

Phytoremediation research – how Romania is placed worldwide

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Abstract

In the last few decades, due to the global industrialization and population expansion the level of pollutants has largely increased, being one of the main environmental problems faced worldwide. Consequently, phytoremediation research had been gathering more and more interest. A study of data selected from Scopus is presented by the authors, identifying trends in publication number, collaboration and impact. The trends are identified at the global level followed by a discussion of how Romania performs with respect to the identified trends. When evaluating the research produced by the Romanian institutions, two characteristics are considered: phytoremediation potential of the plants in the Danube Delta and the coastal region and the phytoremediation research temporal evolution and international impact. The paper presents a quantitative analysis without adding variable weights to citations and publications based on the publications ranks offering an overview of the national research status in this research area.

Keywords: phytoremediation, bioremediation, evaluation

1. Introduction

In the last few decades, due to the global industrialization and population expansion the level of pollutants has largely increased, being one of the main environmental problems faced. The rate of production and release of pollutants exceeded, at present, the natural processes of biodegradation. The term bioremediation it is used for technologies which accelerate the natural processes that degrade and detoxify the chemicals from soil and water (DIVYA et al. [3]). Seeking technological remedies to stop environmental pollution, physical, chemical and biological processes are essential. Heavy metals are toxic pollutants of water resources, non-degradable, who persist in the environment, with the possibility of accumulating in living organisms and becoming a risk factor regarding the health of population, (MEHMET et al. [10]). An alternative perspective is bioremediation technique that relies on the use of biological organisms for solving the environmental problems, for example water or soil purification (VIDALI, [19]). Phytoremediation methodology refers to the use of plants and microorganisms to remediate some contaminants present in soil and water, being one of the most inexpensive and environmentally friendly approaches considered. Phytoremediation utilizes a variety of plant processes and the physical characteristics of plants to aid in remediation of contaminated sites through stabilization, removal and degradation of pollutants from soil and water (ROBINSON et al. [14]; MARTINEZ et al. [9]). (CHIBUIKE & OBIORA [2]) argues that bioremediation is an efficient method of treating polluted soils, being one of the widely accepted methods nowadays, mainly carried in situ. The bioremediation method is a common approach for treating heavy

metal polluted soils. The role of plants in enhancing in situ bioremediation is not a novel idea, (ERICKSON et al. [4]) was promoting this approach.

UWAGBOE [18] conducted a study on the local plants in Nigeria to assess their phytoremediation potential of oils contaminated soils and (AMER[1]) is also arguing the phytoremediation is a valid tool for petroleum contaminated soils. (SIGNES-PASTOR et al. [17]) presented a phytoremediation assessment of arsenic contaminated soils in the Bengal delta, while (FAWZY et al. [6]) investigates the plants from the Nile River and delta that could be usefully utilized in the biomonitoring and phytoremediation programs. (PARVAN et al. [11]) is presenting their view on the effect of bioremediation technologies on oil contaminated soil. Under the FP7-People program, the European Commission funded the Phyto2Energy project (PROJECT_ID-610797, [13]), coordinated by Poland, running until 2018, whose objective is to develop an innovative approach that combines phytoremediation and production of biomass approach in the heavy metal contaminated areas. The contaminated land in Europe is wide spreading (about 2.5 million sites contaminated across Europe), the EUROPEAN ENVIRONMENT AGENCY (EEA) [5] report estimating that approximately 14% of these sites require remediation. At the global level, India, China, Pakistan, Bangladesh, have a severe soil contamination and phytoremediation for soils and water as gained growing interest in the last decade, (SHARMA & PANDEY[16]). SHARMA & PANDEY [16] states that phytoremediation research is performed globally, especially in United States, Africa and Asia, less so in Europe, however the methodologies are still in early stages and more research is needed for both the understanding and the knowledge of the bioremediation technologies. It was argued that there are different approaches on phytoremediation, (SCHWITZGUEBEL et al. [15]), while the European trend is research driven and based on outcomes, the American trend is more application and experience driven.

