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ROLE OF CYANOBACTERIA IN HEAVY-METAL REMOVAL FROM WATER AND WASTEWATER BY BIOSORPTION PROCESS

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ABSTRACT: Heavy metal toxicity has been a subject of concern for the past few decades. Due to the emerging awareness about the detrimental health hazards and adverse effects across all the levels of any ecosystem, the removal of heavy metals (HM) from contaminated water systems and soil has gained the profound attention of the scientific community for the last couple of decades. Living and dead cells of biological organisms have found to have capable of retaining the harmful HMs substantially from aqueous and solid matrix. This review encompasses the efficacy of cyan bacterial cells in removing HMs from contaminated water and wastewaters. The different strains collected from different sources which are capable of removing specific species have been discussed along with the biotic and biotic factors affecting the process have been assessed. Also, the mechanism of toxicity and removal of HMs through biosorption and bioaccumulation by these cells have been taken into consideration. The thorough knowledge of the cyanobacterial removal of HMs can be a solution towards sustainable, cost-effective green technology.

INTRODUCTION: The Increase in toxic heavy metal contamination has been a significant worldwide problem for the last few decades. Heavy metals are elements having atomic weights between 63.5 and 200.6 and a specific gravity greater than 5.0. In metallurgy, a heavy metal may be defined on the basis of density chemists would likely be more concerned with chemical behavior, whereas in physics, the distinguishing criterion might be the atomic number. There are many industries all over the world that produces waste containing heavy metals like, lead (Pb), zinc (Zn), copper (Cu), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and mercury (Hg) [1].

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Among the most prevalent heavy metals, Chromium (VI) is an oxidizing agent and carcinogenic in nature which can cause cancer in the digestive tract and lungs, epigastric pain, nausea, severe diarrhea, vomiting, and hemorrhage [2]. Cd was listed as a category -I carcinogen by the International Agency for Research on Cancer (IARC) and a group B-I carcinogen by the USEPA used in metal refineries, smelting, mining, and the photographic industry [3]. Copper, which is required for the development of tissue and bone, is also required for enzyme synthesis. However, it causes headache, vomiting, nausea, liver and kidney failure, respiratory problems, and abdominal pain [4].

Heavy metals can be removed by three different methods: chemically, physically, and biologically. In both the physical and chemical methods, the heavy metal ions removal includes chemical precipitation, ion-exchange, adsorption, membrane filtration, electrochemical treatment technologies, *etc*. In biological methods, many groups of

organisms are capable of removing these metals from the surrounding liquid matrix. Bacteria are capable of acting a bio-sorbent due to their high surface to volume ratio and a high number of potentially active sorption sites [4]. Fungal strains have also been reported for remediation of heavy metals from polluted soils and water [5, 6]. Green algae and cyanobacteria (blue-green algae) are also known for their capacity to remove heavy metals. Cyanobacteria are a group of photosynthetic bacteria, some nitrogen-fixing, that live in a wide variety of moist soils and water either freely or in a symbiotic relationship with plants or lichen-forming fungi [7]. Cyanobacteria are cosmopolitan microorganisms that play an important role in many ecosystems. It can be found in almost every terrestrial and aquatic habitat ocean, freshwater, damp soil, temporarily moistened rocks in deserts, bare rock and soil, and even Antarctic rocks [8]. Cyanobacteria can remove these heavy metals by different biological processes like bio-sorption, bio-accumulation, and cellular uptake of those metals. The biosorption process is most common because their EPS (extracellular polysaccharides) are more accurate and have more potential than chemical and biological processes. The present study investigates and demonstrates the removal efficiency of different cyanobacterial strains for heavy metals from contaminated water sources through the biosorption and bioaccumulation process and the various biotic and abiotic factors affecting the process.

Heavy Metal Toxicity on Cyanobacteria: The cytotoxicity of heavy metals has been studied and discussed by the scientific community for over the last few decades. The pathway of cytotoxicity of different heavy metals have also been established. For example, mercury, having the ability to cross the biological membrane and high affinity towards thiol and amino groups of enzymes, becomes capable of damaging membranes and several cellular enzymes [9]. The heavy-metal (HM) toxicity has been reported in all the trophic levels of the food chain of terrestrial and as well as aquatic ecosystems. The incidents of the thinning of eggshells and the reduced fertility due to low sperm count in humans are the direct proof of the HM biomagnification across the food chain. As other primary producers of an ecosystem, cyanobacteria are also affected by HM's presence in water bodies. The studies by Al-Amin *et al*. 2021 show that the cyanobacterial cellular mechanism is hampered by the efflux of HMs inside the cell. The HMs get their entry inside the cell through carriers and transporters [10]. The transport of HMs again can be active, which involves the breakdown of ATP, which yields energy, or passive, which doesn't involve energy input. The HMs namely, Arsenic, Cadmium and Chromium directly affect the enzymatic reaction of hydrolysis taking place in the reaction center (RC) of photosynthesis inside the cytoplasm. The breakdown of water yields reactive oxygen species (ROS) which may further cause DNA damage and inactivation of significant cellular enzymes and also may lead to cellular apoptosis by triggering caspases [11]. Therefore, the cyanobacterial cells have developed their own mechanism of combating the challenges of HM accumulation. There arethree major mechanisms through which cyanobacterial cells captures HMs. Extracellular polysaccharides (EPS) present in the outer layer of the Gram-negative cell wall of those cells can bind HMs because of the presence of anionic groups. The cytoplasm of the cyanobacterial cells has metallothionine enzymes which is rich in thiol groups having cysteine rich moiety. Those enzymes can capture HMs through the negatively charged thiol groups and therefore resist those HMs from reacting with the active cellular molecules like important enzymes. The third way of challenging the problem is to reflux the accumulated HMs back to the extracellular matrix which can be achieved through membrane transport proteins [10].

Collection Area and Culturemedia of the Cyanobacterial Strains: In the domain of Bacteria, Cyanophyta occupies a wide species pool. Cyanophyta, also known as cyanobacteria, is a group of photosynthetic bacteria, some of which are nitrogen-fixing. Since 1986, many scientists have provided us with good scientific literature on heavy metal removal in cyanobacteria. In the Class of Cyanophycean, many species are capable of removing heavy metals with different processes. The main focus of the discussion is the organisms responsible or capable of removing heavy metals. Different species of cyanobacteria developed their biomass in different growth mediums shown in Fig1. Cyanobacteria species are grown in BG11 medium, which is a very well-known culture

media. Cyanobacteria are not only grown in BG11 media but also optimally grown in different other growth media as well. For removal of metal ions, total 14 cyanobacterial growth media have been reported invarious researchers, Allen-Arnon, Aqueous artificial medium, ASN-III, RC saline, BG11, BG11 (without EDTA), ATCC, Chu-Ten, HGZ, LB medium, Parkers's Medium, Schlosser liquid medium, Seawater medium, and Zarrouk medium are few of those **Table 1**. BG11 shows the highest use, i.e., 35.6%, among those commonly used as growth media for cyanobacterial strains. The bar diagram in **Fig. 1** gives a clear knowledge of different media for culturing cyanobacteria for heavy metal removal.

