

## Patent Analysis on Bioremediation of Environmental Pollutants

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### Abstract

The scientific literature published in peer reviewed journals is the limited source of information for most of the scientists and academicians. As neither all researches nor their technological strategies are published in papers, therefore, lots of information remains missing. The systematic patent analysis using authenticated patent database makes it possible to find out technological strategies adopted by potential researchers. In spite of that, the research gaps along with research directions in a particular research field can also be identified. The aim of present study was to analyze the patenting trends in bioremediation technologies for environmental pollutants. This analysis was based on various criteria i.e. patenting trend over time, country-wise and assignee-wise comparisons and types of technology used in various patents. The Delphion database was used to retrieve bioremediation patents filed during 1990 to 2013. Out of 443 patents, United States accounted for maximum patent publications, followed by China, Japan, Korea, India etc. Yearly analysis revealed that maximum (35) patents were published in 2005. Out of 31 patent assignees, the United States Secretary of Agriculture obtained maximum patents followed by Exxon Research and Engineering Co. Comparison among technological groups indicated that maximum patents (33%) were associated with technologies for reclamation of contaminated soil followed by wastewater and sewage treatment technologies (22%) and use of micro-organisms (20%) natural as well as genetically engineered for bioremediation of environmental pollutants. Further, identification of process/product based utility of screened patents revealed that 80% patents were directed towards processes of bioremediation while 20% were products for assisting bioremediation.

**Keywords:** Patent analysis; Bioremediation; Phytoremediation; Phytoextraction; Environmental pollutants

### Introduction

To meet the world's growing needs; global industrial revolution has contributed in polluting the environment by producing extremely toxic chemical and biological wastes in bulk. To protect the environment from existing pollutants, there is a need to promote innovation in pollution abatement technologies. After various international environmental agreements, governments of different countries have focused on green product and process innovations to minimize environmental risk, but there has been little interest in developing eco-friendly technologies for removing the environmental pollutants. Considering this, bioremediation has now been emerged as a technological advancement to decontaminate the polluted sites either aquatic or terrestrial, in an effective, eco-friendly manner without generating secondary wastes. Bioremediation involves naturally occurring organisms to break down or neutralize inorganic and organic pollutants into less toxic or non-toxic forms. Some examples of bioremediation related technologies are phytoremediation, rhizofiltration, bioaugmentation, biostimulation, landfarming, bioreactor, and composting. As a part of bioremediation, Phytoremediation employs metal accumulating plants for removing toxic wastes via absorption, adsorption and extraction of contaminants from water and soil [1,2]. Thus, better environmental protection can be achieved by promoting eco-innovative bioremediation technologies.

Patent analysis of bioremediation could assist the scientists, stakeholders (technologists, business leaders, attorneys, etc.), policy planners and researchers to access technology updates, develop new process and product, plan future research strategies and take key decisions for developing R&D investment plans for more economic and environmental gain. Earlier workers also measured environmentally motivated innovations, such as pollution control technologies and green energy technologies, and for general purpose technologies with environmental benefits. Lanjouw and Mody [3] counted the number of patents in nine environmental fields (viz. Industrial air pollution, water pollution, vehicle air pollution, solid waste, incineration of waste,

alternative energy, oil spills, radioactive waste and recycling and reusing waste), Nameroff et al. [4] studied green chemistry patents, Johnstone [5] analysed renewable energy patents, and Sun et al. [6] studied the pattern of environmental patents by ownership in China. Since, patents are the best measure of innovative activities, therefore the objectives of present study were (i) to analyse overall patent activity in the field of bioremediation, (ii) to assess global distribution of bioremediation patents, their patenting trend over time and assignees, (iii) to identify potential areas for future research and development in bioremediation technologies.

