



REVIEW ARTICLE

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Potential Microbial Diversity in Chromium Mining Areas: A Review

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ABSTRACT

Mining is viewed as one of the principal economic activities that have the potential of contributing to the financial development of the country. On the other hand, the environmental and health impacts of mining on surrounding communities have been a major affair to governments, public, stakeholder, and individuals. The harsh environments are inhabited by abundant microbes that help in driving biogeochemical cycles. This article herein reviews microbial diversity in these degraded ecosystems which will expand our understanding of microbial processes and their ecological roles in extreme environments.

Keywords: Chromium mining, microbial diversity

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INTRODUCTION

Minerals and mineral products are the main keys of most industries and some form of mining is executed nearly each and every country around the world. It boasts major financial, environmental and social effects in the countries or regions where it is performed, and beyond. For lots of developing countries mining reports for a dominant percentage of Gross Domestic Product and, often, for the mass of foreign exchange earnings and foreign investment. The chromium industry involves the mining of chromite ore and the utilization and production of chromium in chemicals, metal, refractories, ferrochromium and stainless steel.

The mining sector is a crucial economic benchmark for many countries and includes the proper utilization of metallic and nonmetallic minerals. Owing to their severe and frequent injuries, causalities and catastrophes it has been considered as one of the major hazardous work environments in many countries around the world. The rapid industrialization unifying with aggressive development of mining industries has not only resulted in degradation of the environmental quality globally but also the cause of primary headache of scientists for an effective measure to control environmental pollution.

CHROMIUM MINING

Chromium is extensively used in metallurgical, chemical, refractory industries. Properties like resistance to corrosion, oxidation, wear and galling and enhancement of hardenability make chromium most versatile and vital. Low carbon is manufactured by chromium and high-carbon ferrochrome and charge chrome which is used as additive in making stainless steels and special alloy steel. Hard lumpy chromite is used for the production of high carbon ferrochrome while, for low carbon ferrochrome, friable ore and fines briquettes. Charge chrome is produced by both Briquetted fines and lumpy ores. The notable source countries of chromite are South Africa, Zimbabwe, Russia, Kazakhstan, Finland and India.

According to Geological Survey of India, Ministry of Mines, Odisha is the primary source of chromium that has substantially 98% of Chromium mining zone present in Sukinda-nuasahi compare to only 1% in Nuggihalli, Sindhuvali, Talur belt of Karnataka and rest are in Bhandara, Nagpur, Sindhudurg belt and Chandrapur belt of Maharashtra, Jojohatu-Roroburu belt of Jharkhand, Jannaram, Konnyapalem,

Lingannapeta Blocks etc of Andhra Pradesh, Namakhal and Thiruchengoddu of Tamil Nadu as shown in figure 1.

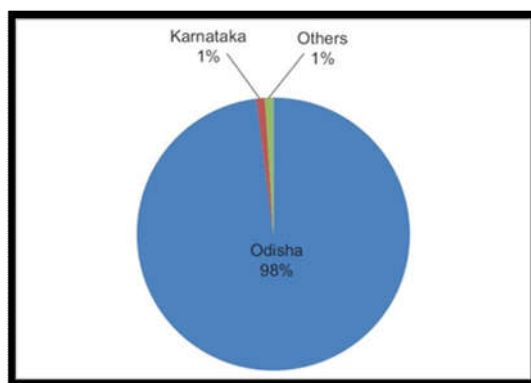


Figure: 1 Chromium mining zone in India

Odisha holds a prominent position both in terms of deposit and production in the mineral map of India. According to Indian Bureau of Mines, Odisha is one of the largest minerals bearing states in India due to the vast and diverse mineral deposits. The state boasts of staggering 16.92% of the total reserves of the country. Mineral reserve in respect to chromite, graphite, bauxite, iron, manganese and coal ore is about 97.37%, 95.10%, 76.67%, 49.74%, 33.91%, 28.56% and 27.59%, respectively. In Odisha, the major hubs of chromite are Jajpur (16 mining leases occupying 4,320.93 Ha of mining area), Keonjhar (5 mining leases obtaining 2,013.123 Ha of mining area) and Dhenkanal districts (3 mining leases occupying 960.8 Ha of mining area).

