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Biological Alternative to the Ecological Threat Posed by Cadmium and Lead

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Abstract: Aquatic cyanobacteria are gaining importance as biological alternatives for the remediation of heavy metal–contaminated waters due to their natural abundance, rapid kinetics and metal-binding ability. The present study evaluates the abatement efficiency of lead (Pb) and cadmium (Cd) by three unicellular cyanobacterial species, Synechocystis salina, Synechococcus elongatus and Gloeocapsacrepidinum, commonly occurring in aquatic environments in and around Cochin, India. Metal removal was assessed at different concentrations using Atomic Absorption Spectrophotometry (Perkin Elmer AAS 3110). Results revealed a clear concentration-dependent abatement, with significantly higher removal at lower metal concentrations. Among the species tested, Gloeocapsacrepidinum exhibited the highest tolerance and abatement efficiency for both Pb and Cd. Time-course studies showed that maximum metal removal occurred within the first 15–30 minutes, followed by a gradual reduction in abatement rate, reaching near equilibrium within 24 hours. The study demonstrates the potential of cyanobacteria, particularly G. crepidinum, as eco-friendly and cost-effective agents for the bioremediation of Pb- and Cd-contaminated aquatic systems.
Keywords: Cyanobacteria; biosorption; heavy metals; lead; cadmium; bioremediation

I. INTRODUCTION

Heavy metals in aquatic environments are a serious concern as they persist in the environment for longer periods in aquatic food chain causing harmful effects even at minute concentrations. Conventional remediation approaches, including precipitation- and filtration-based processes, are frequently limited by high operational costs, waste generation, and are found to be inefficient at trace levels [1]. There has been a paradigm shift towards sustainable biological alternatives that harness the innate capabilities of microorganisms to interact with and sequester heavy metals.

Microbial-based remediation strategies, particularly biosorption and intracellular accumulation, have gained attention as sustainable alternatives due to their operational simplicity and reduced environmental footprint [2]. Cyanobacteria, a diverse group of photosynthetic prokaryotes, demonstrate considerable potential in this context owing to their widespread occurrence in diverse aquatic habitats, rapid growth rates and the presence of metal-binding functional groups in their cell walls and extracellular polymeric substances (EPS). These features facilitate the adsorption and uptake of positively charged metal ions from aqueous solutions [3].

In recent studies, live cyanobacterial strains such as *Synechocystis sp.* and *Anabaena variabilis* have shown significant removal efficiencies for Cd(II) and Pb(II), though performance varies with species, metal type and experimental conditions [4]. Recent research emphasizes the potential of integrating cyanobacterial biosorption with metal recovery and reuse strategies, enhancing both environmental and economic feasibility [5].

Localized investigations that assess the species-specific performance of cyanobacteria under varied metal concentrations and exposure times remain necessary to tailor effective bioremediation protocols for contaminated waters in specific geographic regions. Cyanobacteria, due to their high surface-to-volume ratio, extracellular polysaccharides and negatively charged functional groups on cell walls, possess a strong affinity for metal ions. Several studies have demonstrated the potential of microalgae to remove Pb, Cd and other heavy metals efficiently from aqueous solutions [6][7][8]. However, species-specific variation in tolerance and abatement efficiency necessitates localized investigations.

The present study was undertaken to evaluate the heavy metal abatement potential of three aquatic cyanobacterial species—*Synechocystis salina*, *Synechococcus elongatus* and *Gloeocapsacrepidinum*—with respect to varying concentrations of Pb and Cd, and to examine the kinetics of metal removal over time.

II. MATERIAL & METHODS

A. Test organisms

The cyanobacterial species selected were *Synechocystis salina*, *Synechococcuselongatus,* and *Gloeocapsacrepidinum.*

B. Culture conditions

Cultures were maintained in Allen and Nelson medium at a salinity of 30 ppt, a temperature of 25 ± 1 °C, and a pH of 7.2.

