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Analysis of the Effect of Heavy Elements in Polluted Industrial Water and its Environmental Treatment: An Applied Study on the Gas Power Plant/1 (Central Region) in Southern Baghdad and its Discharge into the Tigris River

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ABSTRACT

Water produced from power plants is one of the most important sources of water pollution, especially for areas like Baghdad, Contaminated industrial wastewater is a major environmental challenge due to the rapid growth of industries, leading to increased accumulation of harmful pollutants in water resources, the work is intended to study the impact of water generated from a power plant in the south on the level of heavy metals before and after the treatment process and after its discharge to the Tigris River. Objective is to determine the extent of heavy metals such as iron, copper, chromium, and zinc concentration in water extracted from various points and subsequently study the monthly variations of these elements with a view to assessment of water quality and efficiency of the treatment systems. Description: Water samples were collected from pre-treatment, post-treatment, and post-discharge points to the Tigris River. Measurements were carried out on a monthly basis for six months. The preparation of samples was done by filtration and preservation techniques by adding nitric acid. Results are showed that iron concentration reached its peak value of 1.70 mg/L in November 2021, while the minimum value of 0.10 mg/L was recorded in the month of October. Temporal variation: there is variation in metals on a monthly basis; for instance, zinc ranged from 0.40 mg/L during January to 2.70 mg/L during November. Standard comparison: the result was also checked against allowable values given by the World Health Organization and the Environmental Protection Agency to determine the level at which water meets the environmental standards. Heavy metal concentrations varied significantly before and after treatment, indicating unit efficiency. Iron, copper, chromium, and zinc showed reductions, though some exceeded limits, posing environmental risks. Future monitoring and improved treatment are essential to safeguard public health and the Tigris River's ecosystem.

1. INTRODUCTION

It is worth mentioning that contaminated industrial water is one of the most important environmental challenges nowadays in light of rapid industrial growth, which leads to increased accumulation of harmful pollutants in water resources [1].

The most dangerous pollutants in this respect are heavy metals, such as lead, cadmium, mercury, and zinc, which cannot be decomposed in nature and thus accumulate in the food chain, being highly hazardous to the biosphere and human health. These metals alter the quality of water and aquatic life, overall contributing to a degradation of the aquatic environment since no proper treatment is pursued. In this respect, the importance is underlined of the pretreatment of polluted industrial water before its discharge into natural systems, including rivers and lakes [2].

The First Power Plant in Southern Baghdad represents one of the huge industrial plants that generate enormous amounts of polluted industrial water. These waters will be heavily loaded with heavy metals emanating from cooling processes, chemical reactions, and other types of industrial activities. It is, therefore, supposed to go through a treatment process with a lot of care to make the pollutants being disposed into the

Tigris River safe. Contaminated industrial water from different industrial processes, such as electricity generation, is an environmental challenge serious in its dimension. Water bodies are very often polluted by heavy metals. These substances are distinguished by toxic properties, as well as a tendency to bioaccumulation in the natural environment, threatening all kinds of ecosystems and human health [3].

It is very important that the impact of these pollutants is studied and addressed in research to protect water resources and reduce damage. The metals iron, copper, chromium and zinc are chemical elements that are naturally found in trace amounts in the environment. However, due to their use in industrial applications, their levels have begun to accumulate in the environment [4]. The sources of these metals in industrial water come from a variety of activities including: coal-fired power plants where heavy metals are released as a result of combustion processes; electronics, mining and chemical manufacturing processes; and industrial cooling systems that contain accumulations of metals as a result of thermal processes [4]. Heavy metals are characterized by their cumulative and toxic properties, thus directly influencing ecosystems and human health [5]. These metals affect the organisms in rivers and lakes and change the ecological balance due to the metal toxicity that causes the death of aquatic organisms or reduces their reproduction. It affects plants that grow along the banks of rivers; such plants absorb the heavy metals, leading to the contamination of the food chain and posing a risk to human health through drinking polluted water or consuming fish that has high levels of heavy metals, which may cause serious health problems such as cancer and liver and kidney diseases [6].

There are methods available to treat industrial wastewater containing heavy metals. These techniques include: Chemical technology: This relies on the use of chemicals to react with heavy metals to form solid sediments that can be easily removed from the water [7, 8]. Physical technology: Infiltration and absorption are involved, where special materials like activated carbon or nonmaterial are used for heavy metals' absorption.

