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Professional paper

Trends in air Pollution: The Use of Mosses as Biomonitors

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Abstract: Air pollution is a major concern throughout the universe due to the effects on living and non-living things. Before an area is said to be polluted, there is the need to carry out a bottom-up or top-down assessment of the environment. Mosses have been widely employed as cheap bioindicators of atmospheric pollution. It reduces the time-frame spent in monitoring and the results are reliable. Several types of research have been undertaken on the spatial and temporal trends in air pollution using mosses. This paper explained what moss is, discussed the cost of biomonitoring using a moss, mapping, and researches undertaken on mosses as bioindicators.

Keywords: Pollution, mosses, Bryophyta, Orthotrichum lyellii, cheap biomonitor, mapping, elements.

INTRODUCTION

There is an attendance problem world over due to air pollution. The major increase in housing, vehicular movements, industrial activities and farming, paved and unpaved roads have increased air pollution. The resultant effects have affected lives (health-wise, even death) and material things (destruction). The air pollution is one of the world's largest environmental health risks. World Health Organization (2014) estimates that air pollution is contributing to about 7 million premature deaths annually. The presence of organic and inorganic chemicals, particulates or biological material in the air has also produced atmospheric pollution. Several effects of air pollution are of global concern, with climate change and stratospheric ozone depletion, being the most serious environmental issues (Ristić *et al.,* 2013).

The atmosphere, hydrosphere, lithosphere, and biosphere are major environmental compartments or conceptual spheres where the flow of matter and energy takes place within every sphere and also between each of them in both directions (Figure 1). Abiotic and biotic processes that take place in the compartments are known to be responsible for the conversion of matter and energy which in turn make the system more complex and influence the distribution and flow of matter and energy (Ristić *et al.,* 2013).

Environmental awareness is increasing both in developed and developing countries. Chemical monitoring has been used to identify pollutants. The method is fascinating because it's so expensive to monitor air because of the time was taken and finance involved. Biomonitoring using lichens, mosses and plants are taken as an alternative method to this. Biomonitoring using these organisms are considered cheap. Mosses are considered reliable indicators of air pollution to ecosystems simply because they get most of their nutrients directly from the air, rain, rather than the soil (Phillips, 2016).

Instrumental and chemical monitoring methods lack information on the effects of atmospheric pollutants on the living organism and hence, there has been an increasing interest in using indirect monitoring methods based on a response of living organisms that may act as trace element bioaccumulators (Ristić *et al.,* 2013; Reski, 2012).

In this paper, we review the application of mosses as biomonitors of various pollutants and their sources in the environment.

What is moss?

Mosses are flowerless plants that grow (0.2–50 cm high) mainly in dense green clumps or mats, damp or shady places. They are composed of simple, one-cell thick leaves that are attached to a branched or unbranched stem that conducts water and nutrients (Hubers and Kerp (2012). The flowerless plants do not possess seeds and when fertilized, they develop sporophytes gametophyte and a sporophyte stages). The spore capsule, often with a supporting stalk (sporophyte and gametophyte stage.). Mosses are classified into division Bryophyta which has eight classes (Figure 1).