Starting with the year 2000 several funding agencies in the United States were interested in funding research focused on phytoremediation. In 2001, the United States Environmental Protection Agency (EPA) together with the National Science Foundation (NSF) and the Office of Naval Research (ONR) launched the Interagency Competition in Phytoremediation, as a continuation of the previous bioremediation research program, with a budget of over \$2 million. The 2001 Interagency Competition in Phytoremediation is a continuation of previous bioremediation research efforts aiming at advancing the-state-of-science of this innovative cleanup approach. The EPA/NSF/ONR joint program on phytoremediation will award more than \$2 million for research in this area. One of the goals of the joint effort was to evaluate the phytoremediation methods and to understand the phytoremediation applications. One can argue that the early research on phytoremediation funded in US broke the ground for this area towards the current status of phytoremediation today, (LELIE et al. [7]).

In the last decade several studies have been published through small research grants funded in the national research institutes or universities, however there was no specific call for projects focused on this direction. This paper investigates the bibliometric research on phytoremediation produced by Romanian researchers, as well as how Romania is placed in the global research network of phytoremediation.

The present study is focused on two directions, first to investigate the phytoremediation potential in the Danube Delta and second to evaluate the phytoremediation research publications and how Romania fits in the global context. For the first investigation the database created under the project BIODIVERS (PN 16-190105 [12]) is used. The database is investigating the bioremediation potential of the plant species in the Danube delta. For the second investigation, the trends of publications in phytoremediation are performed on data obtained from searches in Scopus. Articles containing a set of keywords that will be defined in the next section, in keywords, abstract and/or title were considered and data was collected from 2000-2015.

2. Materials and methods

The database created under the BIODIVERS project, consisting of 1 entry, contains information related to the plant architecture, soil agro-chemistry and response to biotic and abiotic factors, alelopathic, bioremediation potential for the plants in the Danube Delta region. The plants in the database were collected using, as sources for documentation, scientific articles, scholarly treatises and encyclopedias both in physical and online support. The documentation and searches were conducted employing specific sets of keywords such as plant biology, roots length, stems length, shoot length, plant botany, leaf dimensions, leaf surface, root type, stem type, leaf description and flower description. Descriptive statistics analysis was performed on the phytoremediation potential of the plants registered in the database as well as a cross tabulation of the phytoremediation potential by region, the results detailed in the next section, *Figure 1, Figure 2*.

The phytoremediation research publications evaluation is performed on Scopus data, on a sample of 44955 publications, retrieved from the Scopus database that covers a period of 16 years, in the interval 2000-2015. The records were extracted from the *Advanced Search* interface using at least one of several bioremediation related keywords (*bioremediation, phytoremediation, bioventing, biostimulation and bioaugmentation*) in a combined field that searches abstracts, keywords and publication titles, i.e. the function *TITLE-ABS-KEYWORD*. The obtained results were exported as a .csv (comma separated value) file that contained information about the authors, subject area, year of publication, author's affiliations, country, source title, etc.

The collaboration network for Romania has been obtained using the author addresses listed in the papers (i.e. from *Authors with Affiliation* field). For each paper we have extracted the country information on all authors and used it to compute a symmetric matrix that determines, for each pair of countries, the strength of the link between them based on the number of publications co-authored. As a graphical method for displaying the inter-relationships between the nodes of the identified collaboration network, we used the chord diagram. The nodes and link sizes are proportional to the values of that appear in the collaboration matrix.

To get a better understanding of the phytoremediation research within Romania, the publications with at least one author affiliated to a Romanian institution were further grouped by several relevant domains: *Agricultural and Biological Sciences (AGRI), Biochemistry, Genetics and Molecular Biology (BIOC), Chemical Engineering (CENG), Chemistry (CHEM), Earth and Planetary Sciences (EART), Engineering (ENGI), Environmental Science (ENVI), Immunology and Microbiology (IMMU), Materials Science (MATE), Medicine (MEDI) and Physics and Astronomy (PHYS)*. To illustrate the intersections of the papers from each domain we used the visualization technique developed by (LEX & GEHLENBORG [8]).

All the mapping and analysis in this article¹ were performed using the open source software R (<https://cran.r-project.org/>) and are dynamically generated.