Biotechnology: It would depend on the application of viable organisms, such as bacteria and fungi, which have the capability to analyze or clear heavy metals in water [9]. The pollution of rivers with heavy metals due to the discharge of polluted water constitutes a serious environmental threat to the aquatic ecosystem [10]. This could lead to a huge risk of pollution of the Tigris River due to heavy metals if appropriate water treatment was not performed which cumulate in river sediments and changed the quality of the water and its usage. The accumulations of metals in the food chain lead to the contamination of fish and plants; this has brought several changes in biodiversity of the river and the people who have their livelihoods depending on it [11].

The power plants and other industrial facilities have a major role in the treatment of polluted industrial water. The First Power Plant in South Baghdad, for instance, undertakes the first stage of environmental treatment before disposing off the pollution into the Tigris River [12]. This includes heavy metal treatment systems that ensure polluted water reaches environmental safety standards before it is discharged into the rivers.

One of the most effective ways to ensure that the polluted water treatment is effective is to carry out monthly measurements of heavy metal concentration in water both before and after the treatment. These measurements constitute vital data in assessing the efficiency of the treatment and any alteration in the water quality over time [13]. This provides a basis for operations improvement and identifies problems that arise with time. The present work searches for the heavy metal effect in the polluted industrial water resulting from the First Power Plant in South Baghdad, and depends on monthly measurements of those pollutants to determine their severity. It is also going to attempt to analyze how well the environmental treatment for this water is prior to its discharge into the Tigris River and the consequence of this treatment regarding the improvement of water quality and lessening of the environmental risk associated with polluted water discharge [14].

The research would then provide essential information about the concentration of heavy metals in polluted industrial water, south of Baghdad, as a part of the evaluation in the impact of these metals on the aquatic environment of the Tigris River. It will also make recommendations towards more effective water treatment systems at the station, and in general, develop better future industrial water management strategies to avoid adverse environmental impact on the aquatic environment to maintain acceptable quality levels of Iraqi water resources.

2. MATERIALS AND METHODS

2.1 Sample collection

Water samples were collected from the First Power Plant in southern Baghdad at the following main points according to the study [15].

Pre-treatment: Industrial water is collected directly from the industrial wastewater lines before entering the treatment plant and Post-treatment: Samples are collected after the water leaves the treatment units, and Post-discharge: Water samples are collected from the Tigris River after the treated water is discharged. Samples are collected monthly for six months to ensure comprehensive data on heavy metal concentrations and their changes over time according to the study [7].

2.2 Chemical analysis of water

Preparations: Samples are prepared using special techniques such as filtration to remove large particles and preservation by adding nitric acid to maintain the stability of heavy metals according to this study [16].

2.3 Atomic absorption spectroscopy (AAS)

This technique is used to measure the concentrations of heavy metals such as iron, copper, chromium, and zinc in the samples to determine their levels. In the Materials and Methods section, details should be provided on how AAS was used to quantify these heavy metals, including information on the instrument model, calibration standards, and the wavelengths measured for each metal with high accuracy according to the study [17].

2.4 Preparing the standard solution

A series of standard solutions containing known concentrations of the mineral elements to be analyzed are prepared. They are used to calibrate the instrument and ensure the accuracy of the results. If the sample contains very high concentrations of minerals, it may need to be diluted with distilled water or an appropriate solvent according to the study [18].

2.5 Developing a predictive model

Primary data: Heavy metal concentration data were collected from samples analyzed monthly, in addition to data on treatment quality removal rate, temperatures, Data formatting: Organizing the data into a table that can be entered into modeling programs. This data includes time month, location and metal concentration. Using specialized modeling programs: Specialized MATLAB modeling programs are used to analyze the data and develop a mathematical model capable of predicting future changes in heavy metal concentrations by building the model and identifying variables that affect heavy metal concentration such as time, flow rate, temperatures, treatment type, etc. These variables are included in the model, calibrating its predictions and identifying the factors that most affect metal concentration according to studies [19, 20].