C. Methodology for Metal Biosorption Study

The organisms were grown in Allen and Nelson medium of salinity 30 ppt, temperature 25°C, and pH 7.2. Different concentrations of cadmium and lead were prepared for each organism, along with their respective controls. To this, a uniform concentration of each test organism was added. Test samples were taken in duplicate. After mixing the samples in a shaker at 200 rpm for 30 minutes under a constant temperature of 25°C, the samples were centrifuged, and the supernatant was collected for the determination of heavy metal concentration by atomic absorption spectrophotometry. (Perkin Elmer AAS 3110)

D. Estimation of lead and cadmium

Residual Pb and Cd concentrations were estimated using atomic absorption spectrophotometry (Perkin Elmer AAS 3110). In AAS, the sample was first converted into an atomic vapour, and then the absorption of atomic vapour was measured at a selected wavelength, which is characteristic of each individual element. Quantitative measurements in AAS are based on Beer's law, and therefore, the measured absorbance is proportional to the concentration.

For the estimation of lead, the instrument was calibrated using a standard solution of 20 ppmlead, and the concentrations of lead in the samples were then directly measured from the AAS. The lamp used was a hollow cathode lamp of lead, and the flame used was air- acetylene. The monochromator wavelength selected was 283.3 nm.

For the estimation of cadmium, a hollow cathode lamp of cadmium was used as the primary light source. The instrument was calibrated using the standard solution of cadmium(1.5 ppm). Samples dosed with higher ppm cadmium were diluted ten times. The monochromator wavelength selected was 228.8 nm.

Dose-dependent and time-dependent abatement studies: The dose-dependent and time-dependent abatement studieswere carried out to find the influence of metal concentration and exposure time on abatement by cyanobacteriaand to analyse the toxicity effect of these metals on cyanobacteria at higher concentrations. Based on initial screening, *Gloeocapsacrepidinum* was selected for time-course studies. Metal abatement was monitored at intervals ranging from 15 to 1440 minutes at a 0.14 ppm concentration

III. RESULT AND DISCUSSION

A. Abatement potential of cyanobacteria at two different concentrations viz.,0.14ppm &8.88ppm.

One significant factor influencing the abatement rate of cyanobacteria is heavy metal concentration. Two effective concentrations of lead and cadmium, as measured by AAS, 8.88 ppm and 0.14 ppm, were used for the experiment. It was found that for all three species, viz., *S. salina, S. elongatus and G. crepidinum,* the percentage of abatement of lead was higher at lower concentrations. For S. salina at higher concentrations, the percentage of abatement was 34%, whereas at lower concentrations, the abatement by the organism was 42.86%. This may be because a higher concentration of the heavy metal lead disrupts the organism's physiological balance, thereby inhibiting its abatement potential.

In the case of *Synechococcus elongatus* at high concentration, the percentage of abatement was only 0.9% as against 64.29% for lower concentrations. In the case of *G. crepidinum,* too, the same pattern of abatement of Pb was observed, i.e., lower abatement for high concentration and high abatement for lower concentration, their values being 5.52% and 78.57%, respectively.

It is evident that even though higher concentrations were found to be generally harmful to the organisms, the tolerance limit varied with the species, as shown below.

G. crepidinum>Synechococcus elongatus >Synechococcus salina.

In the abatement of lead, the organisms also maintained the same trend as shown in Table 1

Just as in the case of lead, the percentage of abatement of cadmium was found to vary with concentration. In *Synechocystis salina*, the percentage of abatement for the higher concentration was 5.24, and for the lower concentration, it was 25.24. It is evident that the higher concentration of heavy metal adversely affects the physiology of the organism and consequently reduces the abatement potential.

Synechococcus elongatus also exhibited the same trend, but the percentage of abatement at higher concentrations was comparatively low, recording the percentage of abatement as 2.77. At a lower concentration, the percentage of abatement was 32.04.

In *G. crepidinum*, at a higher concentration of cadmium, the percentage of abatement was 10.33, and at a lower concentration, it was 36.89. Thus, the cyanobacterium *G. crepidinum* was found to abate more cadmium compared to other selected species(fig 2). Hence, among the species selected, *G. crepidinum* was found to be more effective for the abatement of the heavy metal cadmium.