3. Results and discussion

Investigating the bioremediation properties of the plants in the Danube Delta region, one could see that 61.3% is covered by the phytoremediation potential, followed by decontamination potential with 22.9% and pollutants removal potential with 11.7%, as illustrated in *Figure 1*. One variable of interest in the database is the region, and it was codified with three levels: coastal area, delta area and fluvial area. Most of the plants identified with phytoremediation potential are the ones in the delta region (50.4%), followed by the coastal region (9.8%). Similarly the decontamination potential and the removal potential are identified mainly in plants from the delta area and the coastal area, as can be seen in *Figure 2*.

¹ This article was created in *Rmarkdown* and it is reproducible.

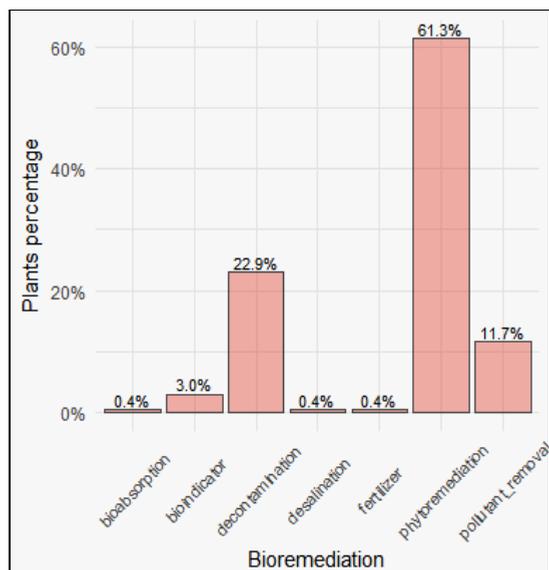


Figure 1. Bioremediation property for the plants in the database

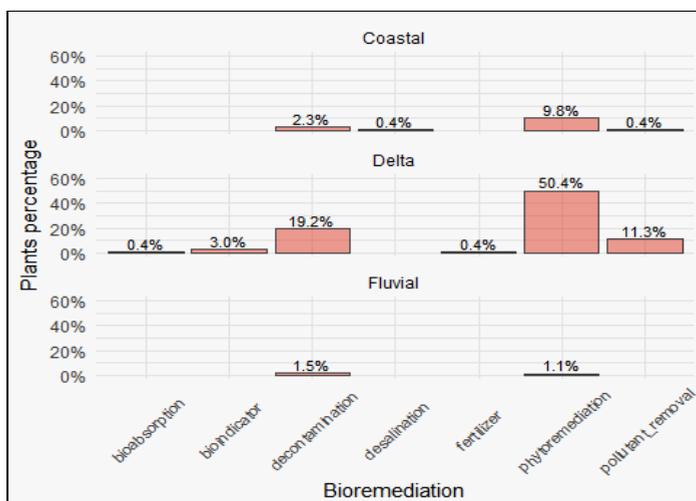


Figure 2. Bioremediation property for the plants in the database by area

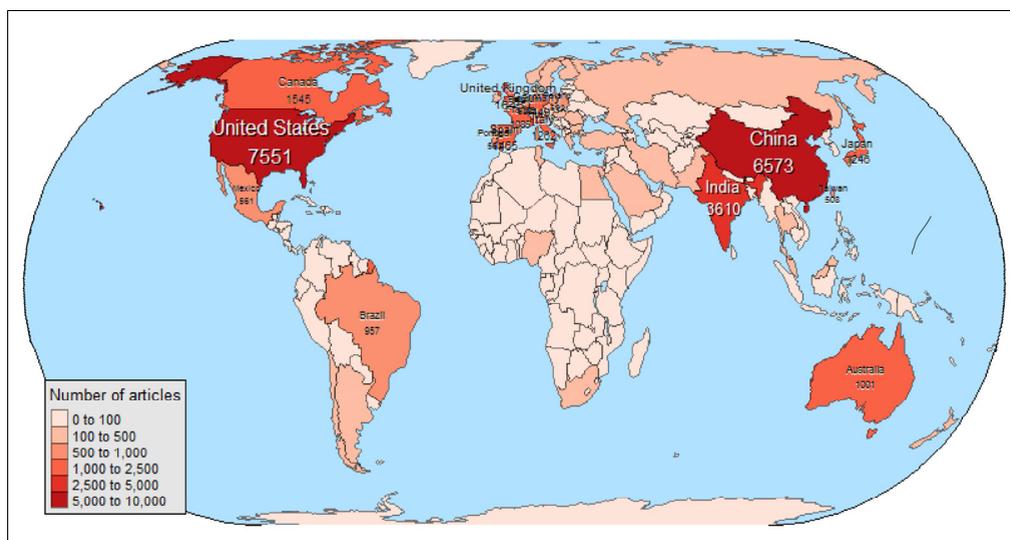
Research in this area in the last decade in Romania did not have dedicated funding and there are only several research groups performing research in this direction. In the Scopus search performed, there were 173 papers published by authors with Romanian affiliation identified. *Table 1* presents the top 10 countries worldwide ranked by the number of publications in bioremediation area in the interval 2005-2015, as well as the ranking of Romania (39 in the world) and the ranking of Pakistan, south Africa and Bangladesh, identified as countries with severe soil contamination and interested in bioremediation and phytoremediation, (SHARMA & PANDEY [16]).