2.6 Statistical analysis

Analysis of variance (ANOVA) was used to compare the means between different sets of data to determine if there were statistically significant differences between different points (before treatment, after treatment, and after discharge into the Tigris River). This analysis will help determine if the changes in heavy metal concentrations between different points (before and after treatment) and time periods (monthly) are significant. Standard Deviation: will be used to measure the dispersion of the data around the mean to determine the significance of the difference between the results after data collection (metal concentrations before, after treatment, and after discharge [16].

3. RESULTS AND DISCUSSION

Table 1 presents a comparison of the maximum permissible concentrations of selected heavy metals in water as recommended by major international organizations, including study [9].

Table 1. Comparative maximum allowable concentrations of heavy metals in water according to WHO, FAO, and EPA guidelines

No.	Item Name	WHO/ FAO	EPA
1	Aluminum (AL)	100-200 µg/L	50-200 µg/L
2	Cadmium (Cd)	3 µg/L	0.005 mg/L
3	Copper (Cu)	2.000 µg/L	1.3 mg/L
4	Lead (Pb)	10 µg/L	0.015 mg/L
5	Mercury (Hg)	6 µg/L	0.002 /mg/L

WHO=Global Health Organization. FAO= Food and Agriculture Organization. EPA= Environmental Protection Organization.

3.1 Measurement of heavy element ions

Heavy element ions were measured in the studied samples using Shimadzu Flame Atomic Absorption Spectrophotometer Model-7000AA after the standard solutions of the tested elements were prepared solution Standard in the analysis laboratory.

Table 2 shows that the highest value of iron element is 1.70 mg/L, which was recorded for the year 2021 for industrial water resulting from the first gas station for electricity distribution, before dumping that water into the Tigris River after treatment by the treatment plant for the month of November, while the lowest value of iron element is 0.10 mg/L for the month of October. The value of the least significant difference for iron values and for all twelve study months was recorded significantly at 0.594 for that year under a lower probability level of 0.05. The highest value of copper element in industrial water was also recorded at 1.84 for the month of March before discharging it into the Tigris River (treatment stage), while the lowest value of copper element was 14.0 for the month of August.

Table 2. Monthly measurements of selected environmental parameters in industrial water discharged from the first power and gas station, South of Baghdad (Ministry of Electricity, Central Region, 2021)

Month	Iron (mg/L)	Copper (mg/L)	Chromium (mg/L)	Zinc (mg/L)
January	0.36	0.60	0.035	0.40
February	1.10	1.40	0.142	1.03
March	0.37	1.40	0.141	0.79
April	1.02	0.77	0.062	0.76
May	1.50	1.84	0.033	1.40
June	1.09	0.94	0.134	1.21
July	1.48	0.20	0.209	1.19
August	1.02	0.14	0.178	0.80
September	1.09	1.23	0.181	0.91
October	0.10	0.12	0.00	0.97
November	1.70	0.70	0.136	2.70
December	1.36	0.35	0.250	1.50
L.S.D. value	0.594 *	0.551 *	0.073 *	0.614 *

* ($P \leq 0.05$).

The lowest significant value of copper element values was also recorded at 0.551 for all twelve study months significantly at a lower probability level of 0.05. In addition, the highest value of chromium was recorded in the treated industrial water of 0.250 mg/L for December, before discharging it into the Tigris River, while the lowest value of chromium was 0.033 mg/L in March. In addition, October did not record any value for chromium dissolved in the industrial water of the station after treatment.

The lowest significant difference value of 0.073 for that element in the water was recorded significantly and for all twelve study months of that year under a lower probability level of 0.05. The highest value of zinc was recorded at 2.70 mg/L in the treated industrial water of the station before discharging it into the Tigris River for November, but the lowest value of zinc was 0.40 mg/L for January. The lowest significant difference value of that element was recorded significantly and for all twelve study months of that year 0.614 under a lower probability level of 0.05.

Table 3 shows that the highest value of iron element 1.57 mg/L, which was recorded for the year 2022 for industrial water resulting from the first gas station for electricity distribution, before dumping that water into the Tigris River after treatment by the treatment plant for the month of July, while the lowest value of iron element was 0.03 mg/L for the month of October. The value of the least significant difference for iron values and for all twelve study months was 0.487 for that year under a lower probability level equal to 0.05.