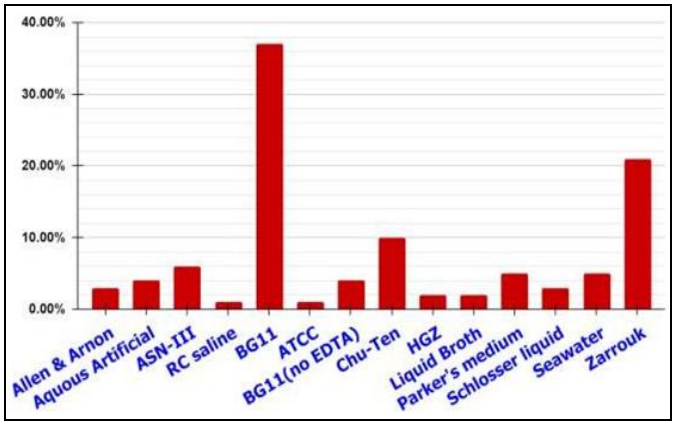

FIG. 1: DIFFERENT GROWTH MEDIA FOR CYANOBACTERIAL STRAINS

Anabaena cylindrica (ATCC 27899) was grown in a modified medium of Allen and Arnon, where one-eighth strength of all components was without phosphate and nickel [12] and also in ATCC medium 61613. *Anabaena doliolum* Ind1 was collected from a water body adjacent to a coal mining site in Cheiruphi, Jaintia Hills district, Meghalaya, India, grown under BG11 medium [14]. The blue-green algae *Anabaena sphaerica* also culturedin the BG11 medium which was collected from the Nile River in the Ismailia canal [15]. Under 10 days' continuous light source *Anabaena* subcylindrica was grown exponentially which was collected from the drainregion in Egypt [16]. Another type of the genus is Aphanothece, where 3 species were reported for heavy metal removal. For the experimental purpose of heavy metal removal, *Aphanothece flocculosa* was purchased from the Department of Botany, University of Toronto, Canada. The strain was cultivated under BG11 media on 10 days of fluorescent light exposure [17]. Aphanothece halophytica is also grown under the BG11 medium supplemented with 18mM $NaNO_3$ [18]. In the Zarrouk medium, *Arthrospira platensis* was cultivated as a heavy metal removal agent [19, 20]. Two strains of *Calothrix* i.e., *Calothrix* sp. (8113) & *Calothrix* sp. (8125) was found to be capable of removing heavy metals [21]. Those species were obtained from the Microbiological Resources Center (MIRCEN), Thailand Institute of Scientific and Technological Research (TISTR), Bangkok. Another culture was collected from TISTIR *Calothrix marchica* (TISTR8109) and the strain was cultured in medium-18 [21]. *Gloeocapsa* sp. F-6 gl was collected from the Institute of Microbiology RAS (Moscow) where it was cultured in D media [22].

Another species of Gloeocapsa sp. was cultured in medium [23]. Gloeothece magna was collected from an irrigation canal at Sohag city, Egypt and grown on BG-11 medium [24]. The genus *Lyngbyaisauni* cellular autotroph, there were 4 species capable of heavy metal removal process under this genus. One of those *Lyngbya* sp. was collected from a pond close to the Banaras Hindu University [25]. *Lyngbya* putealis HH-15 was cultured on BG-11 medium and collected from Haryana, India [26].

Other 2 species *i.e., Lyngbya wollei* & *Lyngbya majuscula* were collected from Russell Lake located in Russellville, AR [27] and East Kolkata Wetland, Kolkata (EKW), West Bengal, respectively [28]. *Mycrocystis aeruginosa* bloom material was collected from Dianchi Lake, Kunming, in southwestern China [29]. Nostoclinckia & Nostoc ruvularis were both isolated from the cultivated soil at Assiut in Egypt. The species were cultured in Chu'sten nutrient medium [30].

Nostocmuscorum, collected from a highly pollute driver Umshyrpi, in East-Khasi Hills district of Meghalaya, India, was cultured in BG-11 media 31 and from Indian Agricultural Research Institute, New Delhi *Nostocmuscorume* was obtained and cultured under Chu's ten medium under laboratory conditions [32, 33]. Nostoc spongiae for me was collected from Chao Praya River in Bangkok and the Pak Kret Nontaburee and Bang-Puu Industrial Estate areas in Thailand [21]. Under the family Oscillatoriaceae, many species of Oscillatoria were found to be capable of removing heavy metal in

different processes of removal. *Oscillatoria angustissima* culture was obtained from the National Facility for Blue Green Algal Collections (IARI, New Delhi, India) [34]. From the ponds close to the campus of the Banaras Hindu University, Varanasi Oscillatoria sp was collected for heavy metal removal studies [25]. Under Phormidium genus manyspecies were reported as a heavy metal removing agent. One species was collected from a thermal springlocated at Néris-les-Bains, Auvergne, France [35]. Also, *Phormidium* sp. was collected from a pond located within the agriculture farmhouse of Banaras Hindu University, Varanasi [25, 36, 37]. The cyanobacterial mat of Phormidium sp was obtained from a disposal site near tannery sludge in Jajmau tannery area in Kanpur [38]. *Phormidium laminosum* [39] also was found in the samearea. *Phormidium tenue* was collected from Nagapattinam coastal area located on the southeast coast of India [40]. *Phormidium valderianum* BDU 30501 was collected from the germplasm collection of the National Facility for Marine Cyanobacteria, Tiruchirappalli, India [41].

Heavy Metal Removal by Cyanobacterial Strains: Various cyanobacterial strains have been reported to play a potential role in heavy metal removal. The mechanism by which these strains effectively remove heavy metals primarily varies among bioaccumulation, biosorption, and bioremediation. Phormidium sp is a genus of filamentous cyanobacteria is widespread in nature and grows into mat-like structures. It has been found to bioaccumulate the toxic heavy metals chromium, copper, nickel, lead [35] and remove cadmium by biosorption [25, 36]. Nostoc muscorum, another filamentous cyanobacterium inhabiting both the terrestrial as well as aquatic environments has been reported to remove cadmium, lead [16, 32, 33, 42], cobalt, copper [16, 42] and zinc [42] by biosorption. Oscillatoria sp which is another genus of filamentous cyanobacterium have been found to show a diversity in the process by which itremoves the heavy metal. This genus has been reported to remove copper by biosorption [25, 36], uranium by bioremediation [43], zinc by bioaccumulation [44,] and bioremediation [43]. whereas cadmium, lead, chromium is removed by biosorption [36, 38] as well as bioremediation [43, 44]. Spirulina plantesis also has shown toxicity removal abilities against a wide range of heavy metals, including cadmium, copper 45, 46, cobalt, zinc 46, chromium, nickel, zinc, aluminum, iron strontium [47]. *Anabaena* sp is another genus of filamentous cyanobacteria that exist as plankton and are known for nitrogen-fixing abilities. Several species of this genus have shown heavy metal removal capacity. *Anabaena* cylindrica has been reported to remove nickel and lead by bioaccumulation mechanism [12,] whereas Anabaenasub cylindrica has been reported to effectively remove cobalt, copper, and lead by biosorption [16]. *Cyanothece* sp, agenus of unicellular oxygenic photosynthesizing cyanobacteria has also been reported to remove chromium, copper, and nickel by biosorption [48, 49]. *Gloeocapsa* sp, either unicellular or made up of small groups of cells grouped within mucilaginous envelopes, has been also found to remove cadmium, copper, leadandzinc by biosorption [22].

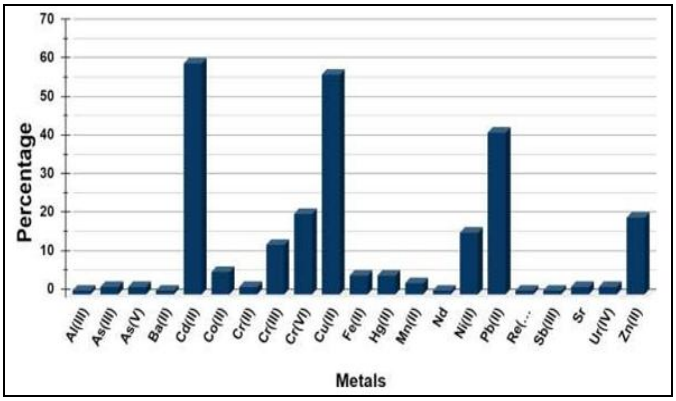

FIG. 2: METALS REMOVED BY CYANOBACTERIA

Mechanism of Heavy Metal Removal through Cyanobacterial Strains: The mechanism of HM removal includes bioaccumulation, bioremediation and biosorption. Among all the processes, biosorption is the most commonly found one in case of cyan bacterial HM removal owing to the capacity of retaining cationic metals of the cellular surface due to binding with phosphate and other anionspresent in the EPS (Extracellular polysaccharides). Presence of anionic groups at the extracellular surface and also on abiotic factors like pH, temperature and contact time. It has been found that the dead biomass of the cyanobacterial cells is also efficient in biosorption compared to live cells, which leads to the advantage of the overall process eliminating the chances of probable toxicity of the live cyanobacterial saxitoxin and other commonly found exotoxins. Amongst all other mechanisms, the process of biosorption has many advantages,

including high removal rate, easier desorption, minimum sludge generation, selective removal of HM species, and low operational cost.

