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Review Article

Fungi: A Remedial Measure for Pollution

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ABSTRACT

Since time immemorial importance of fungi has been immense right from Irish Blight of potatoes to Black rust disease of wheat which caused havoc once upon a time. Fungi cause diseases in humans and animals as well. They not only cause diseases but also have lot of benefits right from first antibiotic Penicillin and many more helpful enzymes they secrete and their special role as decomposers in all ecosystems. These have been found to degrade even pollutants, heavy metals, toxic metals, polyaromatic hydrocarbons and other industrial chemicals (Saha et al., 2017). They pick up nutrients and other materials from the surroundings and it is because of this they find a special place in bioremediation and many more ecofriendly processes.

With this backdrop an attempt has been made in the present paper to study their role in bioremediation. Besides new ways which can be thought about for their further exploitation and use in the agriculture which is the backbone of our country's economy and sustenance.

Keywords: *Bioremediation, Mycoremediation, Microfiltration, Biomagnification, Bioaccumulation, white rot fungi.*

INTRODUCTION

India is an agricultural country and it is but natural that it is our backbone. There is a serious problem of population, pollution and poverty, the three $P^{\{s\}}$ and these are interrelated. There is a need for more and more food production. Agriculturists are doing their best to keep pace with the ever-increasing population. New varieties, and techniques are being researched and worked upon.

The greatest achievement of our agricultural sector has been green, golden and white revolution. At least now we can be called self-sufficient to some extent. Still, we have to find solution for the ever-increasing population. Besides, we have problem of pollution of our extremely precious natural resources the air, water and soil. It is quite obvious for agricultural production pollution free soil is required along with pollution free water and air. Health of the people is dependent on the food they consume, and in turn healthier the people stronger the nation.

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With more and more awareness about environment related issues people have become conscious. people no more want to compromise on health-related issues. As such agriculturists are also compelled to take steps accordingly.

Due to excessive mining, oil spills and most probably indiscriminate use of pesticides, herbicides, insecticides and fertilizers in conventional farming has made pollution levels alarming. As such there is need for remedy.

The soil which is polluted with different types of pollutants is the place where plants utilize nutrients and make food (photosynthesis) hence are called producers. It is these producers which pass it on to other organisms up the trophic levels. Thus, all food chains and food webs rather ecosystems are dependent on the producers (Mahmood & Malik, 2014, Nica et al., 2012 & Matsubara et al., 2006). Mostly plants take up these. Fungi on the other hand being decomposers help in all ecosystems by releasing nutrients back to nutrient pool and help producers to fix up these again. No ecosystem can function without decomposers. Since they secrete enzymes and can utilize different substrates, they have been found to act on pollutants also. By virtue of biodegradation and biodeterioration these fungi help not only removing these pollutants but also help in reducing their toxic levels. Different fungal species for different locations and have been suggested by earlier studies. (Larsson & Fick, 2009 & Rangasamy et al., 2015).

Lot of literature is available on the role of fungi on organic pollutants (Singh et al., 2011) Even mushrooms have been given title of "Saviours of World" (Stamets,2005), Singh et al., 2013). Stamets is of the opinion that remediation of contaminated soil and water from oil spills and chemical toxins can also be taken care of by utilising fungi. Especially it is the fine fungal hyphae which is quite versatile in picking up these pollutants from the surroundings. As the process of uptake goes on the concentration and quantity of such pollutant from traces reaches toxic levels which can be hazardous and cause of concern. (Bioaccumulation & biomagnification).

In order to clean the soil environment along with phytoremediation cleaning process by fungi also takes place. The toxic material/pollutant so absorbed by the fungi gets removed from the soil. This process is called Mycoremediation. Thus, the soil so cleaned after Mycoremediation is no longer toxic and a cause of health hazard. It can support healthy produce.

With this backdrop an attempt has been made to study the role of fungi in bioremediation. This study can help in generating ideas to overcome problem of pollution and devise means to have maximum benefit for the agricultural sector.

Soil Pollution

Soil is the most important factor for agriculture as it is the place where crops, vegetables actually food is generated for all. In India an estimate of land use pattern is given. (Harms et al., 2011) Total land is 328 million hectare, out of which 43.6% is agricultural land, waste land 12.2%barren and uncultivable land is 8.4%. As per this study nonagricultural use has increased by 11.73 million hectares from 1950-2000 and is still increasing due to ever increasing population (Harms et al., 2011). Excessive population has resulted in industrialization and development and lot of waste generated has resulted in various types of pollution (Zhao et al., 2014 & Saha & Panwar, 2010).