Chromium:

Chromium is a naturally occurring element generally found in rocks, animals, plants, soil and in volcanic dust and gases. It has different oxidation states ranging from +2 to +6. Cr (VI) and Cr (III) are the most permanent forms though having distinct biological, geochemical and toxicological properties. Cr (III) is considered to be less toxic than Cr (VI) and is found naturally at a narrow range of concentration. Hexavalent chromium is widely used in industries such as textile dyeing, corrosion inhibition, electroplating, wood treatment and tanning all of which produce a discharge of chromium-containing effluents [1]. The property of high solubility makes Cr (VI) a hazardous contaminant of water and soil when discharged by industries that produce or utilize chromium. Cr (VI) is a potential contaminant of groundwater that can participate in the trophic transfer in food chains when it is released to the environment. Owing to its dangerous properties, Cr (VI) is identified by The United States Environmental Protection Agency as one of the 17 chemicals posing the greatest threat to humans [2].

Is chromium dangerous?

Trivalent chromium (Cr-III) and Hexavalent chromium (Cr-VI) are the two most common types chromite found. Trivalent chromium (Cr-III) is formed in the mineral chromite and also considered as an essential trace element in human diets; high doses can cause health problems and harm sensitive plants and animals. Human activities like chromite mining and Cr-III can be converted into Cr-VI by ferrochrome processing, which is about 100-1000 times more toxic than Cr-III and is known as the cause of cancer.

HOW ARE PEOPLE EXPOSED TO CHROMIUM?

There are many ways by which people can expose to chromium such as skin contact with contaminated soil or water, breathing contaminated air, drinking contaminated water or eating contaminated food, dust or soil (for example, from dirty hands or food). According to Canadian and Ontario Regulations and Guidelines for chromium; In India, drainage from a chromite mine and its overburden piles caused chromium contamination of 250-3000 ug Cr/L in surface water. Another Indian study sampling near an open pit chromite mine recorded high Cr-VI levels in groundwater (30 - 800 ug/L) and surface water (30 - 140 ug/L). These concentrations are far above the Canadian and American Cr-VI Water Quality Guidelines for Protection of Aquatic Life (1 and 16 ug/L, respectively) and the Dutch regulation for total chromium in groundwater. No studies were found regarding how these pollution levels affected the health of plants and animals.

Toxicity of chromium

Nasal and skin irritations, allergies, ulceration, eczema, perforation of ear drum, respiratory tract disorders and lung carcinoma can induce in humans by Cr (VI) exposure [3, 4, 5]. Moreover, Cr (VI) denotes the efficiency to damaging fetal development; accumulate in the placenta, [6]. The pollution cause as Cr (VI) in the environment affects the structure of soil microbial communities [7], reduces microbial growth and activities related to enzyme, with a consequent perseverance of organic matter in soils and

accumulation of Cr (VI) [8]. Due to its capability to easily penetrate cellular membranes Cr (VI) is toxic. Cell membrane damages caused by oxidative stress induced by Cr (VI) have been widely reported, both in prokaryotic and eukaryotic cells, with effects like membrane integrity loss or inhibition of the electron transport chain [9, 10]. Moreover, Cr (VI) enters cells using the sulfate transport system of the membrane in cells of organisms that can use sulfate [11, 12, 13, 14, 15, 16]. Once Cr (VI) entered into cells, reactions occur spontaneously with the intracellular reluctant as glutathione and ascorbate, the short-lived intermediates Cr (V) and/or Cr (IV) are generated, the end-product Cr (III) and free radicals [17, 18, 19]. Cr (V) is oxidized to Cr (VI) and a reactive oxygen species, referred as ROS, is produced due to the process in the cytoplasm that easily combines with protein-DNA complexes. On the other hand, Cr (IV) has the capability of binding to cellular materials and changing their normal physiological functions [20, 21]. Cr (VI) can induce mutagenic, carcinogenic and teratogenic effects making it a very dangerous chemical form on biological systems. Cr (VI) can induce oxidative stress in cells, damaging its DNA [22]. Inside of cells, the Cr (III)-DNA adducts and related hydroxyl radical oxidative DNA damages have a central role in originating the genotoxic and mutagenic effects [23]. Moreover, the formation of Cr (III)-DNA binary adducts and L-cysteine-Cr (III)-DNA and ascorbate-Cr (III)-DNA ternary adducts likely increase both genotoxicity and mutagenicity in human cells [24, 25]. Promutagenic effect is induced significantly by the formation of DNA protein cross-linking, a process favoured by Cr (VI) [25]. Owing to the dangerous effects cause to human health, Cr (VI) has been identified as priority pollutants and listed as a Class A human carcinogen by the US Environmental Protection Agency (USEPA) [26]. The cell membrane is nearly impermeable to Cr (III); thus it has only about one thousandth of the toxicity that of Cr (VI) [27, 28]. Taking all possibilities into account it can be concluded that, depending on its oxidation state, chromium have various biological effects. Cr (VI) that is highly toxic to most organisms compared to Cr (III) which is relatively innocuous [29, 30].