One can identify from *Figure 3* the top countries that perform the research in this area, China competing strongly with United States for the leading research in this area. The Chinese 12654

Table 1

ID	Country	Number of articles
1	United States	7551
2	China	6573
3	India	3610
4	United Kingdom	1645
5	Canada	1545
6	Spain	1465
7	Germany	1449
8	Italy	1262
9	Japan	1246
10	France	1085
20	Pakistan	437
31	South Africa	302
39	Romania	173
52	Bangladesh	70

government has requested a loan from the World Bank (project is expected to be delivered in the fiscal year 2017) to support Hunan province's efforts on improving agriculture production base safety and quality by cleaning up heavy metals, phytoremediation being considered another emerging low-cost in-situ technology (Report No: PAD 938, World Bank). The publications of the top countries identified in *Table 1* can be compared with either developed countries or countries identified as having severe soil contamination problems. India is another country where phytoremediation research has developed rapidly in the last decade, ranking the country on the third position based on the research publications produced.

**Figure 3.** World map with the number of publications for each country

The worldwide focus on research on phytoremediation can be identified by the percentage of publications in this area from the total number of publications. As can be seen from *Figure 4*, starting with 2010 there is a steady increased interest in this area of research, a significant increase being identified from 2013 to 2014. The intensification of industrial activities and the demographic explosion has resulted in severe environment pollution, with dramatic consequences on the atmosphere, water and soil and the academic community is responding to these problems, by increasing the interest and research efforts needed to solve these issues.

The countries focus on research in this area can be identified from *Figure 5*, where it can be seen that the number of publications in China is rapidly growing, after 2010 the phytoremediation research being significantly above the worldwide average. United States was leader in research publications up until 2009, followed by a period when the research interest in this area was dropping rapidly, however from 2012 there is a slowly increase in the publication number.

At the European level it can be noted from Table 1 that UK has the largest number of publication in the time frame analyzed (1645 publications), followed by Spain (1465 publications) and Germany (1449 publications). However, from *Figure 5*, it can be seen that both Spain and UK had a constant interest in the research in this area in the analyzed time interval, the number of publications per year being uniformly distributed by year. Germany did not express too much interest compared with the two countries up until year 2006; however, after 2006 Germany has a rapid increase in the number of publications in this area, and will be by year 2006, the top country in Europe regarding the number of publications in phytoremediation area, although there is a slight decrease in the number of publications from 2014 to 2015.