### Methodology

#### Patent databases searched

The relevant patents in the context of bioremediation were retrieved from different databases on the basis of priority of filing during 1990 to 2013. The databases searched included publicly available e.g. USPTO, EPO, SURFIP, WIPO and FREEPATENTSONLINE and subscription based database Delphion. Delphion is an authenticated databases which covered United States Patents - Applications (US), United States Patents - Granted (US), Derwent World Patents Index (DWPI), European Patents - Applications (EP-A), European Patents - Granted (EP-B), German Patents - Applications, German Patents - Granted, INPADOC Family and Legal Status, Patent Abstracts of Japan, Switzerland and WIPO PCT Publications. As Delphion do not cover

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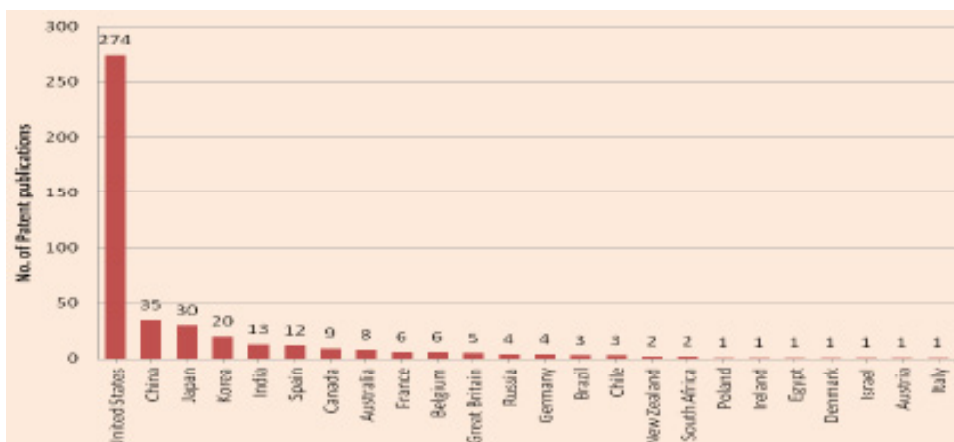


Figure 1: Geographical distribution of bioremediation patents.

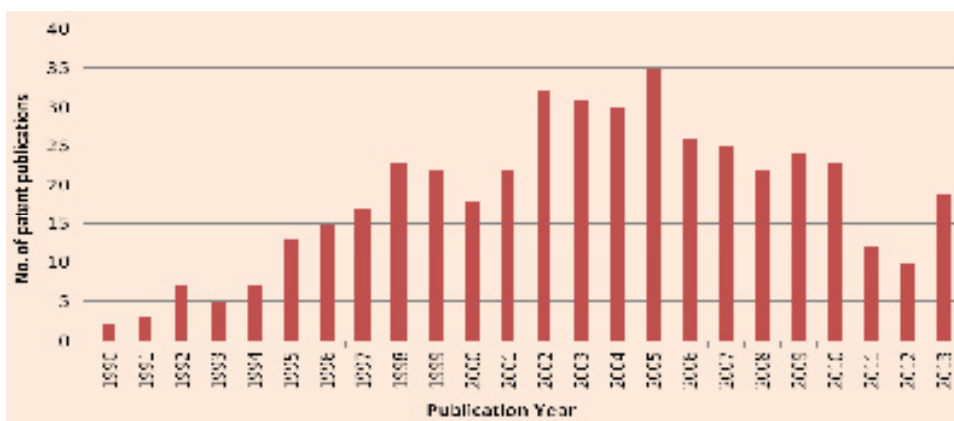


Figure 2: Yearly trend of bioremediation patents.

Indian Patent data of granted and filed patent application, therefore, the Indian patents on bioremediation were retrieved from Indian Patent Information Retrieval system separately.