The bioaccumulation of HM is a cellular process where the cations are accepted inside the cell cytoplasm through simple diffusion or passive and active transport through carrier proteins **Fig. 4**.

After the cations has successfully get their passage inside, those recaptured by the cytosolic metallo thionine proteins but if they are freely moving then they exhibit cytotoxicity leading to cellular damage in several ways **Fig. 5**.

Bioremediation means the total transformation of the HM in their valency level, changing those from toxic to non-toxic form.

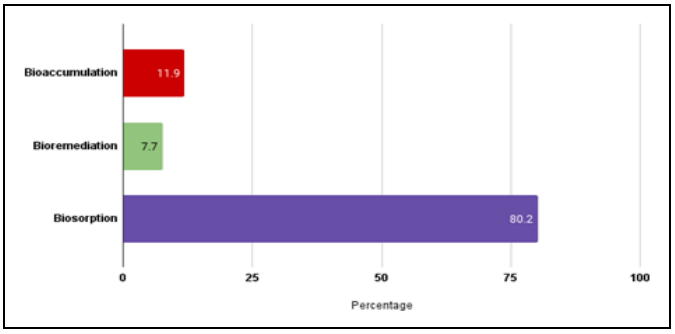

FIG. 3: DIFFERENT BIO-REMOVAL PROCESS

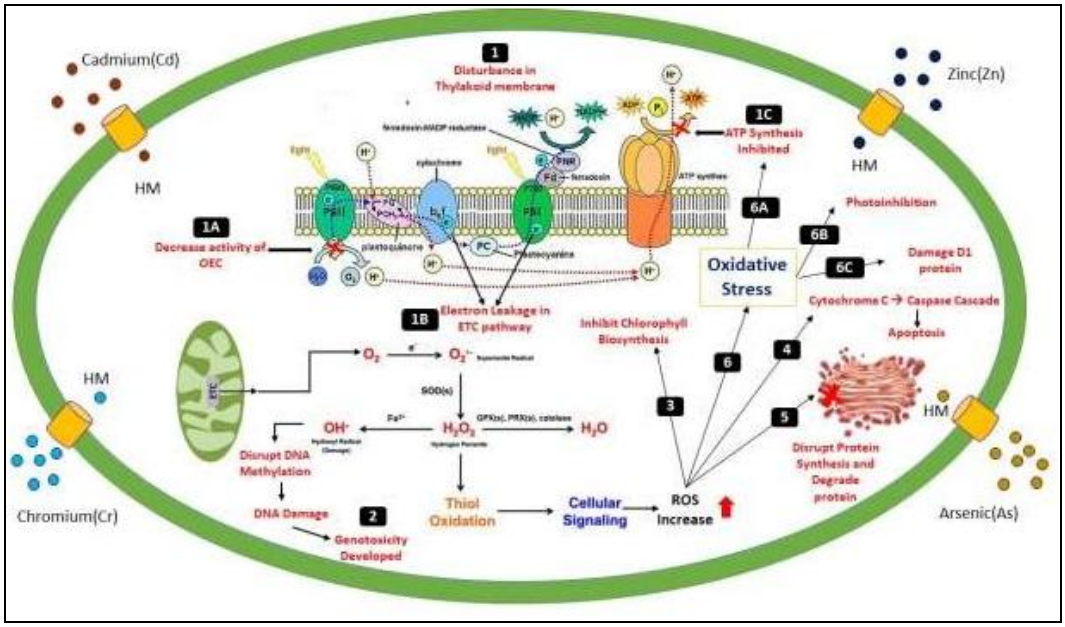

FIG. 4: EFFECT OF HEAVY METAL ON CYANOBACTERIAL CELL

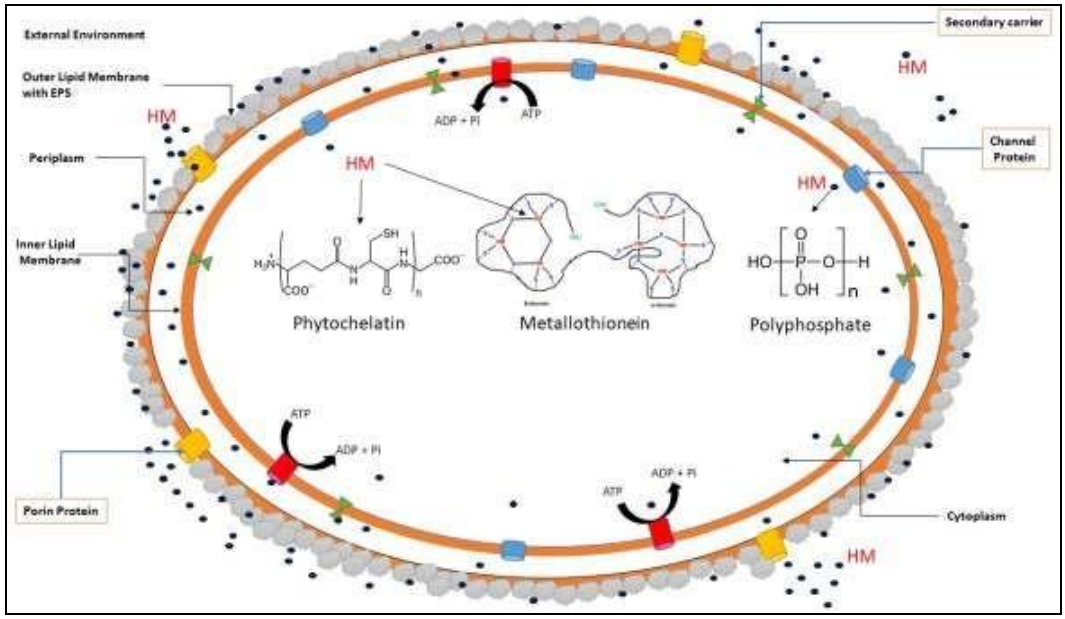

FIG. 5: MECHANISM OF HEAVY METAL STRESS TO LERANCE OF CYANOBACTERIAL CELL

Adsorption Iotherms for Cyanobacterial Heavy Metal Removal: The cyanobacterial heavy metal removal had followed different isotherms which had found to be mostly Freundlich and Langmuir isotherms. For a few years many literatures confirm that many isotherms are directly involved and show specific results on heavy metal removal through cyanobacterial strains. Among 79 cyanobacterial species **Table 1** different isotherms in biosorption such as Langmuir isotherm, Freundlichisotherm, Redlich- Peterson isotherm, Khan isotherm, Sips isotherm, Temkin isotherm, Dubinin Radushkeiso therm and Langmuir–isotherms were noticeable for metal removal. Under biosorption process different isotherms were demonstrated in **Fig. 3**. *Anabaena doliolum* Ind1 showed Langmuir 14 & Freundlich isotherm [42] and *Oscillatoria limnetica* shows three types of isotherm Langmuir, Freundlich & Redlich-Peterson [50], like those many cyanobacterial species showing their involvement in the metal removal process. In the last fewdecades' research shows a list of metals which were removed by cyanobacteria. In this study we demonstrate different cyanobacterial species successfully removed 18 heavy metals. 18 metals with different oxidation states are also involved in this bioprocess removal action. Like' Sliver (AgIII)' is removed by both the process of biosorption which follows Freundlich isotherm, and accumulation by the species *Microcystis aeruginosa* [51].