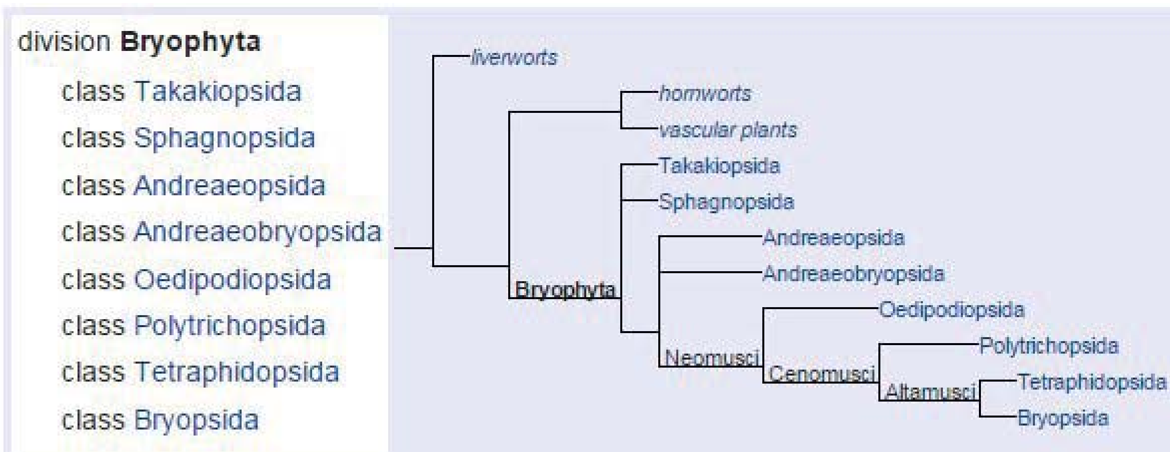

Figure 1. Classes of Bryophyta

Moss has a fairly weak stem which is fairly short when standing erect (tufty growth form) and the other growth form (trailing) which makes the moss look like a creeping plant. Moss has rhizoids. They are anchoring structures, root-like, which has non-absorptive functions of true roots. Different moss parts possess different types of leaves according to the growth form (Australian Natural Herbarium (2012).

Cost of monitoring

According to Harmens (2010), monitoring pollutants in rainwater or airborne particles samples require frequent sampling and is expensive, according to them, monitorings are only done at a limited number of locations across Europe. On the other hand, mosses sampling is relatively cheap, they can be obtained from many locations in Europe, and scientists can get useful information by sampling them just every five years. The heavy metals analysis for moss costs them $50 per site, a low cost that makes it possible to sample extensively. In the study of Gatziolis *et al.* (2016), it was noted that the determination of pollutants in bioindicator costs less than using instruments, using moss samples cost about $150 for laboratory analyses and manpower.

The United States researchers from the Forest Service have turned to the use of cheap ally (moss). The researchers gathered 346 samples of *Orthotrichum lyellii* moss grown on the trunks of hardwood trees in Portland, from locations around the city and were analyzed for their concentrations of cadmium, arsenic, and selenium cations (**DeWeerdt, 2016).**

Biomonitor

Moss is a superb air pollution monitor because it gets all of its water and nutrients from the atmosphere, storing whatever compounds happen to be present in the local environment. A final version of the United States Forest Service (SFS) study published on April 7 in Science of the Total Environment says that while moss has been used as "bioindicators" by the Forest Service and other agencies for decades, this was the first time it's been used to generate a detailed map of air pollution in a city.

The cadmium portion of the moss study revealed that moss is an effective bioindicator of cadmium levels in the air (Donovan *et al*., 2016b).

Moss has been used by Sweden researchers to detect air pollution in forests since the 1960s Donovan *et al*. (2016a). Moss doesn't have roots; it's like a sponge, absorbing moisture, and nutrients from the air, as well as contaminants. These contaminants are stored in the moss tissues, making them a living record of pollution levels in the surrounding environment. Because some species of moss are very sensitive to air pollution, they are indicators of good or bad air quality. If certain sensitive species are declining, it's an indication that the air quality is declining.

Mapping

Moss is a low-cost way of mapping air pollution and has the potential to revolutionize the enforcement of environmental regulations. In 2013, a team of the United States scientist, Jovan and Donovan of Forest Service's Pacific Northwest Research Station in Portland, Oregon embarked on a research on pollution using moss samples, this lead to a detailed and rigorous mapping of air pollution in a United States city. The study showed that moss can serve as a low-cost screening tool to help cities strategically place their expensive and limited instrumental air-quality monitors (Sands, 2016).

Previous Studies on air pollution using mosses.

Vuković *et al*. (2015a), studied the level of air pollutants in 16 polycyclic aromatic hydrocarbons (PAHs), and 41 major elements, trace elements, and REEs using *Sphagnum girgensohnii* moss bag method. From the results obtained, it was observed that the moss under investigation had concentrations of PAHs, Sb, Cu, V, Ni, and Zn cations, while the moss had the same REE concentrations of North American Shale Composite and Post-Archean Australian Shales due to anthropogenic activities. The results clearly demonstrated the seasonal variations in the moss enrichment of the air pollutants.

Vuković *et al*. (2016), studied the harmful effects of human long-term exposure to intense traffic emissions in the urban area of Belgrade (Serbia) using moss bags (The *Sphagnum girgensohnii* and *Hypnum cupressiforme*). Forty-eight locations were monitored for a period of 10 weeks. Concentrations of 39 elements were determined. The results obtained depicted that the exposed moss bags were enriched with Sb, Cu, and Cr. It was concluded that concentrations of each elements were dependent on traffic emissions.