There are many reasons for soil degradation, which include chemical degradation (Chemical toxicity and salinity etc) due to irrigation with contaminated water. Industrialization and modernization no doubt has helped improve economic growth but at the cost of environment (Harms et al., 2011). There are other anthropogenic activities which have added

to the pollution levels. (Mosa et al., 2016, Rangasamy et al., 2015 & Rhodes, 2012).

Wastewaters, untreated effluents of the various industries and their indiscriminate disposal results in pollution not only of water bodies but also of soils, because water of these polluted water bodies knowingly or unknowingly gets utilized for irrigation of different types of crops (Rawat et al., 2009, Rhodes, 2012, Zhao et al., 2014 & Saha, 2005). As already known that crops have a tendency to pick up and accumulate these pollutants, their tissues undergo further magnification and thus transfer up the trophic levels and is a cause of concern as it ultimately affects the health of the people (Mahmood & Malik, 2014 & Saha et al., 2010).

Heavy metal pollution especially of agricultural soil has been on rise (Sharma et al., 2008). Industrial effluents have also been reported to be the cause of oil pollution especially heavy metals. Heavy metals are non-biodegradable and tend to be magnified. They pose risk to human health hence need to be removed. Long time exposure to heavy metals has toxic effect on plant, soil, microorganisms and ultimately human health. Not only this these heavy metals get passed on to higher up trophic levels in food chains and food webs.

Arsenic levels along with Zinc and cadmium levels have also increased in ground and surface waters, which is used for irrigation purposes (Panwar et al., 2010). Ground water is polluted due to pesticide, textile and other industrial effluents

Which are dumped into water bodies like rivers and lakes etc (Bhupal et al., 2009, Nica et al., 2012, Govil et al., 2001, Govil et al., 2008, Krishna & Govil, 2008, Larsson & Fick, 2009, Lenka et al., 1992, Orisakwe et al., 2012, Panwar et al., 2010, Raj et al., 2011, Singh, 2006 & Singh, et al., 2020). This has resulted in change in cropping pattern and a reduction in crop yield (Bhupal et al., 2009, Kumar et al., 2018, Larsson et al., 2007, Larsson & Fick, 2009, Lenka et al., 1992 & Matsubara et al., 2006).

Cause of Concern

The cause of concern and burning problem is that of Arsenic in the soils of Karnataka and Maharashtra. Arsenicosis and arsenic related cancers have been reported from the areas (Bhagure & Mirgane, 2011 & Chakraborti et al., 2013). Atmospheric deposits of heavy metals in industrial areas which ultimately lead to pollution of agricultural lands has also been reported (Rhodes, 2012 & Saha & Sharma, 2006). Besides there has been contamination of soils due to agricultural activities like indiscriminate use of chemical pesticides, herbicides, weedicides, rodenticides, fungicides and chemical fertilizers (Adhikari et al., 2012, Gupta et al., 2013, Falandysz & Treu, 2017, Krishna & Govil, 2008 & Kumar & Maiti, 2015).

Due to industrialization, population explosion and other factors from the above explanation it is quite obvious that the condition of soil, ground water and air is quite polluted thus reason for biosorption, bioaccumulation and biomagnification by crops grown in such land. Biomagnification being carried on up the trophic levels thus a cause of concern as it reaches toxic and harmful levels.

Remedy

Removal of pollutants from the soil by the agency of plants is called phytoremediation, by the agency of microorganisms is called micro remediation and by the agency of fungi is called Mycoremediation. All these if utilized for cleaning soils it is called bioremediation and the organisms are called bioremediaters (Zhao et al., 2014). Bioremediation is preferred over chemical remediation as it can result in addition of other pollutants. Bioremediation is environment friendly. It not only helps in picking up pollutants from the polluted areas but also include breakdown of toxic organic pollutants into nontoxic rather harmless materials. (Rhodes,

2014, Gowd et al., 2010, Gupta et al., 2014, Gupta & Diwan, 2016 & Gupta et al., 2015) Heavy metals and radioactive substances cannot be decomposed but can be converted into harmless entities. In short bioremediation actually is cleaning of soil by the agency of living organisms (Barkat, 2011 & Rhodes, 2013).