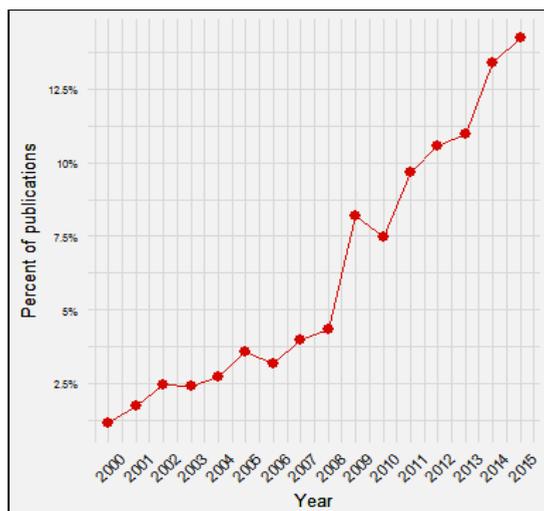


Figure 4. Percentage of papers with bioremediation and phytoremediation per year

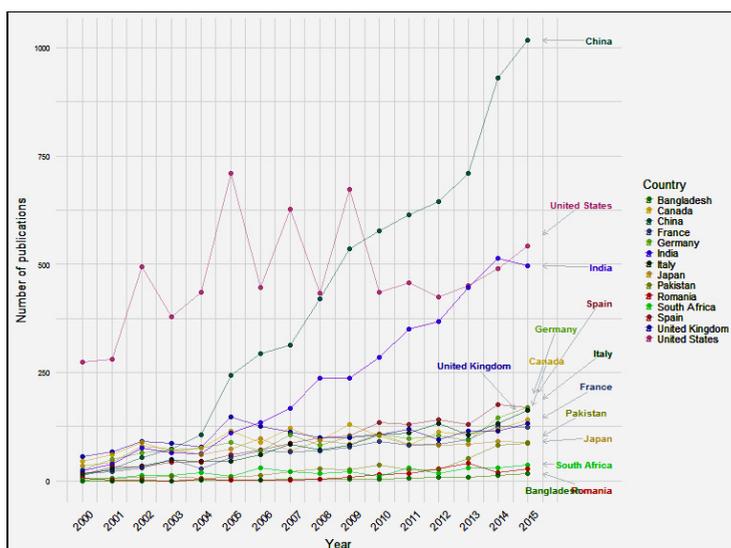


Figure 5. Evolution of the number of publications per country

Looking at how Romania is placed in the global research network of phytoremediation, the collaboration chord diagram in *Figure 6* and the *Table 2* illustrates the fact that Romania does not collaborate too much with institutions from other countries; most of the publications registered in Scopus under phytoremediation are co-authored by researchers with Romanian affiliations.

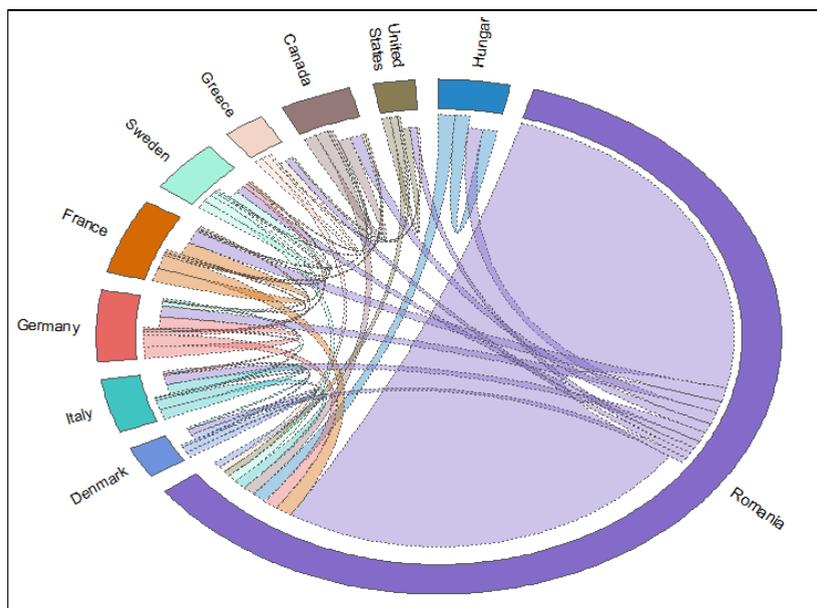


Figure 6. Collaboration chord graph

There are few publications in collaboration, the top collaboration countries being France, Germany, Hungary, Italy and Canada, *Table 2*. The number of coauthored papers with these countries is similar; hence no characteristic could be identified. Since Romania is part of the Phyto2Energy research grant (Project ID: 610797, FP7-People, 2014-2018) coordinated by Poland, and partners with Germany one would expect that the number of collaborative papers with these partner institutions to increase by the end of the project.