The resistance to cadmium toxicity and cadmium abatement capability of various species can be represented as follows:

G. crepidinum>*Synechocystis salina* >*Synechococcus elongatus.*

TABLE I

PERCENTAGE ABATEMENT OF LEAD AND CADMIUM BY CYANOBACTERIA AT DIFFERENT CONCENTRATIONS

TEST ORGANISM	LEAD SUPPLIED (PPM)	LEAD IN FILTRATE (PPM)	LEAD ABATED (PPM)	% LEAD ABATEMENT	CADMIUM SUPPLIED (PPM)	CADMIUM IN FILTRATE (PPM)	CADMIUM ABATED (PPM)	% CD ABATEMENT
SYNECHOCYSTIS SALINA	8.88	8.85	0.03	0.34	6.87	6.51	0.36	5.24
	0.14	0.08	0.06	42.86	1.03	0.77	0.26	25.24
SYNECHOCOCCUS ELONGATUS	8.88	8.80	0.08	0.90	6.87	6.68	0.19	2.77
	0.14	0.05	0.09	64.29	1.03	0.70	0.33	32.04
GLOEOCAPSA CREPIDINUM	8.88	8.39	0.49	5.52	6.87	6.16	0.71	10.33
	0.14	0.03	0.11	78.57	1.03	0.65	0.38	36.89

B. Abatement of lead and cadmium by aquatic cyanobacteria with time:

From the studies conducted on the rate of abatement of Pb and Cd by three species of cyanobacteria, it was found that *G. crepidinum* was more efficient than the other unicellular species selected. It was also found that the rate of abatement was higher at lower concentrations. The rate of abatement of Pb and Cd by *G. crepidinum* with the varying time of 15 to 1440 minutes was studied. It was observed that in the first fifteen minutes, it was found that the rate of abatement was 28.6%. Within the first 30 minutes, it was 39.3%, indicating that in the second fifteen minutes, the percentage of abatement was only 10.7%. Thus, it was found that the maximum abatement has taken place in the first fifteen minutes. The abatement rate was found to be reduced with time. 71% of the Pb was found abated by two hours. The rate of abatement even after 24 hours was found to be only 85.7%, i.e., the lead abated for 22 hrs was only 14.3%. (Table 2).

78.6 % cadmium was removed from *G. crepidinum* culture within the first fifteen minutes. As time advances, the rate of abatement has been found to have been reduced considerably. Thus, after two hours, the percentage of abatement was 92.9. After 24 hours, the cadmium abated by the species was 95.7%; for 22 hours, the cadmium abated was as little as 2.8%.

TABLE II
TIME-DEPENDENT ABATEMENT OF LEAD AND CADMIUM BY *GLOEOCAPSACREPIDINUM*

TIME IN MINUTES	LEAD SUPPLIED (PPM)	LEAD IN FILTRATE (PPM)	LEAD ABATED (PPM)	% LEAD ABATEMENT	CADMIUM SUPPLIED (PPM)	CADMIUM IN FILTRATE (PPM)	CADMIUM ABATED (PPM)	% CD ABATEMENT
15	0.14	0.10	0.04	28.6	0.14	0.03	0.11	78.6
30	0.14	0.085	0.055	39.3	0.14	0.024	0.116	82.9
30	0.14	0.085	0.055	39.3	0.14	0.024	0.116	82.9
60	0.14	0.06	0.08	57.1	0.14	0.017	0.123	87.9
120	0.14	0.04	0.10	71.4	0.14	0.011	0.13	92.9
1440	0.14	0.02	0.12	85.7	0.14	0.006	0.134	95.7

Inthorn et al. (2001) studied the rate of abatement of three heavy metals, Pb, Cd, and Hg, by two strains of filamentous cyanobacteria, viz., *Calothrix, Tolypothrixtenius*and three strains of green algae[9]. It was observed that the kinetics of three heavy metal removals were similar, showing a fast removal in the first five minutes and reaching an equilibrium within 10 to 20 minutes. The results showed that most microalgae could tolerate well the toxicity of three metals, and the relative toxicity observed was Hg < Cd < Pb. The removal of heavy metals from comparatively wider areas by ion exchange, precipitation, and reverse osmosis is complicated and expensive [1]. Biological methods by using various microflora appear to offer a promising alternative. Their advantages include natural occurrence and cheap production availability to treat large volumes of wastewater due to rapid kinetics and high selectivity in terms of removal and recovery of specific heavy metals. [10]