Mycoremediation has been studied in detail many fungi especially white rot fungi (Pleurotus sps) edible mushrooms (Gupta, 2020, Ali et al., 2019, Sharma et al., 2008 & Singh et al., 2013). Mycoremediation has been found to be advantageous over bacterial remediation (Zhao et al., 2014). Bacteria require pre-exposure to contaminant and their enzymes cannot work at certain levels which is not the case with fungi (Adenipekun & Lawal, 2012).

Many White rot fungi found useful include *Phanerochaete chrysosporium, Pleurotus tuberregium, Pleurotus pulmonarius, Agaricus bisporus, Trametes versicolor* etc (Adenipekun & Lawal, 2012), Orisakwe et al., 2012 & Sharma et al., 2008). White rot fungi have been found to biodegrade polyaromatic hydrocarbons, polychlorinated biphenyls, dioxins, chemical pesticide residues, effluents from paper and pulp mills, dye stuffs and heavy metals (Sharma et al., 2008). Microfiltration can also be carried out utilizing fungal mycelia to remove toxic substances and microorganisms from the soil (Rangasamy et al., 2015 & Singh et al., 2013). Sequestration of heavy metals and pollutants by white rot fungi is a safer way and has been attributed to characteristic fungal metabolism and tolerance to heavy metals (Dunbar, 2017). Since these are edible fungi are a source of proteins and many nutrients. Mycoremediation with white rot fungi will be like killing two birds with one stone, cleaning of soil including microfiltration and taking care of malnutrition, but safety of utilizing these harvesting after bioremediation is still to be verified (Saha et al., 2017, Kulshrestha, 2013 & Mahimairaja et al., 2000).

CONCLUSION AND FUTURE PERSPECTIVE

There is no doubt about this fact that fungi especially white rot fungi can be utilized for bioremediation of the contaminated soil (Akcil et al., 2015). They have been found to be more effective as compared to bacteria. Most of these species are edible and source of proteins and nutrients, can be utilized for remediation, filtration and malnutrition or protein deficiency. Although safety of utilizing these harvesting after bioremediation requires detailed study. Since they can pick up heavy metals from the soil a detailed study is required for finding bio extracting methods of these metals, as there is a demand for these metals. Work on this aspect is going on (Diep Mahadevan, & Yakunin, 2018). At present heavy metal removal is carried out by means of rapid chemical methods like precipitation, coagulation, flocculation, membrane filtration (Barkat, 2011 & Singh et al., 2011), but it can lead to addition of more chemical pollutants to soil. Thus, there is a need for green technology as designed on the basis of green engineering principles (Anastasi et al., 2013). There is a need for cost effective, ecofriendly and safe simple biologically driven heavy metal cleansing technology (Dhal et al., 2011 & Fawzy et al., 2017). The method should be such that there should be direct extraction and utilization of the metals without generating any waste product (Fu et al., 2012, Gillespie & Philip, 2013 & Goswami et al., 2010b). Further detailed study is required to find a solution in a sustainable and economical way. Mycoremediation should be followed by immediate bio extraction of the pollutants especially metals and without wasting or further getting them dumped in the soil.

REFERENCES

Adenipekun, C. O., & Lawal, R. (2012). Uses of mushrooms in bioremediation: A review. Biotechnol. Molec. Biol. Rev., 7(3), 62-68. DOI: 10.5897/BMBR12.006.

Adhikari, T., Wanjari, R. H., & Biswas, A. K. (2012). Final Report of the project entitled "Impact assessment of continuous fertilization on heavy metals and microbial diversity in soils under References 309long-term fertilizer experiment" (Submitted to Ministry of Forest and Environment, New Delhi), p 175.

Ali, H., Khan, E., & Ilahi, I. (2019). Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation, Journal of Chemistry. Pages 1-19 DOI: 10.1155/2019/6730305.

Akcil, A., Erust, C., Ozdemiroglu, S., Fonti, V., & Beolchini, F. (2015). A review of approaches and techniques used in aquatic contaminated sediments: metal removal and stabilization by chemical and biotechnological processes. J Clean Prod. 86, 24–36. journal ISSN :0959-6526DOI 10.1016/j.jclepro.2014.08.009.