S. no	Scientific name of the cyanobacteria	Growing Medium	Metal removed by the strain	Process of removal	Abiotic Conditions			Analytical Methods	Ref.
					Temp(◦C)	pH	Light Intensity/ Photoperiod		
1	*Anabaena doliolum Ind1*	BG11	Cd(II)	Biosorption (L)	25	CultureMedium7	fluorescent light with a photon fluence rate of 50µmol/(m2.sec)	FTIR	14
2	*Anabaena sphaerica*	BG11	Cd(II)	Biosorption (F,L,D-R)	25±2	Biosorption5.5	continuous illumination (2500lux)	FTIR	15
		BG11	Pb(II)	Biosorption (F,L,D-R)	25±2	Biosorption3	Continuous illumination (2500 lux)	FTIR	15
3	*Anabaena spiroides*	-	Cd(II)	Biosorption (F,L,R-P)	25	Culture Medium4-5	fluorescent light(50mmol photon /m2/s,12 hlight/darkcycle)	-	50
		-	Cu(II)	Biosorption (F,L, R-P)	25	Culture Medium4-5	fluorescent light(50mmol photon /m2/s,12 hlight/dark cycle)	-	50
		-	Pb(ll)	Biosorption (F,L,R-P)	25	Culture Medium4-5	fluorescent light(50mmol photon /m2/s,12 hlight/dark cycle)	-	50
4	*Anabaena subcylindrica*	-	Co(II)	Biosorption	30	Culture Medium 7.8	:ontinuous light for 10 days	Statistical	16
		-	Cu(II)	Biosorption	30	Culture Medium 7.8	continuouslightfor10days	Statistical	16
		-	Cu(II)	Biosorption	30	Culture Medium 7.8	continuouslightfor10days	Statistical	16
		-	Pb(II)	Biosorption	30	Culture Medium 7.8	continuouslightfor10days	Statistical	16
5	*Anabaena variabilis*	BG11	Cr(VI)	Biosorption (F)	23	Culture Medium8	12/xmol photon m -2 s -1 provided by white fluorescent tubes	-	55
6	*Anabaena variabilis NIES23*	-	Cd(II)	Biosorption	-	-	-	-	53
		-	Cu(II)	Biosorption	-	-	-	-	53
		-	Pb(ll)	Biosorption	-	-	-	-	53

		-	Zn (II)	Biosorption	-	-	-	-	53
7	*Anacystis nidulans*	Aqueousartificial Culture Medium	Cd(II)	Biosorption (F)		-	illuminated and dark conditions	AAS, Spectrophotometry	45
		Aqueousartificial Culture Medium	Cu(II)	Biosorption F)		-	illuminated and dark conditions	AAS, Spectrophotometry	45
8	*Aphanothece flocculosa*	BG11	Hg(II)	Biosorption (F,L)	22	Culture Medium 6	fluorescent lighting	AAS	17
		BG11	Zn (II)	Biosorption(L)	30◦C withoutCO2 supplementation,Isolated25◦C	Culture Medium6.5, ıre Medium7.5	cool-white fluorescent lamps atanirradiance of 60E/m2/s1	Spectrophotometry	18 , 21
9	*Aphanotheces acrum*	-	Nd	Biosorption	-	Acidic Culture Medium	-	-	54
10	*Aulosira fertilissima*	-	Cd(II)	Biosorption (F,L) L(appropriate)	Biomasswas driedat80◦C in ahot air oven	Culture Medium pH5.0±0.2	-	-	58
		-	Cu(II)	Biosorption (F,L) L(appropriate)	Biomasswas driedat80◦C in ahot air oven	Culture Medium pH5.0±0.2	-	-	58
		-	Ni(II)	Biosorption (F,L) L(appropriate)	Biomass wasdried ıt 80◦C in a hotairoven	Culture Medium pH5.0±0.2	-	-	58
		-	Pb(ll)	Biosorption (F,L) L(appropriate)	Biomass wasdried ıt 80◦C in a hotairoven	Culture Medium pH5.0±0.2	-	-	58
		-	Zn (II)	Biosorption (F,L) L(appropriate)	Biomass wasdried ıt 80◦C in a hotairoven	Culture MediumpH5.0±0.2	-	-	58
		-	Cu(II)	Biosorption (F,L,S, R-P,K,T,GL)	Experimenton 25±2◦C	Absorption Medium pH.5.0 ±0.2	-	-	25
11	*Cyanospiracapsulata PCC9502*	Zarrouk Medium	Cu(II)	Biosorption	28±1C	-	"Fluorescent lampwithaphotonfluxof 100µmol (photon)m-2s-1		66, 67
12	*Cyanospiracapsulata ATCC43193*	Zarrouk Medium	Cr(III)	Biosorption	Cultivated at 28±1◦C	CultureMedium11	photon flux of 580µmol(photon)m−2s−1 photosyntheticactiveradiation (PAR)	AAS, Spectrophotometry	68
		Zarrouk Medium	Cr(VI)	Biosorption	Cultivated at28±1◦C	CultureMedium11	photon flux of 580µmol (photon) m−2s−1photosyntheticactive	AAS, Spectrophotometry	68

							radiation (PAR)		
13	*Cyanothece ET5,TI4, PE14, VI22,CE4)*	Seawater Medium	Cr(III)	Biosorption	Cultivated at 35±1◦C	ıre Medium8.5	photon flux of 580µmol(photon)m−2s−1 photosyntheticactiveradiation (PAR)	AAS, Spectrophotometry	68
		Seawater Medium	Cr(VI)	Biosorption	Cultivated at35±1◦C	ıre Medium8.5	photon flux of 580µmol (photon) m−2s−1photosynthetic active radiation (PAR)	AAS, Spectrophotometry	68
14	*Cyanothecesp.*	Seawater Medium	Cr(III)	Biosorption	Culture30± 1◦C	CultureMedium5	photon flux of 100µmolphotonm-2s-1	AAS	69
		Seawater Medium	Cu(II)	Biosorption	Culture30± 1◦C	CultureMedium5	-	AAS	69
		Seawater Medium	Ni(II)	Biosorption	Culture30± 1◦C	CultureMedium5	-	AAS	69
15	*Gloeocapsacalcarea*	BG11	Cr(III)	sorption (F,L)	Culture28± 3◦C	OptimalAbsorption2	3000lx (with 24 hillumination) usingcoolfluorescent tubes	Spectrophotometry	71
16	*Gloeocapsasp*	-	Cd(II)	Biosorption(L)	Culture28± 3◦C	Culture Medium8-8.2	30µmolphotonm-2s-1	FTIR,AAS	22
		-	Cu(II)	Biosorption(L)	Culture28± 3◦C	Culture Medium8-8.2	-	FTIR,AAS	22
		-	Pb(ll)	Biosorption(L)	Culture28± 3◦C	Culture Medium8-8.2	-	FTIR,AAS	22
		-	Zn (II)	Biosorption(L)	Culture28± 3◦C	Culture Medium8-8.2	-	FTIR,AAS	22
		-	Pb(II)	iosorption(F.L)	Culture25◦ C	Culture Medium3,4, 5,6,7, absorption-4	400µEm-2 s-1	-	23
17	*Gloeothecemagna*	BG11	Mn(II)	Biosorption(F)	25±1◦C	ıre Medium7.4	24µEm-2s-1	Spectrophotometry,IR spectra	72
		BG11	Cd(II)	Biosorption(F)	25±1◦C	CultureMedium 7.4	-	Spectrophotometry, IRspectra	72
18	*Gloeothece sp.PCC6909*	-	Cu(II)	Biosorption	Culture30± 1◦C	OptimalAbsorption 5	fluorescentlight(50mmolphotonm2s1,12 hlight/darkcycle)	TEM,SEM ,Lowry colorimetric	70
		-	Cu(II)	Biosorption	25◦C	Optimalabsorption atpH4.5–5.5	-	TEM	73
19	*Hapalosiphonschmidlei*	-	Cd(II)	Adsorption	Experiment 25±2◦C	CultureMedium 7.5	-	-	21
20	*Lyngbyamajuscula*	-	Cu(II)	sorption (F,L)		Biosorption6	-	FTIR,EDX ,SEM	28
21	*Lyngbya putealisHH-15*	BG11	Cr(VI)	sorption (F,L)	Culture28± 3◦C	Culture Medium8.5, Biosorption3	3000lx	-	26