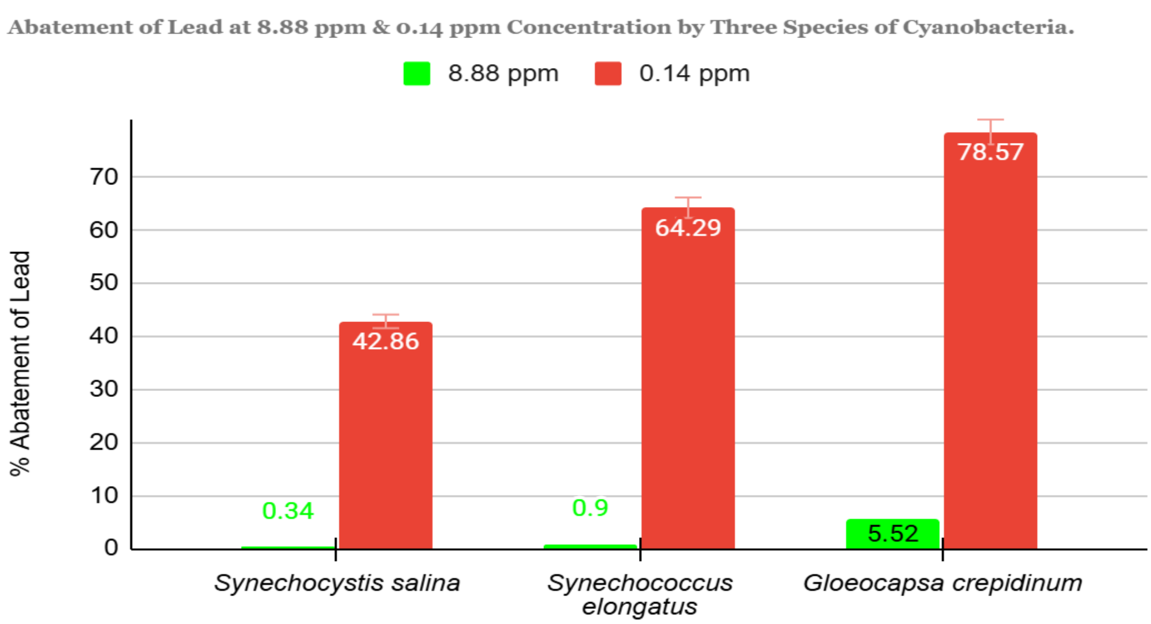

Fig. 1: Graph showing abatement of lead by three species of cyanobacteria

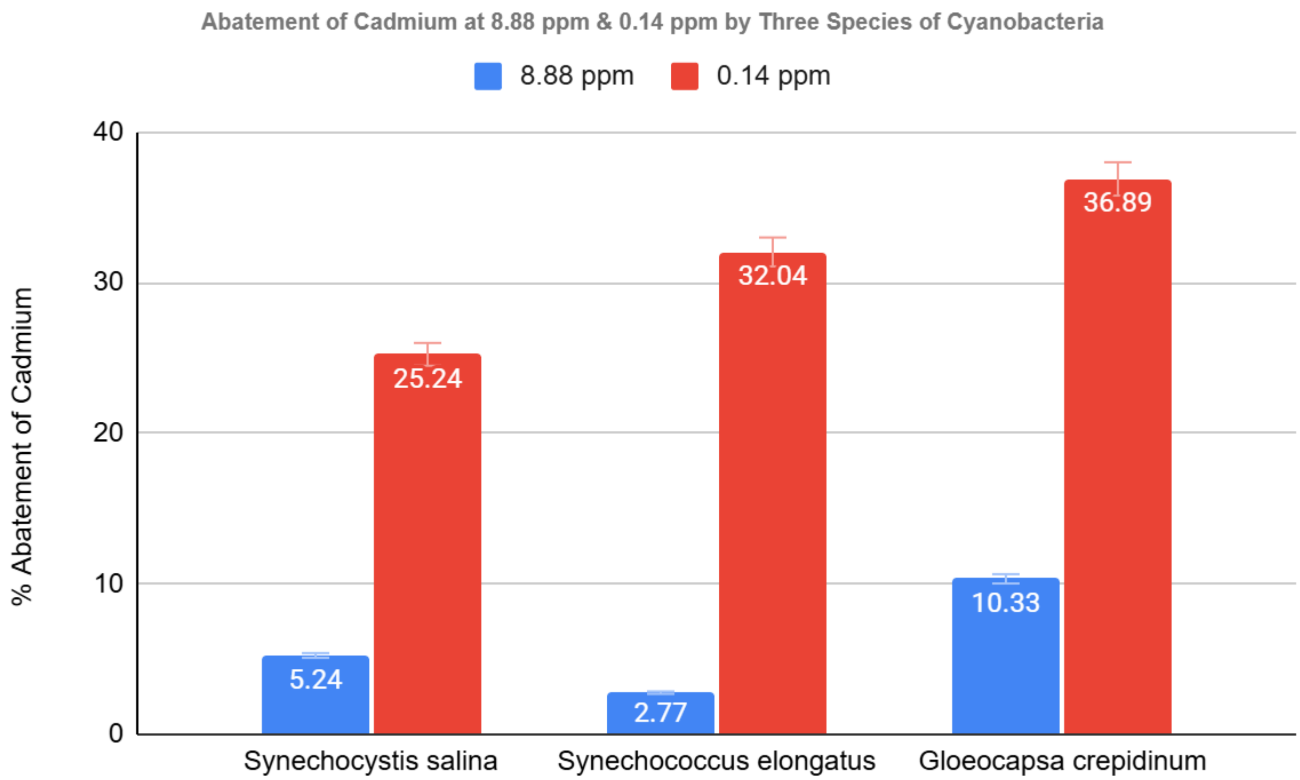

Fig. 2 : Graph showing abatement of Cadmium by three species of cyanobacteria

IV. CONCLUSIONS

The present investigation demonstrates that heavy metal abatement by cyanobacteria is strongly influenced by metal concentration and exposure time. Reduced abatement at higher concentrations may be attributed to metal-induced physiological stress. Among the species studied, *Gloeocapsacrepidinum* showed superior tolerance and abatement capacity for both Pb and Cd, indicating species-specific resistance mechanisms.

The lower efficiency of cyanobacteria at higher concentrations of lead and cadmium is mainly due to the saturation of available metal-binding sites and the toxic effects of these metals on cellular functions. Elevated metal levels can interfere with photosynthetic processes, trigger oxidative stress, and disrupt key enzymes and transport systems involved in metal uptake. In addition, at higher concentrations, the bioavailability of lead and cadmium decreases, which further restricts biosorption and bioaccumulation, ultimately resulting in reduced removal efficiency [11]

The rapid removal observed during the initial exposure period suggests a predominantly passive biosorption mechanism involving ion exchange and surface complexation. Similar fast kinetics have been reported for cyanobacteria and microalgae by Inthorn et al. (2001). Compared to conventional physicochemical methods, cyanobacterial remediation offers advantages such as low cost, eco-friendliness, and high selectivity [10].