Anastasi, A., Tigini, V., & Varese, G. C. (2013). The bioremediation potential of different Eco physiological groups of fungi. In: Goltapeh, E. M. et al (eds) Fungi as bioremediators. Soil Biol 32, 29–49. DOI:10.1007/978-3-642-33811-3_2 Corpus ID: 58944666.

Barkat, M. A. (2011). New Trends in removing heavy Metals from industrial waste water. Arabian Journal of Chemistry: 4(4), pp361-377. ELSIVIER, doi: 10. 1016 /j. arabjc .2010.07.019.

Bhagure, G. R., & Mirgane, S. R. (2011). Heavy metal concentrations in groundwaters and soils of thane region of Maharashtra, India. Environ Monit Assess 173, 643–652. https://doi.org/10.1007/s10661-010-1412-9.

Bhupal Raj, G., Singh, M. V., Patnaik, M. C., & Khadke, K. M. (2009). Four decades of research on micro-and secondary- nutrients and pollutant elements in Andhra Pradesh. Research Bulletin. AICRPMicro- and Secondary-Nutrients and Pollutant Elements in Soils and Plants, IISS, http://www.iiss.nic.in/downloads/Coordinator%20Report%20(2007-10). pdf.

Chakraborti, D., Rahman, M. M., Murrill, M., Das, R., Siddayya, Patil, S. G., Sarkar, A., Dadapeer, H. J., Yendigeri, S., Ahmed, R., & Das, K. K. (2013). Environmental arsenic contamination and its health effects in a historic gold mining area of the Mangalur greenstone belt of Northeastern Karnataka, India. Journal of hazardous materials, 262, 1048–1055. https://doi.org/10.1016/j.jhazmat.2012.10.002.

Dhal, B., Das, N. N., Pandey, B. D., & Thatoi, H. N. (2011). Environmental quality of the boula-nuasahichromite mine area in India. Mine Water Environ 30, 191–196. DOI 10.1007/s10230-010-0134-0.

Diep Mahadevan, R., & Yakunin, A. F. (2018). Heavy metal removal by Bioaccumulation using Genetically Engineered Microorganisms. Front. Bioeng. Biotechnol. 6, 157. https://doi.org/10.3389/fbioe.2018.00157.

Dunbar, W. (2017). Biotechnology and the Mine of tomorrow. Trends Biotechnol. 35, 79-89. doi: 10.1016/j.tibtech. 2016.07.004. Epub 2016 Sep 6.

Falandysz, J., & Treu, R. (2017). Fungi and environmental pollution, Journal of Environmental Science and

Health, Part B, 52(3), 147. doi: 10.1080/03601234.2017.1261535.

Fawzy, E. M., Abdel-Motaal, F. F.,& EL-Zayat, S. A. (2017). Biosorption of Heavy metals on to different ecofriendly substrates J. Toxicol Environ Health Sci 9(5), 35-44.

Fu, Y. Q., Li, S., Zhu, H. Y., Jiang, R., & Yin, L. F. (2012). Biosorption of copper (II) from aqueous solution by mycelial pellets of Rhizopus oryzae. Afr. J. Biotechnol. 11, 1403–1411.

Gillespie, I. M. M., & Philip, J. C. (2013). Bioremediation, an environmental remediation technology for the bioeconomy. Trends Biotechnol. 31, 329–332.

Goswami, S., Das, M., & Guru, B. C. (2010b). Environmental degradation due to exploitation of mineral resources: a scenario in Orissa. The Bioscan 2, 295–304.

Govil, P. K., Reddy, G. L., & Krishna, A. K. (2001). Contamination of soil due to heavy metals in the Patancheru industrial development area, Andhra Pradesh, India. Environ Geol 41, 461–469. DOI:10.1007/s002540100415.

Govil, P. K., Sorlie, J. E., & Murthy, N. N. (2008). Soil contamination of heavy metals in the Katedanindustrial development area, Hyderabad, India. Environ Monit Assess 140, 313–323. doi: 10.1007/s10661-007-9869-x.

Gowd, S. S., Reddy, M. R., & Govil, P. K. (2010). Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the ganga plain, Uttar Pradesh, India. J HazardMater 174, 113–121. doi: 10.1016/j.jhazmat.2009.09.024.

Gupta, D., Huang, H., & Corpas, F. (2013). Lead tolerance in plants: Strategies for phytoremediation. Environ. Sci. Pollut. Res. 20, 2150–2161. doi: 10.1016/j. jhazmat.2009.09.024.