Chromium Mining

With the help of different antropogenic activities chromium enters the environment. Environmental pollution caused by chromium and its compound is mainly because of large number of industrial operations including mining, pigment production, chrome plating, petroleum refining, wood preservation, leather tanning, pulp processing, textile manufacturing and electroplating. Due to seepage from chromate mines or improper disposal of mining tools and supplies, and inappropriate disposal of industrial production equipment; groundwater contamination may occur. With hexavalent chromium, the water from chromite mines is invariably contaminated. Without any treatment, mine water is released into the adjoining water sources, which includes chromium compounds in different valence state. Hexavalent chromium is produced due to still unknown chemical reactions, and this percolates to the subsoil and terrestrial water sources. Damage is being done by the effluents to the subsoil and surface water sources in adjacent areas and waste dumping sites.

For the eradication and treatment of surface water or groundwater (known as pump and treat) a variety of technologies are used. Once on the surface, water comprising Cr (VI) can be decreased by Fe (II) compounds followed by several methods including alkaline precipitation, ion exchange, etc. Electrochemical reduction is another procedure used where Cr (VI) reduction is followed by alkaline precipitation in which Fe (II) forms electrochemically, Rather being added as a purchased chemical, and acidic reduction of the Cr at pH < 3.0 with sulfur dioxide, sodium bisulfite, or sodium metabisulfite and sodium sulfite, completes the transformation to Cr (III). If reduction with a sulfite compound is used there is a greater possibility for incomplete conversion of Cr (VI) to Cr (III). Thereupon, these reactions must be supervised cautiously to ensure complete conversion to Cr (III), which eventually precipitates out of solution as Cr(OH)₃.

For *in situ* remediation of groundwater and soil, various types of geochemical regression or anaerobic biological treatment procedures have been designed which make use of Chromium's ability to change the valence state of the oxidized, toxic, and highly mobile nature of Cr (VI) and transform it into the more stable, nontoxic, and immobile Cr (III). Cr (III) eventually precipitates out as Cr (III) hydroxide [Cr(OH)₃]. In these technologies, Cr becomes less toxic and immobile but not completely removed from the environment. There are many treatment methods which are using sulfur-based reductants; anaerobic biodegradation enhancements such as lactic acids, molasses, chemical reductants, elemental iron technologies to mould a reducing environment.

REMEDIATION TECHNIQUES

Soils, sediments and water are the sources of metal impurities. Metal contaminants can be formed through the industrial process like refining, electroplating and mining. A critical factor to the remediation of metals is non-biodegradability, but conversion can be possible through complexation, sorption,

methylation and alteration in valence state. Remediation deals with the removal of pollution or contaminants from environmental media like groundwater, surface water soil or sediment.

