Pollutant Loads for Rural Watershed by AvSWAT. *Korean J. Soil Sci. Fert.* 40(1) Pp. 12-17.
- Joshua N. H. and Islam M. N., 2015. Water Pollution and its Impact on the Human Health. *Journal of Environment and Human*, 2 (1).
- Layout, Port Harcourt, Nigeria: A Remote Sensing and GIS Techniques. *Journal of Research in Environmental and Earth Science*, 8 (4), Pp. 10-17. www.questjournals.org.
- Melake, B. A., Endalew, S. M., Alamirew, T. S. and Temesegen, L. M., 2023. Bioaccumulation and Biota-Sediment Accumulation Factor of Metals and Metalloids in Edible Fish: A Systematic Review in Ethiopian Surface Waters. *Environmental Health Insight*. 17, Pp. 1-10. <https://doi.org/10.1177/11786302231159349>
- Mugosa, B., Durovic, D., Nedovic-Vukovic, M., Barjaktarovic-Labovic, S., and Vrvic, M., 2016. Assessment of Ecological Risk of Heavy Metal Contamination in Coastal Municipalities of Montenegro. *International Journal of Environmental Research and Public Health*, 13(393), Pp. 1-15. <https://doi.org/10.3390/ijerph13040393>
- Nawrot, N., Wojciechowska, E., Rezanian, S., Walkusz-Miotk, J. and Pazdro, K., 2020. The Effects of Urban Vehicle Traffic on Heavy Metal Contamination In Road Sweeping Waste And Bottom Sediments Of Retention Tanks. *Science of the Total Environment*, 749, Pp. 1-15. <https://doi.org/10.1016/j.scitotenv.2020.141511>
- Onyekuru, S. O., Nwankwoala, H. O., and Uzor I., 2017. Heavy metal analysis of Otamiri River in Imo state, South-Eastern Nigeria. *Biodiversity International Journal*, 1(5), Pp. 172 - 175.
- Shanbehzadeh, S., Dastjerdi, M. V., Hassanzadeh, A. and Kiyanizadeh, T., 2014. Heavy Metals in Water and Sediment: A Case Study of Tembi River. *Journal of Environmental and Public Health*, 2014, Pp. 1-5.
- Singh, V., Ahmed, G., Vedika, S., Kumar, P., Chaturvedi, S. K., Rai, S. N., Vamanu, E. and Kumar, A., 2024. Toxic Heavy Metal Ions Contamination in Water and Their Sustainable Reduction by Eco-Friendly Methods: Isotherms, Thermodynamics and Kinetics Study. *Scientific Reports*, 14 (7595), Pp. 1-13
- Temesgen, M. and Shewamolto, A., 2022. River Pollution by Heavy Metals and Associated Impacts on the Adjacent Community, the Case of Holeta and Golli Rivers, Holeta Town, Ethiopia. *Journal of Environmental and Public Health*, 2022, Pp. 1-11. <https://doi.org/10.1155/2022/8064816>.
- Temitope, A. E., Ebeniro, L. A., Oyediran, A. G., and C-Oluwatosin T. J., 2016. An Assessment of Some Heavy Metals in Sediment of Otamiri River, Imo State, South-Eastern Nigeria. *Open Access Library Journal*, 3, Pp. 1-6.
- Tong, X., Zhou, Y., Liu, J., Qiu, P. and Shao, Y., 2022. Non-Point Source Pollution Loads Estimation in Three Gorges Reservoir Area Based on Improved Observation Experiment and Export Coefficient Model. *Water Sci and Technol*, 85(1), Pp. 27-38
- Ubuoh, E. A., Nwawuikie, N., Obeta, M. C. and Osujieke, D. N., 2014. Environmental Risk Assessment of Heavy Metal Concentrations in Road Runoff with Absorption Atomic Spectrophotometer (AAS), Imo State, Nigeria. *Journal of Environment and Earth Science*. 4(5), Pp. 62-69. www.iiste.org.
- Ukabiala, O., Chinwe1 C., Obinna N., A. Akeem, A., and Alo B. I., 2010. Assessment of Heavy Metals in Urban Highway Runoff. *Journal of Environmental Chemistry and Ecotoxicology*. 2(3), Pp. 34-37.
- Yoo, K. H. and Kang M. S., 2004. Agricultural Nonpoint Source (NPS) Pollution and Best Management Practices in the United States, International Symposium on Management Strategies for Agricultural and Rural Nonpoint Source Pollution. NIAST
- Zhang, S., Fu, K., Gao, S., Liang, B., Lu, J., Fu, G., 2023. Bioaccumulation of Heavy Metals in the Water, Sediment, and Organisms from The Sea Ranching Areas of Haizhou Bay in China. *Water*, 15(12), Pp. 1-16. <https://doi.org/10.3390/w15122218>
- Zhang, X., Chen, X., Zhang, W., Peng, H., Xu, G., Zhao, Y. and Zhenling, S., 2022. Impact of Land Use Changes on the Surface Runoff and Nutrient Load in the Three Gorges Reservoir Area, China. *Sustainability* 14, Pp. 1-21