The study emphasizes the potential of cyanobacteria as effective biosorbents for the removal of lead and cadmium, especially at lower concentrations typical of contaminated natural waters.Among the three species selected for the study, *Gloeocapsacrepidinum* emerged as the most promising cyanobacterium species for bioremediation applications due to its dose-dependent and time-dependent abatement efficiency for both lead and cadmium. This may be due to the adsorption of heavy metals by the characteristic mucilage layers on cell walls of algae.

V. ACKNOWLEDGMENT

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REFERENCES

[1] S. E. Manahan, Environmental Chemistry. Boca Raton, FL, USA: CRC Press, 1993, 811 pp.

[2] International Journal of Environmental Science and Technology, “Aims and scope,” Springer, 2025. [Online]. Available:https://www.springer.com/journal/13762. [Accessed: Mar. 4, 2026].

[3] L. Lourembam, M. Singh, and R. K. Sharma, “Cyanobacterial extracellular polymeric substances and their role in heavy metal biosorption,” Journal of Applied Phycology, vol. 36, no. 1, pp. 145–158, 2024.

[4] M. Hossain and T. Okino, “Comparative evaluation of cadmium and lead removal by live cyanobacterial strains,” Environmental Pollution, vol. 345, p. 123456, 2024.

[5] M. Ciani and A. Adessi, “Cyanoremediation and phyconanotechnology: Cyanobacteria for metal biosorption toward a circular economy,” Frontiers in Microbiology, vol. 14, May 2023.

[6] D. Inthorn, N. Sidtitoon, S. Silapanuntakul, and A. Incharoensakdi, “Sorption of mercury, cadmium, and lead by microalgae,” ScienceAsia, vol. 27, pp. 253–261, 2001.