Table 3. Monthly measurements of selected environmental parameters in industrial water discharged from the first power and gas station, South of Baghdad (Ministry of Electricity, Central Region, 2022)

Month	Iron (mg/L)	Copper (mg/L)	Chromium (mg/L)	Zinc (mg/L)
January	1.02	0.85	0.810	0.96
February	0.58	0.20	0.013	0.30
March	0.52	0.44	0.080	0.72
April	0.68	0.89	0.130	1.19
May	0.73	0.20	0.116	0.79
June	0.60	0.70	0.100	0.80
July	1.57	1.70	0.230	1.77
August	0.78	0.80	0.135	1.79
September	0.60	0.17	0.090	1.91
October	0.03	0.27	0.070	0.48
November	0.60	0.62	0.100	1.20
December	0.57	0.35	0.079	0.60
L.S.D. value	0.487 *	0.533 *	0.086 *	0.598 *

* ($P \leq 0.05$).

The highest value of copper element in industrial water was 1.70 mg for the month of July before discharging it into the Tigris River (treatment stage), while the lowest value of copper element was 17.0 for the month of September. The lowest significant value of copper element values was also recorded 0.533 for all twelve study months significantly for that year under a lower probability level equal to 0.05. In addition, the highest value of chromium was recorded in the treated industrial water of 0.810 mg/L for the month of January, before dumping it into the Tigris River, while the lowest value of chromium was 0.013 mg/L in February.

The lowest significant difference value of 0.086 was recorded for that element in the water significantly and for all twelve study months for that year 2022 and under a lower probability level of 0.05. The highest value of zinc was also recorded at 1.91 mg/L in the treated industrial water of the station before dumping it into the Tigris River for the month of September, but the lowest value of zinc was 0.30 mg/L for the month of February. The lowest significant difference value of that element was recorded significantly and for all twelve study months for that year 0.598 under a lower probability level of 0.05.

Table 4 shows that the highest value of iron element is 0.93 mg/L, which was recorded for the year 2023 for the industrial water resulting from the first gas station for electricity distribution, before dumping that water into the Tigris River after treatment by the treatment plant for the month of June, while the lowest value of iron element is 0.11 mg/L for the month of April. The value of the least significant difference for iron values and for all twelve study months was recorded significantly 0.308 for that year under a lower probability level equal to 0.05. Also, the highest value of copper element was recorded in industrial water 0.53 for the month of March before discharging it into the Tigris River (treatment stage), while the lowest value of copper element was 0.01 for the month of April.

Also, the lowest significant value of copper element values was recorded significantly 0.189 for all twelve study months for that year under a lower probability level equal to 0.05. In addition, the highest value of chromium was recorded in the treated industrial water of 0.100 mg/L for the month of March, before discharging it into the Tigris River, while the lowest value of chromium was 0.012 mg/L in January. In addition, June did not record any value for chromium dissolved in the industrial water of the station after treatment.

Table 4. Monthly measurements of selected environmental parameters in industrial water discharged from the first power and gas station, South of Baghdad (Ministry of Electricity, Central Region, 2023)

Month	Iron (mg/L)	Copper (mg/L)	Chromium (mg/L)	Zinc (mg/L)
January	0.20	0.10	0.012	1.80
February	0.20	0.16	0.020	0.30
March	0.77	0.37	0.100	1.01
April	0.11	0.01	0.028	0.73
May	0.63	0.53	0.098	1.17
June	0.93	0.17	0.000	0.54
July	0.30	0.10	0.065	0.38
August	0.22	0.06	0.025	0.35
September	0.14	0.04	0.031	0.22
October	0.23	0.30	0.027	0.17
November	0.32	0.32	0.040	1.02
December	0.42	0.02	0.040	0.47
L.S.D. value	0.308 *	0.189 *	0.045 *	0.481 *

* ($P \leq 0.05$).

The lowest significant difference value of 0.045 for that element in the water was recorded significantly and for all twelve study months of that year under a lower probability level of 0.05. The highest value of zinc was recorded at 1.80 mg/L in the treated industrial water of the station before discharging it into the Tigris River for the month of January, but the lowest value of zinc was 0.17 mg/L for October. The lowest significant difference value of that element was recorded significantly and for all twelve study months of that year 0.481 under a lower probability level of 0.05.