		BG11	Cr(VI)	sorption (F,L)	Culture28±3◦C	CultureMedium 8.5,	-	-	26
			Cr(VI)	Biosorption [F,L,T, (D-R), (F-H),(D-R&B), (E&T),BET]	28±3◦C	-	3000luxusingcoolfluorescenttubes	-	26
22	*Lyngbyasp.*	-	Cd(II)	Biosorption (F,L,S, R-P,K,T,GL)	Experimenton 25±2◦C	Biosorption5.0± 0.2	-	-	25
		-	Cu(II)	Biosorption (F,L,S,R-P,K,T, GL)	Experimenton25±2◦C	Biosorption5.0± 0.2	-	-	25
		-	Pb(ll)	Biosorption (F,L,S, R-P,K,T,GL)	Experimenton 25±2◦C	Biosorption5.0± 0.2	-	-	25
	Lyngbyawollei	-	Cu(II)	Biosorption	Culture 23±2◦C,Culture45◦C	Culture MediumpH7 ± 1	-	Statistical	27, 74
23	*M. aeruginosa f.aeruginosaNIES 44*	-	Cd(II)	Biosorption	-	-	-	-	53
		-	Zn (II)	Biosorption	-	-	-	-	53
		-	Cu(II)	Biosorption	-	-	-	-	53
		-	Pb(ll)	Biosorption	-	-	-	-	53
		-	Cd(II)	Biosorption(L)	Inoculated 22-26◦C	-	40 W whitefluorescentlamp	-	29
24	*Microcystisaeruginosa*	-	Hg(II)	Biosorption(L)	Inoculated 22-26◦C	-	-	-	29
		-	Pb(ll)	Biosorption(L)	Inoculated 22-26◦C	-	-	-	29
		-	Ur(IV)	sorption (F,L)		OptimalUptake4-8	-	-	75
		-	Ag(III)	Biosorption(F), Bioaccumulation	Inoculated 25◦C	-	200µmolm-2s-1	-	51
		-	Cd(II)	iosorption(F), Bioaccumulation	Inoculated 25◦C	-	-	-	51
		-	Cu(II)	Biosorption(F), Bioaccumulation	Inoculated 25◦C	-	-	-	51
25	*Microcystis aeruginosaf. flos-aquaestrain C3-40*	-	Cd(II)	Biosorption, Bioaccumulation	-	Metal that wasbound bycapsularpolysaccharideat pH8 to9	-	Colorimetric	76
		-	Cu(II)	Biosorption, Bioaccumula	-	Metal that wasbound bycapsularp	-	Colorimetric	76

				tion		olysaccharid eat pH8 to9			
		-	Mn(II)	Biosorptio n, Bioaccumula tion	-	Metal that wasbound bycapsularp olysaccharid eat pH8 to9	-	Colorimetr ic	76
		-	Pb(ll)	Biosorptio n, Bioaccumula tion	-	Metal that wasbound bycapsularp olysaccharid eat pH8 to9	-	Colorimetr ic	76
26	*Microcystissp.*	-	Cu(II)	Biosorption		Biosorption2	-	-	77
		-	Cd(II)	Biosorption(F)	Experimen ton 29±2◦C	Biosorption6 .5-7	-	-	78
		-	Cu(II)	Biosorption(F)	Experimen ton 29±2◦C	Biosorption6 .5-7	-	-	78
		-	Zn (II)	Biosorption(F)	Experimen ton 29±2◦C	Biosorption6 .5-7	-	-	78
		Parker's Medium	Cr(II)	Biosorption(F)	Culture29± 2◦C	Culture Medium9.2, Biosorption6	72µmol photon m-2s-1lightintensity	IRspectra	79
		Parker's Medium	Fe(II)	Biosorption(L)	Culture29± 2◦C	Culture Medium9.2, Biosorption6	-	IRspectra	79
		Parker's Medium	Ni(II)	Biosorption(F)	Culture29± 2◦C	Culture Medium9.2, Biosorption6	-	IRspectra	79
		Parker's Medium	Cu(II)	sorption (F,L)	Isolated at29±2◦C	ıre Medium9.2	72µmolphotonm2s-1 lightintensity	-	59
27	*Nostoc calcicolaHH-12*	BG11	Cr(VI)	sorption (F,L)	Culture28± 3◦C	Biosorption3	3000lx	-	63
28	*Nostoccalcicol a*	Allen &Arnon' s nitrogenf ree Medium	Cu(II)	ntracellularUp take	Culture24± 1◦C	-	illuminated withcool whitefluorescentlights (intensity50/xEm-2s-1,	-	58, 59
29	*Nostoccommu ne*	-	Cd(II)	sorption (L,F)	roomte mperature 30±2◦C	Biosorption6	-	FTIR	80
		-	Zn (II)	sorption (L,F)	roomte mperature 30±2◦C	Biosorption6	-	FTIR	80
30	*Nostoclinckia*	Chu-Ten Medium	Cd(II)	Biosorption(L)	Culture30± 2◦C	CultureMedi um 7.1-8	5Wm−2lightintensity	-	30
		Chu-Ten Medium	Zn (II)	Biosorption(L)	Culture30± 2◦C	CultureMedi um 7.1-8	5Wm−2lightintensity	-	30
31	*Nostocmuscor um*	BG11	Zn (II)	sorption (F,L)	Culture25± 2◦C	ıre Medium7.5	under continuouslight at a photonfluence rateof50	FTIR,EDX ,SEM	31

							µmol/m2/s.		
		Chu-Ten Medium	Cd(II)	Biosorption	Culture25± 1◦C	Biosorption6	16-hlight/dark cycle.	Statistical	33
		Chu-Ten Medium	Pb(ll)	Biosorption	Culture25± 1◦C	Biosorption5	16-hlight/dark cycle.	Statistical	33
		Chu-TenMedium	Cd(II)	Biosorption (L,F),Intracellular uptake	Culture25± 1◦C	IntracellularUptake7	16-h light/darkcycle.	Statistical	32
		Chu-Ten Medium	Pb(ll)	sorption (L,F), Intracellular uptake	Culture25± 1◦C	Intracellular Uptake 6	16-h light/darkcycle.	Statistical	32
		-	Co(II)	Biosorption	Grownat30 ◦C	-	undercontinuous lightfor10days.	Statistical	16
		-	Cu(II)	Biosorption	Grownat30 ◦C	-	undercontinuous lightfor10days.	Statistical	16
		-	Cu(II)	Biosorption	Grownat30 ◦C	-	undercontinuous lightfor10days.	Statistical	16
		-	Pb(II)	Biosorption	Grownat30 ◦C	-	under continuouslightfor10days.	Statistical	16
		-	Cr(Vi)	Biosorption(F, L)	Culture25◦ C	-	-	FTIR	81
		-	Cd(II)	sorption (L,F)	Culture25-30◦C	Biosorption3	was 40–47 µmolphotons m−2 s−1(cool white light)withat16:8light:darkcycle.5 Wm−2light intensity	-	42
		-	Cu(II)	sorption (L,F)	Culture25-30◦C	-	was40–47µmolphotonsm−2s−1 (cool white light) withat16:8light:darkcycle.5 W m−2 lightintensity	-	42
		-	Pb(ll)	sorption (L,F)	Culture25-30◦C	-	was40–47µmolphotons m−2 s−1(cool white light) with at16:8 light: darkcycle.5Wm−2 lightintensity	-	42
		BG11	Zn (II)	sorption (L,F)	Culture25-30◦C	-	was 40–47 µmolphotons m−2 s−1(cool white light)withat16:8light:darkcycle.5 W m−2 lightintensity	-	42
32	*Nostocpunctiforme.*	BG11	Cr(III)	Biosorption(F, L)	Culture28± 3◦C	Biosorption2	-	SEM	71
33	*Nostocrivularis*	Chu-Ten Medium	Cd(II)	Biosorption(L)	Isolatedat 30±2◦C	CultureMedium 7.1-8	5 Wm−2light intensity	-	30
		Chu-Ten Medium	Zn (II)	Biosorption(L)	Isolatedat 30±2◦C	CultureMedium 7.1-8	5 Wm−2light intensity	-	30
34	*Nostoc sp.(accession no.KX814344)*	BG11	Cr(III)	sorption (F,L)	Cultured at30±2◦C	ıre Medium6	under continuouslightwithaphotonrateof 50µmolm−2s−1.	FTIR,EDX	82
35	*Nostoc*	BG11	Cr(III)	Biosorption	Culture	Throughout	Cool whitefluorescent	AAS	69