Špirić *et al.* (2014), worked on four moss species (*Hypnum cupressiforme, Pleurozium schreberi, Homalothecium sericeum* and *Brachythecium rutabulum*). The aim was to biomonitor air pollution with Hg in Croatia using cold vapour atomic absorption spectrometry (CV-AAS) method. From the results obtained, mercury ranged from 0.010 to 0.145 mg kg^{-1} with a median value of 0.043 mg kg^{-1}. The Hg distribution map showed the sites of the country with high levels of this element.

Gatziolis *et al.* (2016), measured twenty-two elements using moss samples obtained in Portland, Oregon with the view of developing citywide maps depicting concentrations of metals in moss and identifying possible air pollution. The results showed that 15 metals which included Cd, Ni, Pb, and As cations were highly right-skewed distributed. It was recommended that constant monitoring should be ensured to determine whether the hotspots pointed out by the moss indicator pose a health risk.

Vukovic *et al*. (2015b), explored the suitability of the moss *Sphagnum girgensohnii* for biomagnetic monitoring in the cities of Belgrade. *S. girgensohnii* moss bags were exposed at three different microenvironments characterized by heavy traffic. The ferro(i)magnetic PM fraction in the moss samples was quantified by Saturated Isothermal Remanent Magnetization (SIRM) and the measured values were compared with the trace element concentration in the moss samples. The results showed that SIRM values were significantly different across the considered urban microenvironments, but a high correlation between moss SIRM values and concentrations of Al, Ba, Co, Cr, Cu, Fe, Ni and Pb cations was found. The results showed that moss bags can be used for biomagnetic monitoring spatial-temporal distribution trends in air pollution.

In another study, Donovan *et al*. (2016b) identified unknown sources of Cd pollution in 346 samples of the moss *Orthotrichum lyellii* from deciduous trees using a modified randomized grid-based sampling strategy across Portland, Oregon. The results of the maps showed very high concentrations of Cd around the two stained-glass manufacturers. The monthly average atmospheric Cd value was 29.4 ng/m^3, which was 49 times higher than Oregon's benchmark of 0.6 ng/m^3, which was high enough to pose a health risk.

Lazi *et al*. (2016), in urban street of Canyon in Belgrade (Serbia), investigated the air pollutant distribution using the moss bag. Operational Street Pollution Model (OSPM) was used to predict the contents of NO_X, NO, NO_2, O_3, CO, BNZ, PM_{10} and trace elements. The results of both methods, modeling, and biomonitoring, showed significantly decreasing trend of air pollutants with height. The results showed that the moss bag technique could be a valuable tool to verify model performance.

Vukovic *et al*. (2014), studied the PAHs and Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr and Zn cations in PM10 samples obtained in Belgrade, Serbia. The metals were determined in the biomonitor earmarked for the sampling (*Sphagnum girgensohnii* moss bags). The results obtained showed that concentrations of PM10, Cd, Ni, and B[a] P exceeded the European Union guidelines. Further research was recommended on the use of *S. girgensohnii* moss bag technique to determine its suitability in indoor pollution monitoring.

Deljanin *et al.* (2013), studied an active moss biomonitoring survey of lead isotopic composition in the Belgrade urban area. Samples of the moss *Sphagnum girgensohnii* were used for the study. The results showed $^{206}Pb/^{207}Pb$ isotopic with a ratio of 1.167-1.184 for samples at 4 m height, and 1.164-1.184 at 8 m height and $^{208}Pb/^{207}Pb$ isotope with the ratio of 4 and 8m height, which was in the range 2.450-2.477 and 2.433-2.471, respectively. The results for moss bags exposed at both heights indicated that Pb still presents in the environment.

Goryainova *et al*. (2016), used *Sphagnum girgensohnii* moss bags to determine the small-scale vertical distribution of some major and trace elements in different types of street canyons (regular, deep and avenue types) in Belgrade and Moscow urban area using neutron activation analysis. The results showed that the accumulation of elements in the exposed moss bags was much in deep and regular street canyons when compared with that of the avenue type, the latter even with the higher traffic flow. It was deduced that *S. girgensohnii* was sensitive to small-scale variations of the total concentrations of elements.