Table 5. Interpreting the results from the comparison

Metal	Your Concentrations (mg/L)	Maximum Allowed Limit (mg/L)
Iron	0.36 - 1.70	0.3
Copper	0.20 - 1.84	1.3
Chromium	0.00 - 0.810	0.1
Zinc	0.30 - 2.70	5.0

The following are general points to take into consideration while interpreting the results from the comparison Table 5:

Iron: The iron concentrations ranged within the range of 0.36 to 1.70 mg/l, beyond the maximum limit of 0.3 mg/l. This means possible risk may be attributed to environmental and human health in regards to possible deterioration of aquatic life and water quality due to high levels of iron.

Copper: The copper values recorded range from 0.20 to 1.84 mg/L, which again falls within the allowable limit of 1.3 mg/L. While this allows for some months below the set limit, the occurrence of higher values leads to possible contamination issues that need identification and addressing.

Chromium: Concentrations range between 0.00 and 0.810 mg/L. Thus, the maximum allowable limit of 0.1 mg/L is grossly exceeded. Indeed, this is a great environmental concern because chromium is toxic to aquatic life and poses hazardous health effects in humans.

Zinc: The levels of zinc range from 0.30 - 2.70 mg/L, which is within the maximum limit of 5.0 mg/L. However, regular monitoring is suggested in order to ensure that the concentration levels do not build up and reach the maximum limit in the future.

The global forecast of heavy metals concentration in water, the iron concentration ranges from 0.36-1.70 mg/L and therefore is beyond the maximum limit set by WHO at 0.3 mg/L [9]. This indicates a critical violation, imposing an imminent environmental and health hazard that can necessitate immediate mitigation actions. On the other hand, copper levels, at close to the limit set by WHO at 1.3 mg/L, recorded predicted levels of 0.20-1.84 mg/L, indicating close monitoring. With the values standing below the threshold in some instances, there is a possibility of exceeding the limit in some months.

Chromium: Although the predicted values range from 0.00 to 0.810 mg/L, against the permissible limit of 0.1 mg/L, it can be stated that the value of chromium generally surpasses its safe limit and hence is hazardous to the aquatic fauna and human health. The predicted values of zinc, ranging between 0.30 - 2.70 mg/L, were well below the permissible limit by WHOM-5.0 mg/L agree with this study [21]. This would mean the present situation of zinc contamination is within the limits but requires constant monitoring. The data and methods were robust enough to ensure the accuracy of the prediction, and R-squared values were also availed to determine the predictive power of the model. Consistency and time-dependent trends were assessed in the heavy metal concentration mentioned in the study [22].

When we go by the predictions of global heavy metal concentrations in water, we note that iron values exceed the 0.3 mg/L WHO maximum permissible limit with predicted concentrations ranging from 0.36 to 1.70 mg/L. This, in turn, signifies a serious environmental and health hazard that could be in dire need of immediate mitigation measures. Copper, on the other hand, reached as high as the limit of the WHO [9], which is 1.3 mg/L, with predicted levels of 0.20-1.84 mg/L and thus needs close monitoring. While some values are below threshold, the probability of exceeding the limit in some months is alarming about copper contamination.

Chromium: Predicted values range between 0.00 to 0.810 mg/L. The permissible limit of this is 0.1 mg/L. It means very often, chromium exceeds the safe limit, which could present hazard in the aquatic ecosystem and also to human health. The zinc concentrations also vary from 0.30 to 2.70 mg/L as predicted. In short, the values are considerably below the WHO permissible limit of 5.0 mg/L. That means the zinc contamination is presently controllable, but further monitoring is suggested. The R-squared is 0.902, which explains the variation percentage of the dependent variable-that we try to forecast-by using independent variables or inputs [23]. Thus, it can be explained that the model explains approximately 90.2% of the variation in data, and the model is really good. Risk prediction-taking into consideration the concentration of metals in water in comparison with the maximum permissible limits: Determining criteria, taking into consideration the current value in mg/L for every metal.

In comparison with the maximum permissible limit. Calculating a ratio between the concentration of each metal and the maximum permissible limit [24]: Risk ratio = Concentration of metal / Maximum permissible limit Risk ratio = Maximum permissible limit / Concentration of metal. If the ratio is greater than 1, this implies there is a risk. You can evaluate the risk depending on the calculated ratios. The risks can be categorized into levels: low risk: 0 - 0.5, medium risk: 0.5 - 1 and high risk: > 1.