Gupta, D. K., Chatterjee, S., & Datta, S. (2014). Role of phosphate fertilizers in heavy metal uptake and detoxification of toxic metals. Chemosphere 108, 134–144. doi: 10.1016/j.chemosphere.2014.01.030. Epub 2014 Feb 18.

Gupta, P., & Diwan, B. (2016). Bacterial exopolysaccharide mediated heavy metal removal: A review on biosynthesis, mechanism and remediation strategies. Biotechnol. Rep. 13, 58–71. doi: 10.1016/j.btre.2016.12.006.

Gupta, V. K., Nayak, A., & Agarwal, S. (2015). Bio adsorbents for remediation of heavy metals: Current status and their future prospects. Environ. Eng. Res. 20, 1–18. DOI: 10.4491/eer.2015.018.

Gupta, V. (2020). Vehicle-generated heavy metal pollution in an urban environment and its distribution into various environmental components. In Environmental Concerns and Sustainable Development; Springer: Singapore, pp. 113–127. ISBN 978-981-13-5888-3.

Harms, H., Schlosser, D., & Wick, L. (2011). Untapped potential: exploiting fungi in bioremediation of hazardous chemicals. Nat Rev Microbiol 9, 177–192. DOI: 10.1038/nrmicro2519 Corpus ID: 24676340.

Krishna, A. K., & Govil, P. K. (2008). Assessment of heavy metal contamination in soils around Manali industrial area, Chennai, southern India. Environ Geol 54, 1465–1472.

Kulshrestha, S. (2013). Report of the expert committee to frame a policy for monitoring of pesticide residues in Fruits & Vegetables. Ministry of Health & family Welfare, Nirman Bhawan.

Krishna, A. K., & Govil, P. K. (2008). Assessment of heavy metal contamination in soils around Manali industrial area, Chennai, southern India. Environ Geol 54, 1465–1472.

Kulshreshtha (2014). Mushroom as a product and their role in Mycoremediation. A.M.B. Express, 4(29). http://www.amb-express.com/ content/4/1/2.

Kumar, A., & Maiti, S. K. (2015). Assessment of potentially toxic heavy metal contamination in agricultural fields, sediment, and water from an abandoned chromite-asbestos mine waste of Roro hill, Chaibasa. India Environ Earth Sci. doi: 10.1007/s12665-015-4282-1.

Kumar, V., Shahi, S. K., & Singh, S. (2018). Bioremediation: An eco-sustainable approach for restoration of contaminated sites. In Microbial Bioprospecting for Sustainable Development; Springer: Singapore, 2018; pp. 115–136. ISBN 9789811300530.

Larsson, D. G. J., & Fick, J. (2009). Transparency throughout the production chain—a way to reduce pollution from the manufacturing of pharmaceuticals? Regul Toxicol Pharmacol 53,161–163. doi: 10.1016/j.yrtph.2009.01.008. Epub 2009 Jan 29.

Larsson, D. J. G., de-Pedro, C., & Paxeus, N. (2007). Effluent from drug manufactures contains extremely high levels of pharmaceuticals. J Hazard Mater 148, 751–755. doi: 10.1016/j.jhazmat.2007.07.008. Epub 2007 Jul 6.

Lenka, M., Panda, K. K., & Panda, B. B. (1992). Monitoring and assessment of mercury pollution in the vicinity of a chloralkaline plant. IV. Bioconcentration of mercury in in-situ aquatic and terrestrial plants at Ganjam, India. Arch Environ Contam Toxicol 22, 195–202. https: //doi.org/10.1007/BF00213285.

Matsubara, M., Lynch, J. M., De Leij, F. A. A. M. (2006). A simple screening procedure for selecting fungi with potential for use in the bioremediation of contaminated land. Enzyme and Microbial Technology, 39(7), Pages 1365-1372.

Mahimairaja, S., Sakthivel, S., & Divakaran, J. (2000). Extent and severity of contamination around tanning industries in Vellore district. In: Naidu, R., Willett, I. R., Mahimairajah, S., & Kookana Ramasamy, K. (eds) Towards better management of soils contaminated with tannery wastes, ACIAR publication no 88. Australian Centre for International Agricultural Research, Can-berra, pp 75–82.

Mahmood, A., & Malik, R. N. (2014). "Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan," Arabian Journal of Chemistry, 7(1), pp. 91–99. DOI: 10.1016/j.arabjc.2013.07.002.