Table 2

Country	Hungary	Romania	Denmark	Italy	Germany	France	Sweden	Greece	Canada	United States
Hungary	6	6	0	0	0	0	0	0	0	0
Romania	6	173	3	5	6	7	4	3	5	3
Denmark	0	3	3	1	0	0	0	0	0	0
Italy	0	5	1	5	1	0	0	0	0	0
Germany	0	6	0	1	6	1	2	0	0	0
France	0	7	0	0	1	7	1	0	1	0
Sweden	0	4	0	0	2	1	4	0	1	0
Greece	0	3	0	0	0	0	0	3	0	1
Canada	0	5	0	0	0	1	1	0	5	0
United States	0	3	0	0	0	0	0	1	0	3

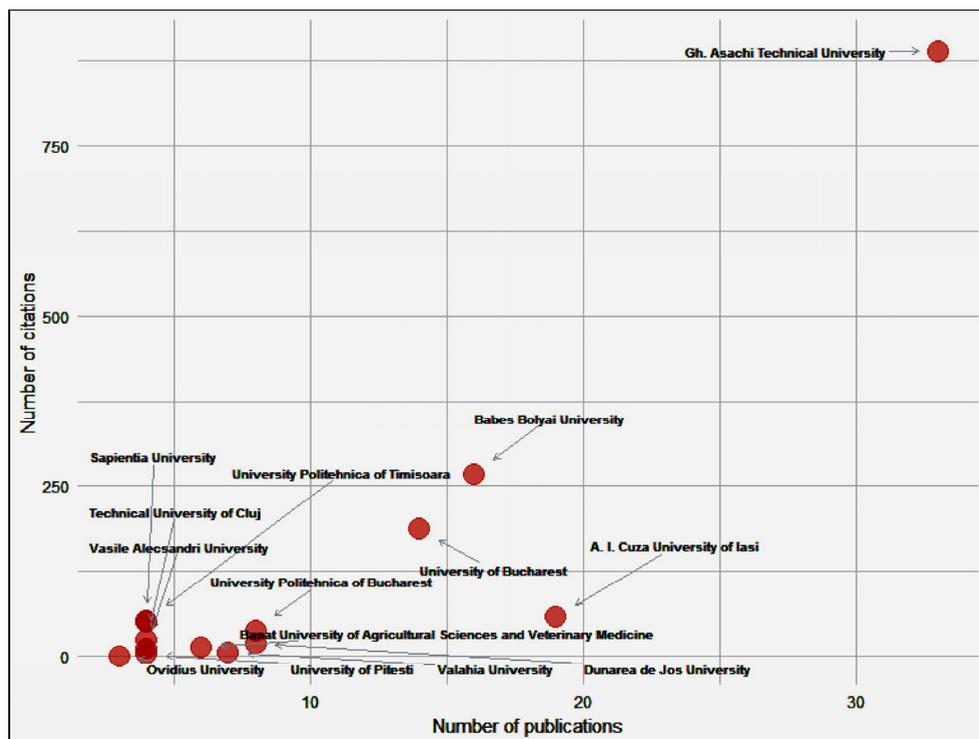


Figure 8. Top universities in Romania

4. Conclusions

The paper presents an evaluation of the bioremediation and phytoremediation research produced between 2000-2015, research that is indexed in Scopus in the world, with a focus on the research produced in Romania. The study also investigates how Romanian research in these areas is compared with the global trend, in terms of publications, collaborations and impact. The temporal evolution of the publications produced by authors with Romanian affiliation does not have a steady increase as the global trend identified, however it does have a positive growth since 2013, as it was identified in the study. The assessment presented in this study is quantitative, focusing on the number of publications and the impact of the research produced (through received citations) and does not consider the qualitative of research developed in this area, namely the prestige of the publication journals, through either the Impact Factor or the Relative Influence Score. The national research should attempt to be published in international journals which are better covered in Web of Science databases than more local-oriented journals.