The remediation of chromium-contaminated sites requires knowledge of the processes that control the migration and conversion of chromium. Advection, dispersion, and diffusion are physical processes affecting the rate at which contaminants can migrate in the subsurface. **Advection** refers to the transport of a solute (chromium) in ground water by the bulk movement flowing downstream. **Mechanical Dispersion** is caused by the different flow path of water particles, in a geological medium. Many flow paths are faster because they follow a more direct path or they are going through larger pores or through the center of pores in which water flows faster because less friction is observed. Other flow paths may be slower as they are closer to the grain boundaries, hence being exposed to more agitation in the pore throat, slowing down the water particle. Mechanical dispersion, a mechanical mixing and dilution of the solute, is caused by different water particles within the bulk movement of groundwater. **Molecular diffusion** is caused by random molecular motion due to the thermal kinetic energy of the solute. The motion of molecules in liquids is smaller than in gases but larger than in solids.

Redox reactions, chemical speciation, adsorption/desorption phenomena control the transformation and mobility of chromium. Chemical speciation and oxidation-reduction are the chemical processes used in remediation techniques.

Chemical speciation is essential for discussing the chemical reactivity of trace constituents in the environment, such as toxicity and biological availability and the geochemical behavior of chemical species. Speciation of an element implies to know the distribution of an element amongst defined chemical species in a system. Many systematic methodologies have been developed for the chemical speciation of elements in environmental samples: typically, sequential leaching methods, hyphenated techniques, such as X-ray spectroscopic techniques, GC-ICP-MS (organometallic components analysis) and others.

Redox reaction refers reduction/oxidation reactions that chemically convert hazardous compounds to nonhazardous or less toxic compounds that have less mobility and more stability. Redox reactions include the transfer of electrons from one compound to another. The most widely used oxidizing agents for the treatment of hazardous contaminants in soil and groundwater is ozone, catalyzed hydrogen peroxide, hydrogen peroxide, potassium permanganate, sodium permanganate, and sodium persulfate. Every oxidant has advantages and drawbacks and while relevant to soil contamination and some source zone contamination, are applied toward remediating groundwater primarily.

Bioremediation:

Bioremediation is a waste management technique that involves the use of living or dead organisms to remove or neutralize pollutants from a contaminated site. This method involves **phytoremediation, bioventing, bioleaching, bioaugmentation, rhizofiltration, and biostimulation** [31]. Bioremediation method is also very useful in chromium eradication. **Phytoremediation** refers to the efficient use of plants to detoxify or immobilize, remove environmental impurities through the physical, chemical, biological or natural activities and processes of the plants. Here by using phytoremediation techniques we can eradicate chromium from the environment [32]. **Bioventing** is a process of stimulating the natural in situ biodegradation of contaminants in soil by providing air or oxygen to existing soil microbes. Bioventing uses low air flow rates to administer only enough oxygen to sustain microbial activity in the unsaturated zone. Oxygen gas is most frequently applied through direct air injection into residual pollutants in soil. Additionally degradation of adsorbed fuel remainder, volatile compounds are biodegraded as vapors move very slowly through the biologically active soil [33]. **Bioleaching** of the sediment was performed with a mixed culture of chemi-autotrophic Fe/S oxidising acidophilic, bacteria, in the presence of elemental sulphur as a substrate. Such element resulted to be major both for cell growth and for metal disintegration [34]. **Bioaugmentation** involves addition of naturally occurring microbes to a contaminated site to enhance degradation [35]. **Rhizofiltration** is a type of phytoremediation, which refers to the access of using hydroponically cultivated plant roots to remediate contaminated water through precipitation of pollutants, concentration and absorption [36]. **Biostimulation** involves the modification of the environment to stimulate existing bacteria capable of bioremediation. It can be done by addition of various types of rate limiting nutrients and electron acceptors, such as nitrogen, phosphorus, oxygen, or carbon (e.g. in molasses form). Bioaugmentation enhances biostimulation.

Discharge of chromium containing wastes has led to the destruction of many agricultural lands and water bodies. Utilization of chromium (Cr) reducing microbes and their products have enhanced the efficiency of the process of detoxification of Cr(VI) to Cr(III). Compared to other conventional methods, bioremediation is highly economical and eco-friendly as this generates no further waste into the environment. Biodiversity is the variability among living organisms from all sources along with

terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. This chapter investigates soil biodiversity pertinent to the excited skin of terrestrial system that gives way to the new technological explorations like the discovery of soil bacteria for anti-carcinogenic activity (The Telegraph 05 September, 2011). The soil environment is one of the most complex biological communities on earth and niche to an even larger share of biodiversity than tropical woodlands. Soil is beaming with life, the fraction of the surface area covered by soil microbes is only about 1×10^{-6} which incidentally is the same percentage of land area on earth that human covers.