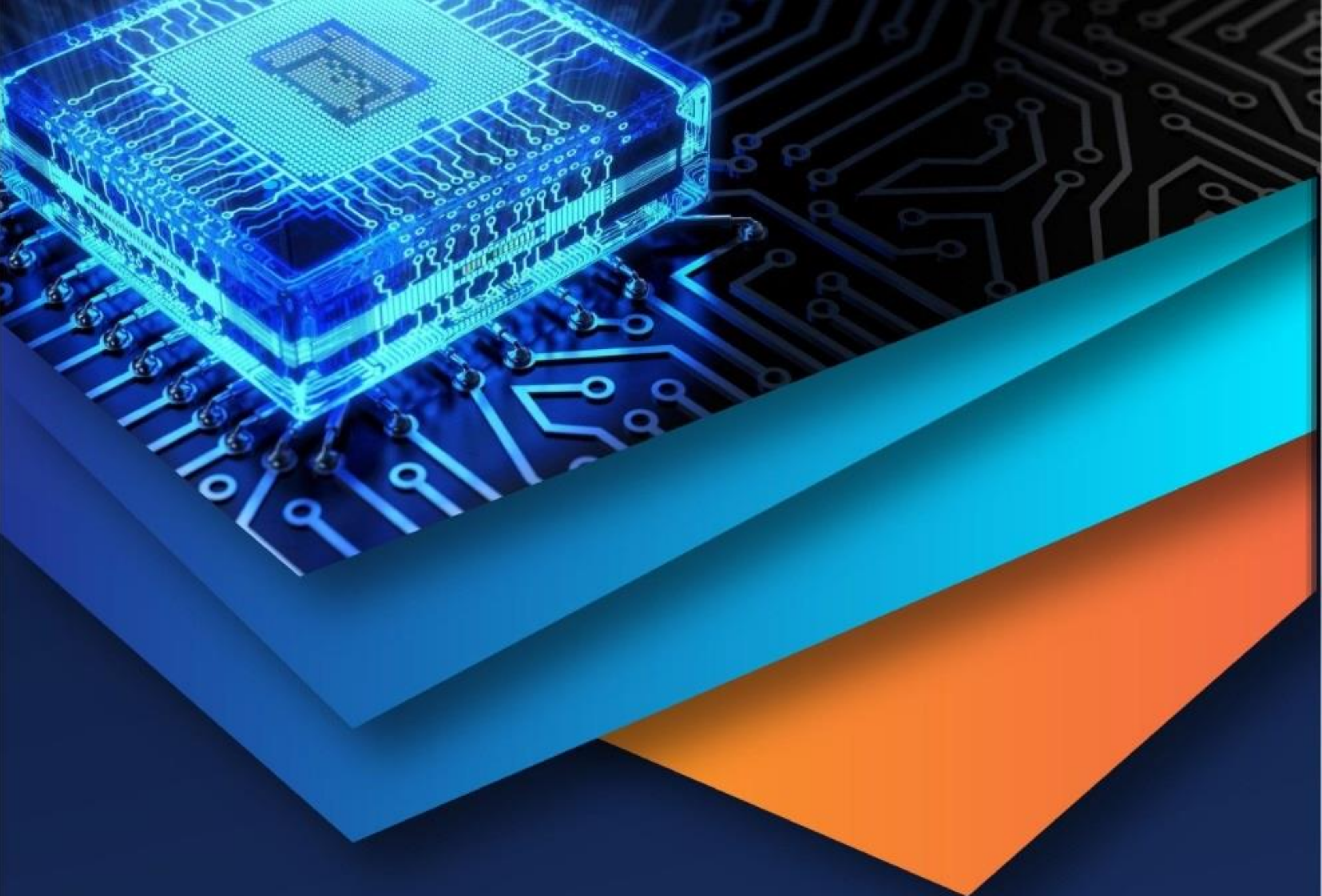
[7] J. Wang and C. Chen, “Biosorption of heavy metals by microbial biomass,” Biotechnol. Adv., vol. 27, pp. 195–226, 2009.

[8] K. S. Kumar, H. U. Dahms, E. J. Won, J. S. Lee, and K. H. Shin, “Microalgae as a promising tool for heavy metal remediation,” Ecotoxicol. Environ. Saf., vol. 190, pp. 110–114, 2020

[9] S. K. Mehta and J. P. Gaur, “Use of algae for removing heavy metal ions from wastewater,” Crit. Rev. Biotechnol., vol. 25, pp. 113–152, 2005.

[10] R. B. Genter, “Bioremediation of inorganic contaminants,” Environ. Sci. Technol., vol. 30, pp. 231–238, 1996.

[11] B. Volesky, “Biosorption and metal removal,” Hydrometallurgy, vol. 59, pp. 203–216, 2007.



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