### Search strategy and analysis

To search patent publications in the field of bioremediation, the methodology was mainly based on appropriate keyword searches in title, abstract and claims fields of all patents available in different databases. The search algorithm for parent string was used as: (“Bioremediation” or “Phytoremediation” or “Phytoextraction”) AND (“Plant” or “bacteria” or “fungal” or “microorganism”). A total of 627 patent documents were retrieved. The abstract of each single patent was scrutinized in order to determine relevancy of patent. The irrelevant patents, not related to bioremediation technologies, were eliminated. This step was undertaken to avoid the potential error of having unrelated patents, thereby improving the quality of searched patent data set. Finally, 443 patent documents were screened according to their relevance. The retrieved data was stored in a MS-Excel worksheet, analysed and interpreted in order to understand geographical distribution of patents, patenting trend over time and major assignees that holds proprietary rights. The patent data have been segregated primarily into five sectors comprising (i) Government (ii) Corporate (comprising industrial organizations and corporate bodies), (iii) Academic (comprising

Academic Institutes and Universities), (iv) Institutional (comprising Research Institutes), and (v) Individuals (comprising individual or group of individuals). The screened bioremediation patents were also classified as per International Patent Classification (IPC) based on their technology areas and utility.

## Results and Discussion

### Geographical distribution of patents

Patents are the indicator of country’s economic growth [7] and patenting activities across the countries transfer and disseminate the technology contained in the patent [8]. Among top five countries, United States (US) was the forerunner sharing 61.85% patents in bioremediation technologies followed by China (7.9%), Japan (6.77%), Korea (4.51%) and India (2.93%) (Figure 1). The other countries viz. Spain, Canada, Australia, France, Belgium, Great Britain, Russia, Germany, Brazil, Chile were less active in bioremediation research. Out of 443 patents, 67% were filed by North American countries, 23% by Asian countries and 10% by European countries. There was a large gap in technological position of US and European countries. Even, Asian countries filed more patents (2 times) than European countries. The recent report suggested that the counties with the largest R&D expenditure are the US>UK>France>Germany>Japan>China>Korea [9]. The case was not the same in present study. The Asian countries

filed more patents indicating more investment on R&D. The position of European countries was declined in patenting activity which may possibly due to less investment in R&D related of bioremediation technologies. China emerged as the world's second patent holder behind the US, which certainly be due to increasing its R&D spends even more than Russia, Britain, Germany, France and Italy combined. Although, other Asian countries particularly Japan and Korea are also rapidly increasing their R&D spends to become technologically strong by more patent filings. Although, highest innovative research in US might be due to having more scientific manpower, improved research facilities, infrastructure and financial resources [10]. As the patent protected technologies are too costly, therefore, government of developed nations should make provisions to disseminate such technologies to poor nations who are far behind in contributing scientific research due to inadequate infrastructure, less funding resources and high cost of importing scientific equipments.

### Patenting trend over time

The results of patenting activity in the field of bioremediation revealed that maximum patents (35) were published in 2005 owing to more R&D activities (Figure 2). As such, the patenting activity was increased sharply since 1990 till 2005, which decreased gradually up to 2012. During 2002-2005, the patenting activities were high indicating that the activity has been very recent and this field has gained importance in recent years. Also, there might be more financial investment in R&D of bioremediation technologies during that period. However, before 1994, there was little patent activity in this field

### Assignees of bioremediation patents

There were 31 assignees active in research related to bioremediation (Figure 3). The United States Secretary of Agriculture (USSA) got maximum number of patents followed by Exxon Research & Engineering Co. and University of Georgia Research Foundation, Inc, Regents of the University of California and Geovation Technologies, Inc. The USSA obtained patents on hyperaccumulating plant species capable of removing or recovering heavy metals from contaminated soils along with the processes for degrading and/or bioremediating waste wood containing organic and inorganic contaminants i.e. chromated copper arsenate (CCA), creosote and pentachlorophenol using a fungal inoculum. Exxon Research & Engineering Co. invented surfactant system for bioremediation of hydrocarbon contaminated soils and water that increases the interface between the hydrocarbon contaminant, microbial nutrients and microflora, and also stimulates the propagation of the microflora, thereby enhancing microbial degradation of the hydrocarbon contaminant. Georgia Research Foundation, Inc. developed process for producing metal resistant transgenic plants using recombinant DNA comprising a nucleic acid sequence encoding a metal ion resistance protein leading to enzymatic reduction of metal ions. The invention also involves a method of phytoremediation of a contaminated site by growing in the site a transgenic plant expressing a nucleic acid encoding a metal ion reductase and a nucleic acid encoding a phytochelatin biosynthetic enzyme. The Regents of University of California also developed method and compositions for enhancing heavy metal phytoremediation of metal contaminated soils