Mishra, A., & Malik, A. (2014). Novel fungal consortium for bioremediation of metals and dyes from mixed waste stream. Bioresour Technol. 171, 217–226. doi: 10.1016/j.biortech. 2014.08.047. Epub 2014 Aug 25.

Mosa, K. A., Saadoun, I., Kumar Helmy, M., & Dhankher, O. P. (2016). Potential Biotechnological strategies for the clean-up of heavy metals and metalloids. Front Plant Sci 7, 1-14.

NAAS, (2012). Sustaining Agricultural Productivity through Integrated Soil Management. Policy Paper No. 56, National Academy of Agricultural Sciences, New Delhi. 24p.

Nica, D. V., Bura, M., Gergen, I., Harmanescu, M., & Bordean, D. M.

(2012). "Bioaccumulative and conchological assessment of heavy metal transfer in a soil-plant-snail food chain," Chemistry Central Journal, 6(1), p. 55.

Nica, D. V., Bura, M., Gergen, I., Harmanescu, M., & Bordean, D. M. (2012). Bioaccumulative and Conchological Assessment of Heavy Metal Transfer in a Soil-Plant-Snail Food Chain. Chemistry Central Journal, 6, 55-60. http://dx.doi.org/10.1186/1752-153X-6-55.

Orisakwe, O. E., Nduka, J. K., Amadi, C. N., Dike, D. O., & Bede, O. (2012). "Heavy metals health risk assessment for population via consumption of food crops and fruits in Owerri, South Eastern, Nigeria," Chemistry Central Journal, 6(1), p. 77. doi: 10.1186/1752-153X-6-77.

Panwar, N. R., Saha, J. K., & Adhikari, T. (2010). Soil and water pollution in India: some case studies, IISS Technical Bulletin. Indian Institute of Soil Science, Bhopal http://krishi.icar.gov.in/jspui/handle/123456789/36060.

Project: Environmental Soil Science Published in: Agriculture. Status of Soil Pollution in India Status of Soil Pollution in India DOI 10.1007/978-981-10-4274-4.

Rhodes, C. J. (2014). Mycoremediation (bioremediation with fungi) – growing mushrooms to clean the earth, Chemical Speciation & Bioavailability, 26(3), 196-198. DOI:10.3184/095422914X14047407349335 Corpus ID: 97081821.

Raj, D. D., Mohan, B., & Vidya Shetty, B. M. (2011). Mushrooms in the remediation of heavy metals from soil. Int. J. Environ Pollut Control Manag 3(1), 89-101. Corpus ID: 30905421.

Rangasamy, S., Purushothaman, G., Alagirisamy, B., & Mahima raja, S. (2015). Chromium contamination in soil and groundwater due to tannery wastes disposals at Vellore district of Tamil Nadu. Int J Environ Sci 6, 114–124. Corpus ID: 87774618.

Rawat, M., Ramanathan, A. L., & Subramanian, V. (2009). Quantification and distribution of heavy metals from small scale industrial areas of Kanpur city, India. J Hazard Mater 172, 1145–1149. doi: 10.1016/j.jhazmat.2009.07.115. Epub 2009 Aug 4.

Rhodes, J. C. (2012). Feeding and healing the world: through regenerative agriculture and permaculture. Sci. Prog., 95(4), 345-446.

Rhodes, C. J. (2013). Applications of bioremediation and phytoremediation. Sci. Prog., 96(4), 417-427. doi: 10.3184/003685012X13504990668392 52.Zhao, S., Shi, X., Li, C., Zhang, H., & Wu, Y. (2014). "Seasonal variation of heavy metals in sediment of Lake Ulansuhai, China," Chemistry and Ecology, 30(1), pp. 1–14. https://doi.org/10.1080/02757540.2013.841894.

Saha, J. K., Selladurai, R., Vassanda Coumar, M., Dotaniya, M. L., Kundu, S., & Patra, A. K. (2017). In book: Soil Pollution - An Emerging Threat to Agriculture (pp.271-315).

Saha, J. K. (2005). Changes in salinity and salinity of soils with continuous application of contaminated water near industrial area. J Indian Soc Soil Sci 53, 612–617.

Saha, J. K., & Panwar, N. (2010). An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. Waste Manag 30,

192–201. DOI: 10.1016/j.wasman.2009.09.041.