	sp.PCC7936				grown30± 1	theexperiment pHconstanton5	tubesgiving a meanphoton flux of 100lmolphotonm-2s-1		
		BG12	Cu(II)	Biosorption	Culture grown30± 1	Throughoutthe experiment pHconstanton5	Cool whitefluorescent tubesgiving a meanphotonfluxof100 lmolphotonm-2s-1	AAS	69
		BG13	Ni(II)	Biosorption	Culture grown30± 1	Throughoutthe experiment pHconstanton5	Cool whitefluorescenttubes giving a meanphotonfluxof100 lmolphotonm-2s-1	AAS	69
		BG11	Cu (II)	Biosorption (F,L)	-	pH8.0	-	-	66
		-	Cr (III)	Biosorption	Cultivated at 28±1◦C	7.5	photon flux of 580µmol(photon)m−2s−1 photosyntheticactive radiation(PAR)	-	68
		-	Cr (VI)	Biosorption	Cultivated at28±1◦C	7.5	photon flux of 580µmol (photon) m−2s−1photosyntheticactive radiation (PAR)	-	68
36	*Oscillatoriaangustissima*	BG11	Cu (II)	Biosorption (F)	grown25± 2°C	Culture Medium7± 0.2,Biosorption 4-5	1100lux	AAS	34
37	*Oscillatoriahomogenea*	ASN,RCsalineMedium, BG11	Sr	Biosorption (L)	incubatedat29	Biosorption9 ± 0.3	1200Lux illumination bywhitefluorescent light	Pixelmicroprobe	83
38	*Oscillatorialaetevirens*	BG11 Without EDTA	Pb(ll)	Biosorption(L)	intained 25 ±2°C	ıre Medium3-7	undera16:8light–darkcycle and anirradianceof ∼30 µmolphotonsm−2−1 provided by coolwhite fluorescentlamps.	EDX,FAAS, SEM	61
39	*Oscillatorialimnetica*	-	Cd(II)	Biosorption (F,L,R-P)	Incubated25◦C	ıre Medium4-5	fluorescentlight(50mmol photon /m2/s,12 hlight/darkcycle)	-	50
		-	Cu(II)	Biosorption (F,L,R-P)	Incubated25◦C	ıre Medium4-5	fluorescentlight(50mmol photon /m2/s,12 hlight/darkcycle)	-	50
		-	Pb(ll)	Biosorption (F,L,R-P)	Incubated25◦C	ıre Medium4-5	fluorescentlight(50mmol photon /m2/s,12 hlight/darkcycle)	-	50
40	*Oscillatoriasp.*	BG11	Cd(II)	Biosorption FandL ((F))	25grown	ıre Medium7.1	cool whitefluoreccent lightintensityin12h light-darkcycle,	AAS	84
		-	Cd(II)	Biosorption (F,L,S, R-P,K,T,GL)	Experimenton 25±2◦C	Culture Medium5, Biosorption5	-	-	25
		-	Cu(II)	Biosorption	Experimen	Culture	-	-	25

				(F,L,S, R-P,K,T,GL)	ton 25±2◦C	Medium5, Biosorption5			
		-	Pb(ll)	Biosorption (F,L,S, R-P,K,T,GL)	Experimen ton 25±2◦C	Culture Medium5, Biosorption5	-	-	25
		-	Cd(II)	Biosorption	-	Biosorption5	-	-	37
		-	Cu(II)	Biosorption	-	Biosorption5	-	-	37
		-	Pb(II)	Biosorption	-	Biosorption5	-	-	37
		-	Cr(VI)	Biosorption(F, L)	-	Biosorption5 .5-6.2	-	FTIR,SEM	38
		-	Mn(II)	Biosorption	-	6.57-6.75	-	-	85
41	*Oscillatoria sp.H1*	BG11	Cd(II)	Biosorption(F, L)	grown25	Adsorption6	12h–12hlight–darkcycle	-	86
	Oscillatoria trichoides	BG11 Without EDTA	Pb(ll)	Biosorption(L)	maintained at25 ±2°C	Biosorption5 - 5.14	undera16:8light–darkcycle and anirradianceof ∼30 μmolphotonsm−2s−1 provided by coolwhite fluorescentlamps.	FTIR,FAAS, Statistical	63
42	*Phormidiumlaminosum*	-	Cu(II)	Biosorption(L)	-		-	-	74
		-	Fe(II)	Biosorption(L)	-		-	-	74
		-	Ni(II)	Biosorption(L)	-		-	-	74
		-	Zn (II)	Biosorption(L)	-		-	-	74
		-	Cu(II)	Biosorption	-		-	-	39
43	*Phormidium sp. .*	-	Cd(II)	Biosorption(F, L, S,R-P, K, T,GL)	experiments25 ±2°C	Biosorption5 ± 0.2	-	-	25
		-	Cu(II)	Biosorption (F,L,S, R-P,K,T,GL)	experiments25± 2°C	Biosorption5 ± 0.2	-	-	25
		-	Pb(ll)	Biosorption (F,L,S,R-P,K,T, GL)	experiments25 ± 2°C	Biosorption5 ± 0.2	-	-	25
		-	Cd(II)	Biosorption	experiments25± 2°C	Biosorption5	-	Kinetics model	36
		-	Cu(II)	Biosorption	experiments25± 2°C	Biosorption5	-	Kinetics model	36
		-	Pb(II)	Biosorption	experiments25± 2°C		-	Kinetics model	36
		-	Cd(II)	Biosorption	experiments25± 2°C	Biosorption5	-	-	37
		-	Cu(II)	Biosorption	experiments25± 2°C		-	-	37
		-	Pb(II)	Biosorption	experiments25± 2°C		-	-	37