Why Bioremediation is better?

Cost: In compare to other types of remedial paths, the total cost of bioremediation is generally significant. It can be used by all categories of people in our society and helpful to the mankind.

Performance: Remedial technologies can be divided into two broad categories, contaminant removal and contaminant destruction. To achieve complete removal and destruction, both methodologies need the practitioner to persist remediation until all of the impurities have been labeled. The Fundamental cause of remedial option break down is the inability of an approach to address sufficient contamination within a system to meet the goals of a project. Bioremediation is machinery which is helpful in mass reduction, complete mineralization and effective across wide range of contaminants, DNAPL (Dense-non-aqueous-phase liquid) source treatment.

Flexibility: Bioremediation can be very effective as a stand-alone strategy. This technique involves remediation of remediation of DNAPL source, ground water, remediation of unsaturated zone and can use after chemical oxidation.

Biological Cr (VI) reduction and removal

Microbial Cr(VI) reduction was first reported in the late 1970s when Romanenko and Koren’Kov (1977) observed Cr(VI) reduction capability in *Pseudomonas* species grown under anaerobic conditions. Hereafter, various researchers have discovered new microorganisms that catalyse Cr (VI) to Cr(V) or Cr(III) under different types of conditions [37, 38, 39]. Some other researchers have also analysed Cr(VI) reduction in consortium cultures isolated from the environment [40, 41]. Cr(VI) reduction is shown to be metabolic (not participating in energy conservation) in particular species of bacteria, but is predominantly dissimilatory/respiratory under anaerobic conditions [42]. In the latter process, Cr (VI) serves as a terminal electron acceptor in the membrane electron-transport respiratory pathway, a procedure developed in energy conservation for growth and cell maintenance [43]. Most microorganisms are conscious to Cr (VI), but some microbial species are resistant and can tolerate high levels of chromate. In bacteria, Cr (VI) resistance is mostly plasmid-borne whereas metal reductase genes have been found both on plasmids and on the main chromosome. Different resistance strategies have been identified, including: Extraction of chromate via the transmembrane sulphate shuttle [44], counter working chromate-induced oxidative stress by activating enzymes involved in ROS scavenging, regulation of iron uptake, which may sequester iron in order to prevent the generation of highly reactive hydroxyl radicals via the Fenton reaction and extracellular reduction of Cr(VI) to Cr(III) which is then removed easily by reacting with functional groups of bacterial cell surfaces [45].

Table 1: List of Bacterial diversity

Sl. No.	Resistant/ Tolerant	Gram positive(+) Or Gram negative(-)	Reduction of Cr(VI)	Reference
1.	<i>Corynebacterium paurometabolum</i> SKPD 1204 (MTCC 8730)	+	60 μ M	46
2.	<i>Pseudomonas</i> sp.	-	75%	46
3.	<i>Acinetobacter</i> sp.	-	75%	46
4.	<i>Alcaligenes</i> sp.	-	75%	46
5.	<i>Cupriavidus</i> sp.	-	75%	46
6.	<i>Corynebacterium</i>	+	75%	46
7.	<i>Pseudomonas fluorescens</i> LB 300	-	20–100 mg/l	47
8.	<i>Bacillus thuringiensis</i>	+		48
9.	<i>Arthrobacter</i> sp.	+	50 μ g/ml	49
10.	<i>Aureobacterium esteroaromaticum</i>	-	2 mmol l ⁻¹	50