In a study from Mahabaleshwar, India, Chakrabortty *et al*. (2004) studied the metal compositions of two moss samples obtained from a remote hill station using an Energy Dispersive X-ray Fluorescence instrument (EDXRF) and Instrumental Neutron Activation Analysis (INAA) techniques. They recorded the abundance of the cations as Al, Sr, Zn, and Rb. All the metals were enriched in the soil samples.

Macedo-Miranda *et al*. (2016), also contributed to the study of air pollution using moss samples *(Fabriona ciliaris* and *Leskea angustata*) obtained from the Toluca Valley (MATV) in Mexico.The team used Absorption atomic spectrometry analysis (AAS) for the determination of the cations (Cr, P, Cd, and Zn). The results obtained depicted that the average metal concentrations in the mosses were in the order of: Zn > Pb > Cr > Cd. It was noted that the concentrations of heavy metals were higher in *Fabriona ciliaris* than *Leskea angustata*. The study concluded that the enrichment of the metals were higher in the raining season and also the metals were suggested to be from an anthropogenic sources.

Jiang *et al.* (2018), in their study compared the metal accumulation power of mosses and vascular species from urban areas and quantified the suitability of the two for monitoring airborne heavy metals. The samples were obtained from the urban area of Wuhan City, Hubei Province, China.The cations determined were Ag, As, Cd, Co, Cr, Cu, Mn, Mo, Ni, V, Pb, and Zn using inductively coupled plasma mass spectrometry. The differences of heavy metals concentration in the samples depicted that the moss species accumulated the heavy metals than tree leaves (3 times to 51 times). The accumulation of heavy metals in the moss samples depended on the metal species and land.

In the Republic of Macedonia, moss surveys (2005 and 2015) was carried out by Stafilov *et al*. (2018). Over 72 samples of the terrestrial moss samples were obtained. Inductively coupled plasma-atomic emission spectrometry (ICP-AES) and atomic absorption spectrometry (AAS) were used to determine 22 elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Rb, Sr, V, and Zn). Comparing the results from the surveys, it was found out that nearly all the potentially toxic elements (As, Cd, Co, Cr, Cu, Ni, Pb, and Zn) increased in concentration in moss samples from 2002 to 2005 but decreased in the samples from 2010 to 2015.

Allajberu *et al.* (2017), used *Hypnum cupressiforme* and *Pseudoschleropodium purum* collected from 44 locations to characterize the toxic metals and metalloids in Albanian air. Inductively coupled plasma-atomic emission spectrometry (ICP/AES) and epithermal neutron activation analysis (ENAA) was the instrumentation used. The results obtained showed that both contamination factors (CF) and pollution loads index (PLI) were depicted at a moderate to high pollution scale. the potential ecological index (RI) results depicted the presence of a high ecological risk. The was potential risk of human exposure to trace metals, especially in the areas with the highest element concentrations.

Bačeva *et al*. (2012), studied the atmospheric deposition of elements in Kavadarci, Republic of Macedonia using moss biomonitoring. The study also determined the possible sources of pollution. In the study network of mosses (31 samples) distributed over 600 km^2 was used. A total of 46 elements were determined by mass spectrometry with inductively coupled plasma (ICP-MS). From the results, according to the distribution pattern of elements determined in the samples, two anthropogenic geochemical associations (Co-Cr-Cu-Fe-Mg-Ni and As-Cd-Cu-Hg-Pb-Zn), were detected. The enrichment ratio confirmed the influence of the dust from the ferronickel plant to the air pollution in this region.

De Agostini *et al*. (2020) analysed the results of a biomonitoring campaign, carried out with *Hypnum cupressiforme* Hedw. moss bags near an oil refinery, situated at the southwestern part of Sardinia island (Italy). The study was based on the effects of rainfall and distance from the source of contamination of 14 trace elements measured over 16 years and to show any increasing or decreasing trends, as well as any peak in presence of airborne pollutants in the area. The annual elements' concentration values were plotted and discussed. The study concluded firstly, that the location of the source of contamination and the rainfall influenced the elemental concentration in the biomonitor in the case study differently, due to the element determined and on the exposure condition, secondly, the bag that contained *H. cupressiforme* provided relatively stable measurements during the 16-year time frame, and thirdly, similar conditions of exposure determined less variable accumulation values.