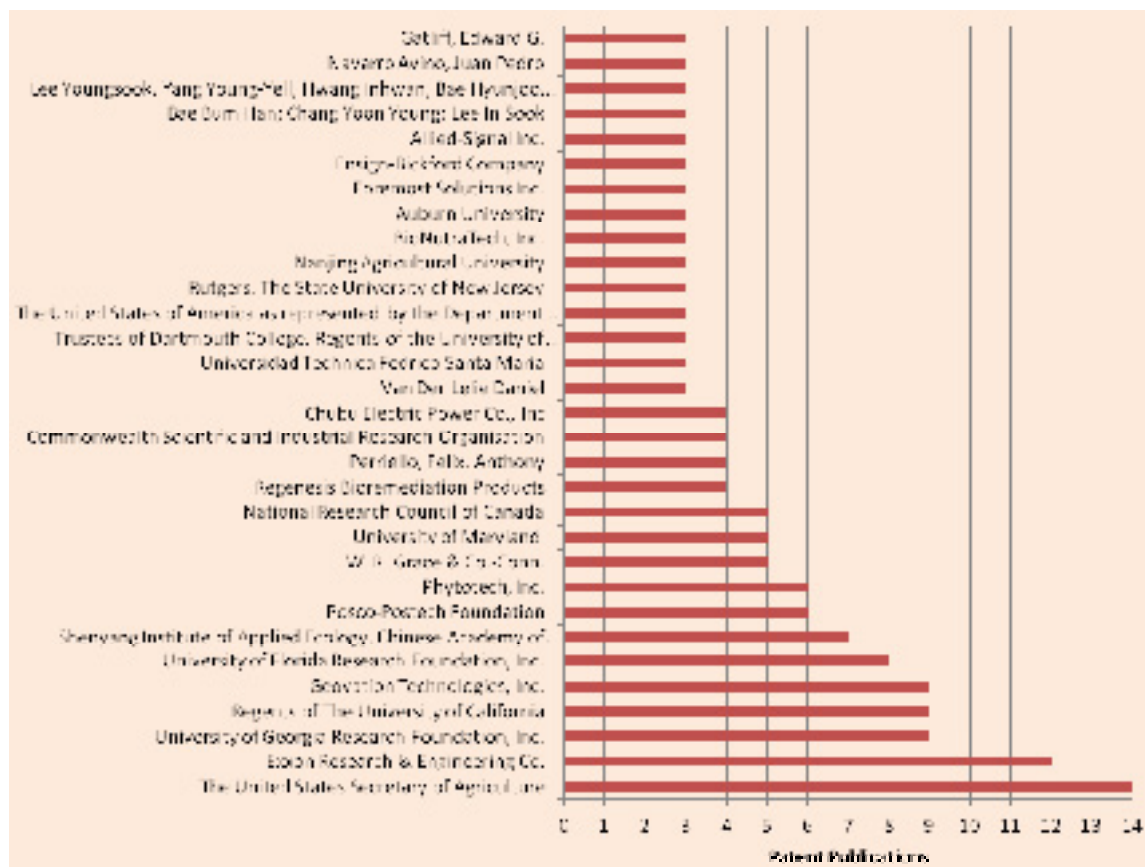


Figure 3: Major Assignees of bioremediation technologies.

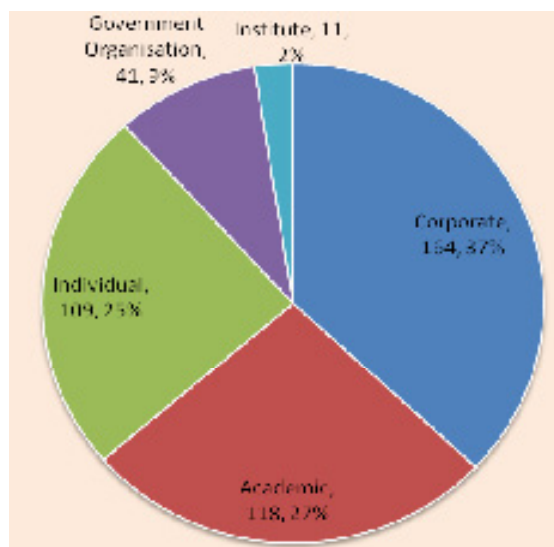


Figure 4: Global distribution of bioremediation patents in different sectors.