		-	Cr(VI)	Biosorption (F,L)	experiments25 ±2°C Biosorption5.5-6.2	-	-	-	38
44	*Phormidiumvalderianum BDU30501*	ASN-III Medium	Cd(II)	Biosorption	grown25±2°C	ure Medium7	under continuouswhite f fluorescentlightat anintensityof1500 lux	-	87
		ASN-III Medium	Co(II)	Biosorption	grown25±2°C	ure Medium7	under continuous whiteffluorescentlightatanint ensity of1500 lux	-	87
		ASN-III Medium	Cu(II)	Biosorption	grown25±2°C	ure Medium7	underrcontinuous whiteffluorescent lightat anintensityof1500 lux	-	87
		ASN-III Medium	Ni(II)	Biosorption	grown25±2°C	CultureMedium 7	under continuous whiteffluorescentlightatanint ensity of1500 lux	-	87
45	*Scytonema schmidlei*	-	Cd(II)	-	Experiment 25±2◦C	CultureMedium 7.5	-	-	21
46	*Scytonemasp.*	-	Cd(II)	Biosorption (F,L,S, R-P,K,T,GL)	Experiment25±2◦C	Biosorption5 ± 0.2	-	-	25
		-	Cu(II)	Biosorption (F,L,S,R-P,K,T, GL)	Experiment25±2◦C	Biosorption5 ± 0.2	-	-	25
		-	Pb(ll)	Biosorption (F,L,S, R-P,K,T,GL)	Experiment25±2◦C	Biosorption5 ± 0.2	-	-	25
		-	As(III)	Biosorption,	-	Biosorption6.9	-	-	88
		-	As(V)	Biosorption,	-	Biosorption6.9	-	-	88
47	*Spirulinamaxima*	Zarrouk Medium	Cd(II)	Biosorption(F)	incubated at30 ±1 °C		-	-	52
		Schlosser liquid M̈edium	Co(II)	Biosorption	xperiment35 °C	Biosorption5	under12:12pho-under 12: 12photoperiodconditions(12 hrlight:12hrdark cycles),	FTIR,SEM Spectrophotometry	89
		Schlosser liquid M̈edium	Cu(II)	Biosorption	xperiment35 °C	Biosorption5	under12:12pho-under 12: 12photoperiodconditions(12 hrlight:12hrdark cycles),	FTIR,SEM Spectrophotometry	89
		Schlosser liquid M̈edium	Mn(II)	Biosorption	xperiment35 °C	Biosorption5	under12:12pho-under 12: 12photoperiodconditions(12 hrlight:12hrdark cycles),	FTIR,SEM Spectrophotometry	89
		-	Zn (II)	Biosorption	xperiment35 °C	Biosorption5	under12:12pho-under 12: 12photoperiods	FTIR,SEM Spectropho	89

							conditions(12hrlight: 12 hr darkcycles),	tometry,	
		Zarrouk Medium	Pb(ll)	Biosorption(F) anddesorption	-	Biosorption5.5	-	-	90
48	*Spirulinamaxima, strainCTM-02*		Cd(II)	Biosorption	incubated at30 ±1 °C	-	-	-	91
		AqueousartificialCulture Medium	Cd(II)	Biosorption(F)	6hrs exposure(bothlight anddarktubes)	-	under illuminatedanddarkconditions	AAS, Spectrophotometry	45
	Spirulinaplatensis	Aqueousartificial Culture Medium	Cu(II)	Biosorption (F)	6hrs exposure(bothlight anddarktubes)	-	under illuminated and dark conditions	AAS, Spectrophotometry	45
		Zarrouk Medium	Hg(II)	Biosorption (F, L)	experiment at 22°C	Biosorption6	fluorescentlighting	AAS, Spectrophotometry	17
		Zarrouk Medium	Pb (ll)	Biosorption (L)	Grownat 20°C	Culture Medium4-5.5	fluorescent lamp(40W,4000lux), in cycles of 12-hlight followed by12hofdarkness.	Statistical	19
		-	Co(II)	sorption (F,L)	24±1 °C	Biosorption6	-	SEM, Statistical	46
		-	Cu(II)	Biosorption (F, L)	24±1 °C	Biosorption6	-	SEM, Statistical	46
		-	Zn (II)	Biosorption (F, L)	24±1 °C	Biosorption6	-	SEM, Statistical	46
		-	Al(III)	Biosorption	xperiment20 °C	ıre Medium8-9	-	FTIR, AA, Neutron Activation Analysis, AAC spectrometer	20
		-	Ba(II)	Biosorption	xperiment20 °C	ıre Medium8-9	-	FTIR, AAS, Neutron Activation Analysis, AACspectrometer	20
		-	Cr(III)	Biosorption	Experiment 20°C	ıre Medium8-9	-	FTIR, AAS, Neutron Activation Analysis, AACspectrometer	20
		-	Fe(II)	Biosorption	Experiment 20°C	ıre Medium8-9	-	FTIR, AAS, Neutron Activation Analysis, AAC spectromet	20

		-	Sr	Biosorption	Experiment 20°C	ıre Medium8-9	-	er FTIR, AAS, Neutron Activation Analysis, AACspectrometer	20
		-	Zn (II)	Biosorption	Experiment 20°C	ıre Medium8-9	-	FTIR, AAS, Neutron Activation Analysis, AAC spectrometer	20
		-	Re (VII)	sorption (F,L)	Experiment 20°C	Biosorption 2	-	FTIR, AAS, Neutron Activation Analysis, AAC spectrometer	20
		Zarrouk Medium	Hg(II)	Biosorption (F)	-		-		92
		-	Cu(II)	Biosorption	Grownat 30 °C	Culture Medium 7.5	-	AAS	93
49	*Spirulinaplatensis (UTEX1926) ulina platensis TISTR8217*	-	Cu(II)	Biosorption	Grownat 30 °C	Culture Medium 7.5	-	AAS	93
		Zarrouk Medium	Cd(II)	Biosorption (L)	cadmiumsolution wascontinuouslystirredat26 ±2°C	Biosorption7	-	TEM	94
50	*Spirulinasp*	-	Pb(ll)	Biosorption (L)	oculated 22-26◦C	-	under lightgeneratedbya40Wwhite fluorescent lamp.	-	29
		Zarrouk Medium	Cu(II)	Biosorption (L)	35◦C	CultureMedium 7.5-8.5	natural sunlight.	Spectrophotometry, AMA	95
		Zarrouk Medium	Cd(II)	Biosorption (L)	35◦C	Biosorption7	-	-	95
		Zarrouk Medium	Cr(III)	Biosorption (L)	35◦C	Biosorption7	-	-	95
		Zarrouk Medium	Cu(II)	Biosorption (L)	35◦C	Biosorption7	-	-	95
		-	As(V)	Biosorption (F,L)	roomtemperature, whichwas ∼35◦C.	Biosorption6 .0± 0.5.	-	SEM, IRspectra	96
		-	Cd(II)	sorption (F,L)	roomtemperature, which was ∼35◦C.	Biosorption6 .0± 0.5.	-	SEM, IRspectra	96
		-	Cu(II)	sorption (F,L)	Room temperatur	Biosorption6 .0±	-	SEM, IRspectra	96

					e, which was ~35◦C.	0.5.			
		-	Ni(II)	sorption (F,L)	roomtemperature, whichwas ~35◦C.	Biosorption6.0± 0.5.	-	SEM,IRspectra	96
		Zarrouk Medium	Cd(II)	Biosorption	32◦C	CultureMedium 9.2	-	AAS,Statistical	97
		Zarrouk Medium	Cr(II)	Biosorption	32◦C	CultureMedium 9.2	-	AAS,Statistical	97
		Zarrouk Medium	Pb(ll)	Biosorption	32◦C	CultureMedium 9.2	-	AAS,Statistical	97
		-	Cr(III)	Biosorption	driedat105 ◦C	CultureMedium 7	-	Spectrophotometry, TEM	98
51	*Stigonemasp.*	-	Cd(II)		Experiment 25±2◦C	CultureMedium 7.5	-	-	21
52	*Synechococcus PCC6301*	BG11	Cr(VI)	Biosorption(F)	23	ıre Medium8	12/xmol photon m -2 s -1 provided bywhitefluorescent tubes	-	55
53	*Synechococcus sp.*	HGZ Medium	Cr(VI)	Biosorption(F, L)	25◦C	Biosorption2	undercontinuous illumination(2klx)	FTIR	99
		HGZ Medium	Pb(II)	Biosorption(F, L)	25◦C	Biosorption3	undercontinuous illumination(2klx)	FTIR	99
		-	Cd(II)	Biosorption	-	-	-	SEM,TEM,FTIR	100
		BG11	Cr(Vi)	Biosorption(F, L)	dried at60°Cfor 24hbeforeuse	Biosorption2	undercontinuous illumination	-	101
54	*Synechocystis sp*	BG11	Cu(II)	sorption (F,L)	iedat60°Cfor 24 hbeforeuse	Biosorption5	under continuousillumination	-	101
		BG11	Ni(II)	sorption (F,L)	iedat60°Cfor 24 hbefore use	Biosorption4.5	under continuousillumination	-	101
		BG11	Sb(III)	Biosorption(F, L)	25◦C	CultureMedium 7	-	FTIR	102
55	*Synechocystis sp. BASO670*	BG11	Cd(II)	Biosorption(L, F),Desorption	25◦C	CultureMedium 6.8	-	EDX,SEM	103
		BG11	Cr(VI)	Biosorption	25◦C	CultureMedium 6.8	-	EDX,SEM	103
		BG11	Cd(II)	sorption (L,F), Desorption	25◦C	ıre Medium6.8	-	EDX,FAAS,SEM	103
		BG11	Cr(VI)	Biosorption,	25◦C	CultureMedium 6.8	-	EDX,FAAS,SEM	103
56	*Tolypothrix*	-	Cd(II)	Biosorption	-	Culture	-	EDX,TEM	53