Gaza and Kugara, (2018), determined the heavy metals pollution of the University of Zimbabwe, Harare, Zimbabwe environment using *Grimmia dissimulate* moss bag. The moss was subjected to heavy metals analysis using Atomic Absorption Spectroscopy. The concentrations were expressed as Relative Accumulation Factors (RAFs) and the means for Cr, Cu, Pb and Zn were 14.38; 18.17; 9.63 and 10.78 respectively. The results showed the concentration order of deposition was Cu > Cr > Zn >Pb and that Zn deposited.

CONCLUSION

Mosses have been regarded as a useful method in biomonitoring. It is an effective screening tool in environmental pollution. It is an inexpensive alternative to the use of an instrument that has provided valuable information on pollution. The results obtained by all the researchers have been used in formulating policies that are used in mitigating the environmental pollution of both developed and developing countries. It saves time in a situation where monitoring instruments need more than a month, moss will provide results for a single location. It is also a good tool for mapping (provision of hotspots) in air pollution.

Table 1: Previous studies on biomonitoring using mosses

S/N	Mosses used	Parameters	Location & Year	References
1	Sphagnum girgensohnii trace elements, and REEs	16 polycyclic aromatic hydrocarbons moss bag (PAHs) 41 major elements	Belgrade, Serbia, 2015	Vuković et al. (2015a)
2	Sphagnum girgensohnii and Hypnum cupressiforme moss bags	39 multi-elements	Belgrade, Serbia, 2016	Vuković et al. (2016)
3	Hypnum cupressiforme, Pleurozium schreberi, Homalothecium sericeum and Brachythecium rutabu-lum	Hg	Croatia, 2014	Špirić et al. (2014)
4	Orthotrichum lyelli Hook	22 multi-elements	Portland, Oregon, 2016	Gatziolis et al. (2016)
5	Sphagnum girgensohnii	SIRM, PM, 10 elements	Dubna, Russian Federation, 2015	Vukovic et al. (2015b)
6	Orthotrichum lyellii	Cd	Portland, Oregon, 2016	Donovan et al. (2016b)
7	Sphagnum girgensohnii moss bag	NOX, NO, NO2, O3, CO, BNZ and PM10	Belgrade, Serbia, 2016	Lazic et al. (2016)
8	Sphagnum girgensohnii moss bag	PAHs and Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr and Zn	Belgrade, Serbia, 2013	Vukovic et al. (2014)
9	Sphagnum girgensohnii	Pb	Belgrade, Serbia, 2011	Deljanin et al. (2013)
10	Sphagnum girgensohnii	Major and Trace metals	Belgrade and Moscow urban Area, 2011	Goryainova et al. (2016)
11	Sphagnum girgensohnii and Hypnum cupressiform	Heavy metals and PAHs	Belgrade, Serbia, 2013	Vukovic et al. (2015c)
12	Pterobryopsis flexiceps, Pin-natellaalopccuroides	Trace elements	Mumbai, India, 2004	Chakrabortty et al. (2004)
13	Fabriona ciliaris, Leskea angustata	Zn, Pb, Cr, and Cd	Toluca Valley, Mexico, 2011	Macedo-Miranda et al. (2016)
14	Haplocladium angustifolium	Ag, As, Cd, Co, Cr, Cu, Mn, Mo, Ni, V, Pb, and Zn	Wuhan City, China	Jiang et al. (2018)
15	The terrestrial moss samples	Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Rb, Sr, V, and Zn	Republic of Macedonia	Stafilov et al. (2018)

16	Hypnum cupressiforme and Pseudoschleropodium purum	Toxic trace metals (Cd, Cr, Co, Cu, Hg, Ni, Pb, and Zn) and metalloids (As)	Albania	Allajberu et al. (2017)
17	Network of Samples (31 moss samples)	Ag, Al, As, Au, Ba, Be, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hg, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Sb, Sm, Sr, Tb, Th, Ti, U, V, Yb, Zn, Zr	Kavadarci, Republic of Macedonia	Bačeva et al. (2012)
18	Hypnum cupressiforme Hedw moss bags	14 trace elements	Southwestern part of Sardinia island, Italy	De Agostini et al. (2020)
19	Grimmia dissimulate bag	Heavy metals (Cr, Cu, Pb, Zn)	Harare, Zimbabwe	Gaza and Kugara, (2018)

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