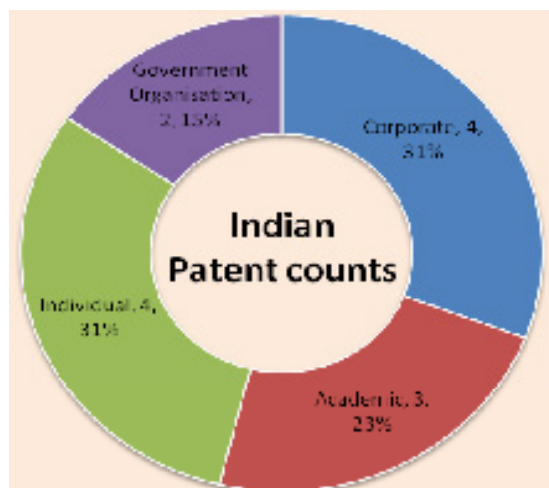


Figure 5: Distribution of bioremediation patents in India.

or waters employing genetically engineered plant (Brassicaceae family) comprising a gene encoding glutamylcysteine synthetase leading to enhanced heavy metal accumulation. They also invented a system for *in-situ* field water remediation using microbial filter. Geovation Technologies, Inc. got patents on solid and liquid chemical compositions for anaerobic biodegradation, detoxification, and transformation of toxic organic and inorganic compounds present in solid and liquid wastes, soils, sediments, and water bodies. The patent involves improved means of (i) promoting the solid-liquid phase extraction and absorption of recalcitrant contaminants from contaminated media, (ii) creating, enhancing, and maintaining anaerobic conditions (i.e., negative redox potential), (iii) providing a source of carbonaceous co-substrates, anaerobic electron acceptors, and nutrient to promote the growth of contaminant-degrading microorganisms, and (iv) providing sources of inoculum of naturally occurring microorganisms which act to promote the biodegradation of contaminants.

Further, the evaluation of technological competencies of different

assignees in the field of bioremediation revealed that maximum patents were filed by corporate sector, while government organizations and institutes showed least interests in patenting activity globally (Figure 4). Even in India, the government organizations were less active towards innovative R&D in bioremediation technologies (Figure 5). In India, government organizations viz. Council of Scientific and Industrial Research and Indian Council of Agricultural Research got 2 patents, whereas corporate sector viz. Bharat Petroleum Corporation Ltd. Indian Oil Corporation Ltd., and M/S Avestha Gengraine Technologies Pvt. Ltd. got 4 patents. Even individual assignees got more patents than government organizations within India. As the individuals are the catalyst and growth centre of every country, therefore government should promote such individuals and groups for developing eco-innovative pollution remediation technologies to leverage environmental protection. The environmental pollution is global issues and has no political boundaries, therefore, government of both developed and developing nations should make efforts for finding eco-friendly solution of pollution and international diffusion and transfer of bioremediation technologies in order to reduce their toxic wastes and contribute in global environmental protection.