5. Acknowledgements

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References

1. AMER, A. KH., Using phytoremediation as a tool for improving a petroleum hydrocarbon contaminated soil, *J. Soil Sci. and Agric. Eng.*, Mansoura Univ., 2 (12), 1303-1314 (2011).
2. CHIBUIKE G. U., OBIORA S. C., Heavy Metal Polluted Soils: Effect on Plants and Bioremediation Methods, *Applied and Environmental Soil Science*, Article ID 752708 (2014).
3. DIVYA M., AANAND S., SRINIVASAN A., AHILAN B. AND UMA A., Bioremediation of Seafood Processing Plant Effluents Using Indigenous Bacterial Isolates, *International Journal of Advanced Biotechnology and Research (IJBR)*, 443-449 (2015).
4. ERICKSON L.E., BANKS M.K., DAVIS L. C., SCHWAB A.P., MURALIDHARAN N., REILLEY K., TRACY J.C., Using vegetation to enhance in situ bioremediation, *Environmental Progress*, 13(4), 228-234 (1994).
5. EUROPEAN ENVIRONMENT AGENCY (EEA) NETWORK-<https://www.eionet.europa.eu/>, (2016).
6. FAWZY MA, BADR NEL-S, EL-KHATIB A, ABO-EL-KASSEM A., Heavy metal biomonitoring and phytoremediation potentialities of aquatic macrophytes in River Nile, *Environmental Monitoring and Assessment*, 184(3), 1753-1771 (2012).
7. LELIE D., SCHWITZGUEBEL J.P., GLASS D. J., GRONSVELD J., BAKER A., Assessing Phytoremediation Progress in the United States and Europe, *Environ. Sci. Technol.*, 35 (21), pp. 446A–452A (2001).
8. LEX, A., AND N. GEHLENBORG. 2014. “Points of View: Sets and Intersections.” *Nature Methods* 11 (8): 779, (2014).
9. MARTINEZ, M., P. BERNAL, C. ALMELA, D. VÉLEZ, P. GARCÍA-AGUSTÍN, R. SERRANO, AND J. NAVARRO-AVIÑÓ. “An Engineered Plant That Accumulates Higher Levels of Heavy Metals Than *Thlaspi caerulescens*, with Yields of 100 Times More Biomass in Mine Soils.” *Chemosphere* 64: 478-85 (2006).
10. MEHMET, E.A., SUKRU, D., CELALETTIN, O., MUSTAFA, K., Heavy metal adsorption by modified oak sawdust: Thermodynamics and kinetics. *J. Hazard. Mater.* 141, 77-85 (2007).
11. PARVAN L., ANTON I., SIRBU C., CIORIANU T., DUMITRU M., MUSAT M., The Effect of Bioremediation Technologies on Mobile Potassium Content from Polluted Soil with Crude Oil, *Romanian Biotechnological Letters*, 21 (4), (2016).
12. PN 16-190105-BIODIVERS, Potentialul Bioeconomic al Deltei Dunarii – DANUBIUS-RI, National Institute of Research and Development for Biological Sciences (2016).
13. PROJECT ID: 610797, Phyto2Energy – Phytoremediation driven energy crops production on heavy metal degraded areas as local energy carrier, 2014-2018.
14. ROBINSON, B.H., R.R. BROOKS, A.W. HOWES, J.H. KIRKMAN, AND P.E.H. GREGG, “The Potential of the High Biomass Nickel Hyperaccumulator *Berkheya Coddii* for Phytoremediation and Phytomining.” *J. Geochem. Explor.* 60: 115-26 (1997).
15. SCHWITZGUEBEL J.P., LELIE D., BAKER A., GLASS D. J., GRONSVELD J., Phytoremediation: European and American trends successes, obstacles and needs, *Journal of Soils and Sediments*, 2(2), 91-99 (2002).
16. SHARMA P., PANDEY S., (2014). Status of Phytoremediation in World Scenario, *International Journal of Environmental Bioremediation & Biodegradation*, 2 (4), 178-191.
17. SIGNES-PASTOR A.J., MUNERA-PICAZO S., BURLO F., CANO-LAMADRID M., CARBONELL-BARRACHINA AA., Phytoremediation assessment of *Gomphrena globosa* and *Zinnia elegans* grown in arsenic-contaminated hydroponic conditions as a safe and feasible alternative to be applied in arsenic-contaminated soils of the Bengal Delta, *Environ Monit Assess.*, 187(6), 387 (2015).
18. UWAGBOE A.I., Assessment of local tropical plants for phytoremediation of petroleum contaminated soil, *Journal of Research in National Development*, 6(1), 1-16 (2008).
19. M. VIDALI, Bioremediation. An Overview. *Pure Appl. Chem.*, 73 (7), 1163-1172 (2001).