The iron risk ratio was: 1.20 to 5.67 (high risk). Copper risk ratio: 0.15 to 1.42 (medium to high risk). The risk ratio with regard to Chromium ranges from 0.00 to 8.10, indicating high risk. Zinc risk ratio: Ranging from 0.06 to 0.54, presenting low risk it would, therefore, be proper to conclude that iron and chromium pose high risks, copper is at medium to high risks, whereas Zinc is at low levels of risk agree with the studies [25, 26].

4. CONCLUSIONS

1) A wide variation was observed in the concentrations of heavy metals before and after water treatment, reflecting the efficiency of the treatment units used. The chemical analysis has shown that treatment units are capable of reducing the concentration of iron, copper, chromium, and zinc with high rates before discharge into the Tigris River.

2) The iron concentrations ranged from 0.36 to 1.70 mg/L, above the maximum permissible limit of 0.3 mg/L, thus posing a potential threat to the environment and human health since high levels of iron deteriorate the quality of water and are harmful to the aquatic organisms.

3) Values of copper detected remained between 0.20-1.84 mg/L and remained around the maximum permissible limit of 1.3 mg/L. Despite the fact that some months of the year remain below the maximum limit, higher values suggest contamination problems that should be scrutinized further.

4) Concentrations of chromium range from 0.00 to 0.810 mg/L and sometimes are above the maximum permissible limit of 0.1 mg/L, giving some insight into the extent of this major environmental problem because chromium in general can be very toxic to organisms living in water and may bring health problems to humans.

5) Regarding Zn, it ranges from 0.30 to 2.70 mg/L out of the maximum limit set at 5.0 mg/L. Monitoring should be continually undertaken to ensure that the concentrations will not build up for a certain period until the maximum is reached.

6) Forecasting the future: By the model of statistical analysis, the major factor affecting heavy metal concentration was found out and future change could be predicted accordingly.

It would, therefore, be reasonable to raise the bar for treatment systems at the plant by improving on monitoring techniques to safeguard the environment and health of the community.

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REFERENCES

[1] Ahamad, M.I., Yao, Z., Ren, L., Zhang, C., Li, T., Lu, H., Mehmood, M.S., Rehman, A., Adil, M., Lu, S., Feng, W. (2024). Impact of heavy metals on aquatic life and human health: A case study of River Ravi, Pakistan. Frontiers in Marine Science, 11. https://doi.org/10.3389/fmars.2024.1374835

[2] Wadeea, S.I., Hamdoon, R.M., Al-Zuhairy, M.S. (2022). Effects of industrial wastewater on water quality of the Tigris River at Baghdad using (GIS) technique. Journal of Techniques, 4(4): 1-11. https://doi.org/10.51173/jt.v4i4.569

[3] Majeed, O.S., Ibraheem, A.K. (2024). Using heavy metals pollution indices for assessment of Tigris River water within Al-Tarmiya City, Northern Baghdad, Iraq. Ecological Engineering & Environmental Technology, 25(3): 113-123. https://doi.org/10.12912/27197050/178457

[4] Aswad, O.A.K., Hasan, M.J., Saeed, J.J., Latif, A.S., Abdulmajeed, A.M. (2025). The relationship between soil oil pollution levels, microbial enzyme activity, and bioremediation strategies. International Journal of Design and Nature and Ecodynamics, 20(3): 655-661. https://doi.org/10.18280/ijdne.200320

[5] Saeed, J.J., Hasan, M.J., Ati, E.M., Latif, A.S., Rasheed, H.A. (2024). Evaluating the stages of environmental pollution and vital indicators in the Qayyarah refinery area, Mosul, Iraq. Nature Environment and Pollution Technology, 23(3): 1655-1661.

[6] Ati, E.M., Abbas, R.F., Al-Safaar, A.T., Ajmi, R.N. (2024). Using microplates to test boron in Zea mays leaf plant and the surrounding soil. Agricultural Science Digest, 44(6): 1056-1061. https://doi.org/10.18805/ag.DF-637

[7] Halder, J.N., Islam, M.N. (2015). Water pollution and its impact on the human health. Journal of Environment and Human, 2(1): 36-46. https://doi.org/10.15764/eh.2015.01005

[8] Ajmi, R.N., Sultan, M., Hanno, S.H. (2018). Bioabsorbent of chromium, cadmium and lead from industrial waste water by waste plant. Journal of Pharmaceutical Sciences and Research, 10(3): 672-674. https://www.jpsr.pharmainfo.in/Documents/Volumes/vol10Issue03/jpsr10031853.pdf.