#### Technology based classification of bioremediation patents

According to IPC, the bioremediation patents were categorized into various technological groups (Figure 6). The maximum (265) patents were covered under B09C followed by C02F (174) and C12N (160). Comparatively, there was less patent in other technology areas viz. A01H, A62D, B09B, C22B, C12P, A01N and A01G (Figure 6). The subclass B09C covers technologies related to reclamation of contaminated soil, however, C02F covers water treatment technologies, and C12N covers micro-organisms or enzymes and technologies for mutation or genetic engineering. The description of each subclass and associated groups along with patent counts are given in Table 1. Also, identification of process/product based utility of screened patents revealed that B09C, C02F, A01H, A62D, B09B, C22B, C12P, A01N and A01G represented process patents while C12N represented product patent, indicating that most of the patents were directed towards processes of bioremediation. Thus, there is a need to give more attention on product based bioremediation technologies employing microbes and enzymes degrading and/or detoxifying hazardous

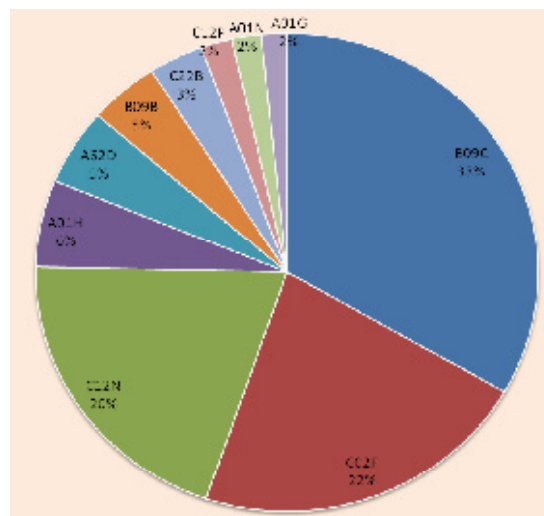


Figure 6: International Patent Classification based distribution of bioremediation patents into various technological groups.

Subclass	Title	Group	Patent records	Description
A01G	HORTICULTURE; CULTIVATION OF VEGETABLES, FLOWERS, RICE, FRUIT, VINES, HOPS, OR SEAWEED; FORESTRY; WATERING (plant reproduction by tissue culture techniques A01H 4/00; propagating unicellular algae C12N 1/12; plant cell culture C12N 5/00)	A01G 1/00	13	Horticulture; Cultivation of vegetables
A01H	NEW PLANTS OR PROCESSES FOR OBTAINING THEM; PLANT REPRODUCTION BY TISSUE CULTURE TECHNIQUES	A01H 1/00	11	Processes for modifying genotypes
		A01H 5/00	36	Flowering plants, i.e. angiosperms
A01N	PRESERVATION OF BODIES OF HUMANS OR ANIMALS OR PLANTS OR PARTS THEREOF; BIOCIDES, e.g. AS DISINFECTANTS, AS PESTICIDES OR AS HERBICIDES; PLANT GROWTH REGULATORS (mixtures of pesticides with fertilisers)	A01N 63/00	15	Biocides, pest repellants or attractants, or plant growth regulators containing micro-organisms, viruses, microbial fungi, animals, e.g. nematodes, or substances produced by, or obtained from micro-organisms, viruses, microbial fungi or animals, e.g. enzymes or fermentates
A62D	CHEMICAL MEANS FOR EXTINGUISHING FIRES; PROCESSES FOR MAKING HARMFUL CHEMICAL SUBSTANCES HARMLESS, OR LESS HARMFUL, BY EFFECTING A CHEMICAL CHANGE; COMPOSITION OF MATERIALS FOR COVERINGS OR CLOTHING FOR PROTECTING AGAINST HARMFUL CHEMICAL AGENTS; COMPOSITION OF MATERIALS FOR TRANSPARENT PARTS OF GAS-MASKS, RESPIRATORS, BREATHING BAGS OR HELMETS; COMPOSITION OF CHEMICAL MATERIALS FOR USE IN BREATHING APPARATUS	A62D 3/00	41	Processes for making harmful chemical substances harmless, or less harmful, by effecting a chemical change in the substances (devices for rendering harmful chemical agents harmless)
B09B	DISPOSAL OF SOLID WASTE	B09B 3/00	36	Destroying solid waste or transforming solid waste into something useful or harmless
B09C	RECLAMATION OF CONTAMINATED SOIL	B09C 1/00	64	Reclamation of contaminated soil (processes for making harmful chemical substances harmless or less harmful by affecting a chemical change in the substances)
		B09C 1/08	22	Chemically
		B09C 1/10	179	microbiologically or by using enzymes
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE (processes for making harmful chemical substances harmless, or less harmful, by effecting a chemical change in the substances A62D 3/00; separation, settling tanks or filter devices B01D; special arrangements on waterborne vessels of installations for treating water, waste water or sewage, e.g. for producing fresh water, B63J; adding materials to water to prevent corrosion C23F; treating radioactively-contaminated liquids)	C02F 1/68	13	Treatment of water, waste water, or sewage by addition of specified substances, e.g. trace elements, for ameliorating potable water
		C02F 3/00	49	Biological treatment of water, waste water, or sewage
		C02F 3/10	13	Biological treatment of water, waste water, or sewage by using Packings; Fillings; Grids
		C02F 3/32	32	characterised by the animals or plants used, e.g. algae
		C02F 3/34	67	characterised by the micro-organisms used
C12N	MICRO-ORGANISMS OR ENZYMES; COMPOSITIONS THEREOF (biocides, pest repellants or attractants, or plant growth regulators containing micro-organisms, viruses, microbial fungi, enzymes, fermentates, or substances produced by, or extracted from, micro-organisms or animal material; PROPAGATING, PRESERVING, OR MAINTAINING MICRO-ORGANISMS; MUTATION OR GENETIC ENGINEERING; CULTURE MEDIA)	C12N 1/14	11	Fungi; Culture media therefor
		C12N 1/20	36	Bacteria; Culture media therefor
		C12N 15/09	23	Recombinant DNA-technology
		C12N 15/29	14	Genes encoding plant proteins, e.g. thaumatin
		C12N 15/31	14	Genes encoding microbial proteins, e.g. enterotoxins
		C12N 15/82	62	This group covers the use of eukaryotes as hosts for plant cells
C12P	FERMENTATION OR ENZYME-USING PROCESSES TO SYNTHESISE A DESIRED CHEMICAL COMPOUND OR COMPOSITION OR TO SEPARATE OPTICAL ISOMERS FROM A RACEMIC MIXTURE	C12P 1/00	16	Preparation of compounds or compositions by using micro-organisms or enzymes; General processes for the preparation of compounds or compositions by using micro-organisms or enzymes
C22B	PRODUCTION OR REFINING OF METALS; PRETREATMENT OF RAW MATERIALS	C22B 3/00	12	Extraction of metal compounds from ores or concentrates by wet processes
		C22B 3/18	16	Extraction of metal compounds from ores or concentrates by wet processes with the aid of micro-organisms or enzymes, e.g. bacteria or algae