11.	<i>Clavibacter michiganensis</i>	-	2 mmol l ⁻¹	50
12.	<i>Cellulomonas flavigena</i>	-	2 mmol l ⁻¹	50
13.	<i>Ochrobactrum anthropi</i>	-	(5.4–39.1)%	50
14.	<i>Bacillus sphaericus</i>	+	800 mg l ⁻¹	51
15.	<i>Pseudomonas putida</i>	-	65%	52
16.	<i>Pseudomonas plecoglossicida</i>	-	55%	52
17.	<i>Proteus mirabilis</i>	-	68%	53
18.	<i>Bacillus subtilis</i>	+	97%	54
19.	<i>Anoxybacillus strains</i>	+	1 mM	55
20.	<i>Acinetobacter calcoaceticus</i>	-	500 ppm	56
21.	<i>Micrococcus luteus</i>	+	500 ppm	56
22.	<i>Serratia marcescens</i>	-	500 ppm	56
23.	<i>Bacillus</i> sp.	+	90%	57
24.	<i>Achromobacter</i> sp.	-	54.2mM	58
25.	<i>Arthrobacter</i> sp. SUK 1201	+	100%	59
26.	<i>Pseudomonas</i> sp.	-	80%	59
27.	<i>Vibrio parahemolyticus</i>	-	445 (µg/ml)	60
28.	<i>Vibrio alginolyticus</i>	-	435 (µg/ml)	60
29.	<i>Acinetobacter</i> sp. IST3	-	82%	61
30.	<i>Klebsiella pneumoniae</i>	-	1.8mM	62
31.	<i>Bacillus firmus</i>	+	950 mM	62
32.	<i>Mycobacterium</i> sp.	+		62
33.	<i>Streptomyces tendae</i>	+	75.5 mg g ⁻¹	63
34.	<i>Streptomyces</i> sp. MC1	+	884 (17 mM)	63
35.	<i>Arthrobacter aureus</i>	+	50 mg/l	64
36.	<i>Staphylococcus capitis</i>	+	81%	65
37.	<i>Acinetobacter calcoaceticus</i>	-	89.39%	66
38.	<i>Desulfomicrobium norvegicum</i>	-	500µM	67
39.	<i>Shewanella</i>	-	260 mg l ⁻¹	68
40.	<i>Desulfovibrio</i>	-	75 µM	69
41.	<i>Escherichia coli</i>	-		70
42.	<i>Bravibacterium</i> sp. CrT-13	+	93.12%	71
43.	<i>Acinetobacter haemolyticus</i>	-	64%	72
44.	<i>Bacillus cereus</i> S-6	+	96.9%	73
45.	<i>Ochrobactrum intermedium</i> CrT-1	-	96%	73
46.	<i>Cellulosimicrobium cellulans</i>	+	23400 (450 mM) 20800 (400 mM)	74
47.	<i>Micrococcus</i> sp.	+	7067 (40 mg/l potassium chromate) 530 (3 mg/l potassium chromate)	75
48.	<i>Brevibacterium</i> sp.	+	7067 (40 mg/l potassium chromate) 4417 (25 mg/l potassium chromate) 1767 (10 mg/l potassium chromate)	76