tenuisTISTR8063	-	Cu(II)	Biosorption	-	Medium7.0 Culture Medium7.0	-	EDX,TEM	53
	-	Pb(ll)	Biosorption	-	Medium7.0 Culture Medium7.0	-	EDX,TEM	53
	-	Zn (II)	Biosorption		Medium7.0 Culture Medium7.0	-	EDX,TEM	53

Cadmium (Cd)' was also removed by many blue-green algae species, *i.e.*, cyanobacteria. The following species are shown biosorption processes with the help of different isotherms for the removal of metal atoms. Spirulina maxima show Freundlich isotherm [52], *Anabaena doliolum* Ind1 shows Langmuir 14 & Freundlich isotherm [42]. *Anabaena variabilis* NIES 23 by the process of biosorption removes themetal [53]; *Anacystis nidulans* removes metal by biosorption, which follows the Freundlich isotherm [45]. *Anabaena inaequalis* shows Freundlich isotherm[51]. Neodymium (Nd)' is a rare earth metal that was removed by a sorption mechanism by *Aphanothece sacrum* [54]. 'Rhenium (Re)' also a transition metal that was removed by *Spirulina platensis* with the help of Langmuir & Freundlich isotherm [47].

In this study we find that among 79 species of cyanobacterial strains listed in **Table 1**, Cadmium (Cd) with II oxidation state is highest and potentially removed by a maximum number of species, approximately 60% of the total listed species. Copper (Cu) & Lead (Pb) holds the second and third position, respectively for removal. Apart from those, Cobalt (Co), Nickel (Ni), Zinc (Zn), and Chromium (Cr) show significant action. All metal ions are listed in **Fig. 4** with a bar diagram.

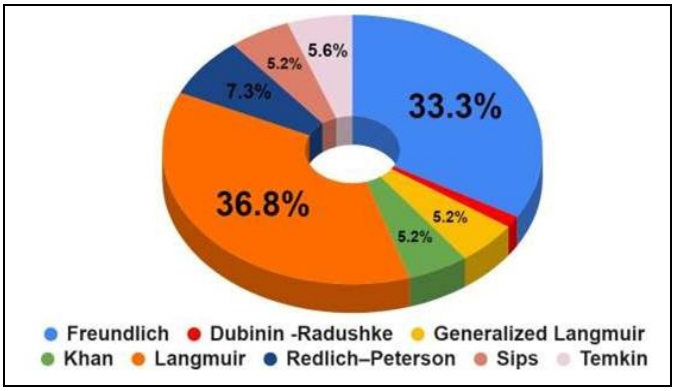

FIG. 6: DIFFERENT TYPES OF ISOTHERMS IN BIO-SORPTION PROCESS

Influence of Phonthe Process of Biosorption: In the removal process of cyanobacteria one of the major and vitalabiotic factors is Ph which was varying in awiderange. Here in t is a section all pH values are discussed, and in many literatures the pH value was reported as a growth medium pH or as a removal medium pH. Many species were cultured at different pH levels, and the bio-removal process occurs at different pHs. In **Table 1** their listed pH levels with culture media as well as removal media. Culture media's pH is important for biomass development, and those biomasses then process heavy metal removal at different pH levels; this phenomenon varies from species to species. For example, seven species of a particular genus *Anabaena i.e.*, a cyanobacterial species, were reported in the range of pH 2-8. *A. cylindrica* was grown in neutral culture medium *i,e* pH 7 12,13, whereas in & *A. doliolum* Ind1, it was also cultured at the same pH *i.e.* pH714.

In the Culture medium two species of *Anabaena* were grown, *Anabaena subcylindrical*, which was in pH 7.8 16, & *Anabaena variabilis*, pH 8 [55]. In the acidic medium (pH4-5) *A. spiroides* was grown [50] and in the last *A. sphaerica* reported in a wide range from acidic to basic but Pb and removed maximum at pH 3 & pH 5.5 respectively by the help of biosorption [15].

The pH of the extracellular matrix highly influences the process of biosorption. It has been observed by [20, 56] that the moderately high pH favors most HM species' physical processes. The group of researchers has reported the same in the case of Cr, Pb, and Cd [46]. The lower pH favors the increased concentration of protons in the extracellular matrix, which inhibits the cationic HMs from binding with the anionic groups, including phosphate and amides on the EPS surface.

The overcrowded protons get dissolved in the higher pH which favors the HMs to bind with the anionic groups in turn incrementing the rate of biosorption. Though at very alkaline pH, formation

of metal hydroxides ions tends to lower the adsorption rate owing to the precipitation of the metal hydroxides.

Temperature and Light in Tensity as in Fuencing Factors: Temperature is one of most important a biotic factors responsible for the removal of heavy metals by cyanobacteria.

In most of the species of cyanobacteria the temperatures were reported in a wide range. From **Fig. 3** we demonstrate the range of temperature in which removal actions were performed. Individual cyanobacterial strains' optimal temp also shown in **Table 1**. We conclude that the temperature between 20°C to 45° C shows a wide range of optimal growth and optimal experimental temperature for 79 cyanobacterial species in **Table 1**, which conducts the heavy metal removal process. Light intensity plays a major role in removing heavy metal in the cyanobacteria in Abiotic conditions. Under the genus of '*Anabaena*', many species can remove heavy metal, and different articles suggest different light intensity and mode for removing heavy metals. In *Anabaena* cylindrica under constant light at the height of 170 μEm-2s-1(photosynthetic ally active radiation) 12, cool white fluorescent lights (at intensity 900 lux), 12-h light/darkcycle [57], was capable of acting as a metal removal agent. In **Table 1** here [79] cyanobacterial species with different genera show different and modified light intensity modes and light color. In this study, we can say that light acts as an abiotic component that regulates the removal process with unknown mechanisms.

CONCLUSION: In the study, we found that cyanobacteria have a tremendous ability to remove heavy metals from the surrounding environments. The BG11 medium shows the highest rate in the growth of many species of the cyanobacterial genus, whereas the RC saline medium shows the lowest growth of the cyanobacteria. Different processes did the heavy metal removal among all the process biosorption shows the maximum removal potential, whereas eutrophication shows the minimum result. Various types of isotherms were followed in the biosorption process, among them Langmuir isotherm and Freundlichi so therm shows 33.3% and 36.8% efficiency respectively to support the biosorption process. Apart from that, many other isotherms also show biosorption processes. In this study, we found that cyanobacteria remove the most amount of Cadmium (Cd), Copper (Cu), and lead (Pb), respectively. Abiotic factors like temperature, pH, and light intensity also take a crucial role in the removal process, and we can say that those abiotic factors can regulate this process. In this study, we noticed that the temperature range between 20-45-degree Celsius is the optimal temperature for cyanobacterial growth, and this wide range of temperatures exhibits potential results. So, we can say that with the help of many abiotic factors and different optimal growth media, cyanobacteria are capable of 18 different types of heavy metals with its surrounding media. The clear mechanism of this heavy metal removal is not crystal clear nowadays, so it is an emerging research area for today's researchers. Its result will go for mankind's wellness.

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