**Table 1:** International patent classification based description of Subclasses and Groups associated with bioremediation technology.

substances present in environment. The IPC results also demonstrated that bioremediation technologies for contaminated water are also available scarcely; therefore, attention should be given in this direction also. As such, the IPC mapping of bioremediation technologies could provide immense help to scientists, technologists, decision makers and researchers to plan future research strategies and R&D investment in thrust areas for more economic and environmental benefits.

## Conclusions

The study concluded that number of patent applications in bioremediation domain is very less. The United States Secretary of

Agriculture exhibited maximum patents. After US, China and Japan had strong patent activity. Most of the patents were directed towards processes for reclamation of contaminated soils using micro-organisms or enzymes. Comparatively, technologies for biological treatment of wastewater are less. The patents on genetically engineered micro-organisms and plants producing more metal chelating compounds e.g. phytosiderophores, phytochelatins and metallothioneins, and nucleic acid sequences encoding multimetal resistance protein are also reduced in number. Very few patents are available on production of metal hyperaccumulating plants by tissue culture techniques. Also, patents on processes for metal recovery using micro-organisms or enzymes are

scarce. These identified research gaps in the field of bioremediation bring out a scope for generating intellectual property. Further, development of products (nucleic acid sequences, metal chelating agents, transgenic plants and micro-organisms) for removing and/or recovering harmful substances from the terrestrial and aquatic environment at a faster rate even in extreme environments could certainly ensure economic and environmental protection as well.

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