49.	<i>Bacillus sp.ev3</i>	+	4800 ($\mu\text{g/ml}$)	77
50.	NBRIP-4	-	2100 ($\mu\text{g/ml}$)	78
51.	<i>Bacillus circulans</i>	+	4500 (mg/l)	79
52.	<i>Leucobacter sp.</i>	+	4500 (mg/l)	80
53.	<i>Bacillus cereus strain VITSCCr02</i>	+	3300 (mg/l)	81
54.	<i>Lysinibacillus fusiformis ZC1</i>	+	3120 (60 mM)	82
55.	<i>Pseudomonas mendocina</i>	-	2080 (40 mM)	83
56.	<i>Pseudomonas corrugata</i>	-	2080 (40 mM)	83
57.	<i>Staphylococcus aureus</i>	+	2000 (mg/l)	84
58.	<i>Pediococcus Pentosaceus</i>	+	2000 (mg/l)	84
59.	<i>Pseudomonas sp.C-171</i>	-	2000 (ppm)	85
60.	<i>Bacillus pumilus</i>	+	1610 ($\mu\text{g/ml}$)	86
61.	<i>Edwardsiella tarada</i>	-	1595 ($\mu\text{g/ml}$)	86
62.	<i>Bacillus lentimorbus</i>	+	1395 ($\mu\text{g/ml}$)	86
63.	<i>Bacillus cereus SJ1</i>	+	1560 (30 mM)	87
64.	<i>Serratia sp.</i>	-	1500 (mg/l)	88
65.	<i>Bacillus sp. ES29</i>	+	1500 (mg/l)	89
66.	<i>Bacillus cereus ES04</i>	+	1500 (mg/l)	89
67.	<i>Arthrobacter crystallopoites</i>	+	500 (mg/ml)	89
68.	<i>Vogococcus fluvialis</i>	+	1300 (25 mM)	90
69.	<i>Corynebacterium hoagii</i>	+	1144 (22 mM)	91
70.	<i>Bacillus maroccanus</i>	+	1040 (20 mM)	91
71.	<i>Cellulomonas turbata</i>	+	624 (12 mM)	91
72.	<i>Methylococcus capsulatus</i>	-	1000 (mg/l)	92
73.	<i>Brucella sp.</i>	-	1000 (mg/l)	93
74.	<i>Burkholderia cepacia</i>	-	1000(ppm)	94
75.	<i>Providencia sp.</i>	-	1000 (mg/l)	95
76.	<i>Leucobacter chironomi sp.</i>	+	936 (18 mM)	96
77.	<i>Intrasporangium sp.</i>	+	884 (17 m mol/l)	97
78.	<i>Exiguobacterium sp. ZM-2</i>	+	643.24 (12.37 mM)	98
79.	<i>Bacillus licheniformis</i>	+	500 (mg/ml)	99
80.	<i>Bacillus PSB1</i>	+	500 ($\mu\text{g/ml}$)	100
81.	<i>Mesorhizobium strain RC3</i>	-	500 ($\mu\text{g/ml}$)	101
82.	<i>Pseudomonas ambigua G-1</i>	-	2000(ppm)	43

Table 2: List of Fungal Diversity

Sl. No.	Resistance/tolerant	Reduction of Cr(VI)	Reference
1	<i>Aspergillus niger FIST1</i>	82%	61
2	<i>Aspergillus flavus</i>		62
3	<i>Aspergillus sp.</i>		62
4	<i>Aspergillus niger</i>		62
5	<i>Aspergillus niger NUA101</i>	17.58 mg Cr(VI)/g	102
6	<i>Paecilomyces sp</i>	50mg/L	103
7	<i>Rhizopus Oryzae</i>	400 mg Cr ⁶⁺ /l.	104
8	<i>Penicillium sp.</i>	60 mg/L	105
9	<i>Penicillium purpurogenum</i>	36.5 mg	105
10	<i>Aspergillus parasiticus</i>	91.6%	106
11	<i>Saccharomyces cerevisiae</i>	44.2%	107

12	<i>Penicillium chrysogenum</i>	40.3%	107
13	<i>Fusarium chlamydosporium SPFS2-g</i>	500 ppm	108
14	<i>Trichoderma</i> sp.	97.39%	109
15	<i>Agaricus</i> sp.	100%	109
16	<i>Fusarium oxysporum</i> (NCBT-156)	90%	110
17	<i>Pichia anomala</i>	50 mg/L	111
18	<i>Trichoderma harzianum</i>	90.2%	112
19	<i>Trichoderma viride</i>	16.075 mgg ⁽⁻¹⁾	113
20	<i>Aspergillus sydoni</i>	1.76 mg/g	114
21	<i>Penicillium janthinellum</i>	1.77 mg/g	114

CONCLUSION

Chromium contamination of soil and water is a major problem in the world. Chromium is the major toxicant found in industrial wastewater and may adversely affect the biological treatment of wastewater. This heavy metal is a potential threat to the environment and to public health primarily because it is non-biodegradable and environmentally persistent. Currently, bioremediation is often the preferred method to deal with Cr contaminated sites because it is eco-friendly, cost-effective and is a “natural” technology. Bacterial and fungal strains are capable of tolerate and reduce hexavalent chromium in soil and effluent which will be further used by the scientists and helpful to the environment as well as mankind.

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