Saha, J. K., Panwar, N., & Singh, M. V. (2010). Determination of lead and cadmium concentration limits in agricultural soil and municipal solid waste compost through an approach of zero tolerance to food contamination. Environ Monit Assess 168, 397–406. doi: 10.1007/s10661-009-1122-3. Epub 2009 Aug 7.

Saha, J. K., & Sharma, A. K. (2006). Impact of the use of polluted irrigation water on soil quality and crop productivity near Ratlam and Nagda industrial area. Agricultural Bulletin IISS-1. Indian Institute of Soil Science, Bhopal, India http://krishi.icar.gov.in/jspui/handle/123456789/35660.

Sharma, R. K., Agrawal, M., & Marshall, F. M. (2008). Atmospheric deposition of heavy metal (copper, zinc, cadmium and lead) in Varanasi city, India. Environ Monit Assess 142, 269–278. doi: 10.1007/s10661-007-9924-7. Epub 2007 Sep 19.

Sharma, S., Goyal, R., & Sadana, U. S. (2014). Selenium accumulation and antioxidant status of rice plants grown on seleniferous soil from north western India. Rice Sci 21, 327–334.

Sharma, S., Kaur, J., Nagpal, A. K., & Kaur, I. (2016). Quantitative assessment of possible human health risk associated with consumption of arsenic contaminated groundwater and wheat grains from Ropar Wetland and its environs. Environ Monit Assess. doi: 10.1007/s10661-016-5507-9.

Singh, G., Sengor, S. S., Aditya, B., & Kumar, S. (2013). Reoxidation of biogenic reduced uranium: a challenge toward bioremediation. Crit. Rev. Environ. Sci. Technol., 44(4), 391-415. https://doi.org/10.1080/10643389.2012.728522.

Singh, H. (2006). Mycoremediation Fungal Bioremediation (Wiley Interscience, Hoboken). ISBN: 978-0-471-75501-2.

Singh, P., Raghukumar, C., Parvatkar, R. R., Mascarenhas-Pereira, M. B. L. (2013). Heavy metal tolerance in the psychrotolerant Cryptococcus sp. isolated from deep-sea sediments of the Central Indian Basin. Yeast. 30, 93–101. doi: 10.1002/yea.2943. Epub 2013 Mar 4.

Singh, P., Pratap, R., & Vaibhav, S. (2020). Contemporary Environmental Issues and Challenges in Era of Climate Change; Springer: Berlin/Heidelberg, Germany. ISBN 9789813295940.

Singh, V., Brar, M. S., Sharma, P., & Brar, B. S. (2011). Distribution of arsenic in groundwater and surface soils in south western districts of Punjab. J Indian Soc Soil Sci 59, 376–380.

Saha, J. K., Selladurai, R., Vassanda Coumar, M., Dotaniya, M. L., Kundu, S., & Patra, A. K. (2017). In book: Soil Pollution - An Emerging Threat to Agriculture (pp.271-315) Project: Environmental Soil Science Published in: Agriculture. Status of Soil Pollution in India Status of Soil Pollution in India DOI 10.1007/978-981-10-4274-4.

Sinha, S., Gupta, A. K., & Bhatt, K. (2006). Distribution of metal in the edible plant grown at Jajmau, Kanpur (India) receiving treated tannery wastewater: relation with physico-chemical proper-ties of the soil. Environ Monit Assess 115, 1–22. doi: 10.1007/s10661-006-5036-z. Epub 2006 Feb 15.

Stamets, P. (2005). Mycelium running: how mushrooms can help save the world. Ten Speed Press, Berkley. ISBN: 978-1-58-008579-3. 339 pages.

Tiwary, R. K., Dhakate, R., Rao, V. A., & Singh, V. S. (2005). Assessment and prediction of contaminant migration in ground water from chromite waste dump. Environ Geol 48, 420–429. DOI: 10.1007/s00254-005-1233-2.

Zhou, D., Li, Y., Zhang, Y., Zhang, C., Li, X. X., Chen, Z., Huang, J., Li, X. X., Flores, G., & Kamon, M. (2014). Column test-based optimization of the permeable reactive barrier (PRB) technique for remediating groundwater contaminated by landfill leachates. J. Contam. Hydrol. 168, 1–16. DOI: 10.1016/j.jconhyd.2014.09.003.