[9] World Health Organization. (2017). Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum. https://www.who.int/publications/i/item/9789241549950.

[10] Das, S., Sultana, K.W., Ndhlala, A.R., Mondal, M., Chandra, I. (2023). Heavy metal pollution in the environment and its impact on health: Exploring green technology for remediation. Environmental Health Insights, 17. https://doi.org/10.1177/11786302231201259

[11] Lin, L., Yang, H., Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: A review. Frontiers in Environmental Science, 10: 880246. https://doi.org/10.3389/fenvs.2022.880246

[12] World Health Organization. (2022). Lead in drinking-water: Health risks, monitoring and corrective actions. https://www.who.int/publications/i/item/9789240020863.

[13] US EPA. (2024). National Primary Drinking Water Regulations. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[14] Singh, A., Sharma, A., Verma, R.K., Chopade, R.L., Pandit, P.P., Nagar, V., Aseri, V., Choudhary, S.K., Awasthi, G., Awasthi, K.K., Sankhla, M.S. (2022). Heavy metal contamination of water and their toxic effect on living organisms. The Toxicity of Environmental Pollutants, pp. 1-22. https://doi.org/10.5772/intechopen.105075

[15] Ati, E.M., Abbas, R.F., Zeki, H.F., Ajmi, R.N. (2022). Temporal patterns of mercury concentrations in freshwater and fish across a al-musayyib river/euphrates system. European Chemical Bulletin, 11(7): 23-28.

[16] Mumtaz, K., Afzal, A., Arif, A., Malik, M.F., Liaqat, S., Aslam, A., Khalid, S.Z., Javed, R., Mahmood, D., Nisa, K., Khurshid, F., Arif, F., Malik, M. (2020). Water pollution and industries. Pure and Applied Biology (PAB), 9(4): 2214-2224. https://doi.org/10.19045/bspab.2020.90237

[17] Chen, B., Wang, M., Duan, M., Ma, X., Hong, J., Xie, F., et al. (2019). In search of key: Protecting human health and the ecosystem from water pollution in China. Journal of Cleaner Production, 228: 101-111. https://doi.org/10.1016/j.jclepro.2019.04.228

[18] APHA. (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). Washington DC: American Public Health Association.

[19] Chowdhary, P., Bharagava, R.N., Mishra, S., and Khan, N. (2020). Role of industries in water scarcity and its adverse effects on environment and human health. In: Shukla, V., Kumar, N. (eds) Environmental Concerns and Sustainable Development. Springer, Singapore, pp. 235-256. https://doi.org/10.1007/978-981-13-5889-0_12

[20] Skoog, D.A., West, D.M., Holler, F.J., Crouch, S.R. (1996). Fundamentals of Analytical Chemistry. Fort Worth: Saunders College Pub.

[21] Dwivedi, S., Mishra, S., Tripathi, R.D. (2018). Ganga water pollution: A potential health threat to inhabitants of the Ganga basin. Environmental International, 117: 327-338. https://doi.org/10.1016/j.envint.2018.05.015

[22] Baird, C., Cann, M. (2012). Environmental Chemistry 5th Edition. W. H. Freeman and Company.

[23] Hanif, M., Miah, R., Islam, M., and Marzia, S. (2020). Impact of Kapotaksha River water pollution on human health and environment.

Progressive Agriculture, 31(1): 1-9. https://doi.org/10.3329/pa.v31i1.48300
[24] Rahmatullah, S.H.A., Ajmi, R.N. (2022). Anti-pollution caused by genetic variation of plants associated with soil contaminated of petroleum hydrocarbons. European Chemical Bulletin, 11(7): 33-44.
[25] Jorgenson, A.K. (2009). Foreign direct investment and the environment, the mitigating influence of institutional and civil society factors, and relationships between industrial pollution and human health. Organization & Environment, 22(2): 135-157. https://doi.org/10.1177/1086026609338163
[26] Kuehl, R.O. (2000). Design of Experiments: Statistical Principles of Research Design and Analysis. Duxbury Press.