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Lichenology and geomatics for monitoring air pollution and climate change impacts

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Abstract: Lichen monitoring has become a widely used standard to evaluate air quality and is an effective early-warning system to evaluate the rate of retreat of glaciers, accumulation of metals, metalloids, polycyclic aromatic hydrocarbons and radioactivity in terrestrial ecosystems. The lack of vascular system, absence of root system and dependence to absorb water and nutrients passively from their environment make it sensitive against environmental perturbation. Lichens have long life and without organ shedding; they are able to accumulate air pollutants for many years. The sensitivity of lichen epiphytes to environmental change has resulted in their wide use as indicator for pollution monitoring and to identify forest habitat for biodiversity protection. The understanding of lichens for the microclimatic changes may be used to estimate the ecological continuity of forest and to establish network for monitoring and climate change. Lichens have numerous functional roles in forests including nutrient cycling (especially nitrogen fixation in moist forest and as component of food webs). In India, a total of nineteen lichen communities are described that may be used to indicate the status of the habitat condition, age structure of forest, type of substrates and predict the surrounding air quality. An attempt was made to utilize lichen properties to monitor air pollution and climate change impact and geomatics tools to expedite the quality of work as robust, timely, reliable and cost-effective.

Keywords: lichens, air pollution, climate change, herbarium, mapping, GPS, geomatics

1. Introduction

Lichens are a group of non-vascular plants composed of mycobiont (fungi) and Photobiont (algae) species growing in a symbiotic relationship. The fungi develop structural support to the organism, and the algae produce nutrition through photosynthesis. Lichens are an extremely diverse plant group, occupying ecological niches on varied physical and biological substrates such as soil, rocks, branches and bark of trees as well as on man-made artefacts. Lichens lack an epidermis, stomata and a waxy cutin, and consequently lack the control over gas exchange as vascular plants do. Due to its unique features, lichens are widely used in air pollution monitoring. Lichens were first recognized as organisms' sensitive to high concentrations of gaseous pollutants such as sulphur dioxide (Rose and Hawksworth, 1981).

The lichen air pollution monitors being widespread, permit a higher sampling density. In this context, lichens are recognized as the best indicator of air pollution and can be utilized as a 'tool' for monitoring different atmospheric pollutants (Haffner et al., 2001). The use of lichens in estimating the quality of the air, from different parts of the world are available since more than four decades and from that time more than 2000 published accounts on the lichen and environmental studies are available in different reputed and dedicated air quality journals worldwide (Shukla et al., 2014). Lichens being natural sampler provide good data on the environmental status of the place. Integrated monitoring programmes are clearly essential in conjunction with physiochemical measurements and geomatics techniques, where lichenologists can investigate lichen diversity as an indicator of atmospheric levels of SO_2, NO_X and O_3 parallel to the measurement of trace metals. It is recognized that a wide range of other substances like ammonia, arsenic, fluorine, alkaline dust (pesticides, fertilizers), heavy metals and radionuclides, chlorinated hydrocarbon and acid rain may also be detected and monitored using lichens. Various heavy metals such as Pb, Cd, Ni, Hg, Cu and Cr are considered to be toxic for many other living organisms, may be accumulated simultaneously in one lichen specimen which may appear to be unharmed in many cases.

The wide geographical distribution of lichens enables one to adopt sampling strategies with a relatively high density of sampling points which considering the nature of air pollution phenomenon greatly enhance the data quality. The distribution map, lichen zone mapping, indices of atmospheric purity and transplantation technique are the most common techniques categorized under active as well as passive methods to monitor environmental pollution at various part of the country. The main aim of the work is to provide some basic methods to assess air pollution and climate change studies with the aid of geomatics techniques.

2. Methodologies

2.1 Field methods

2.1.1 Floristic survey

Floristics may be defined as a compilation of species present in an area and the distribution information for those species. A complete and accurate species list is an ideal basis for understanding the flora of the area studied which provides ecological information about the unit and information necessary for determining appropriate species for biomonitoring as well as information concerning the resources of the unit. The collection and identification of lichens involve recognizing habitats, substrates and specimens in the field, and using the appropriate collection, curation, and identification procedures. Quality assurance (QA) and quality control (QC) standards must be met, and prior to the fieldwork, literature review on lichens of the study area should be done. The surveyed species needs to be geotagged using a handheld global positioning system (GPS) receiver. The statistically significant number of records spread over a wide geographic area can be used for niche modelling using bioclimatic indices and machine learning algorithms (Singh et al., 2016).

2.1.1.1 Sample collection

The collections of lichens are valuable for comparing lichen floras, community structure, and elemental concentrations with herbarium samples collected in pre pollution eras. It is important to obtain adequate amounts of tissue for analysis. The GPS should be used to record the latitude and longitude of the sample location, so that its habitat can be compared at genus or species level, moreover, an interpolated map of the pollutant concentration can be developed using geomatics techniques. Similarly, the records of lichen specimens collected in the past from a particular area and its comparison with the present diversity (revisit of the sites) can provide an assessment of important changes on plant community and ecological parameters which can be correlated with climate change.

Changes in lichens at the community or population level are used as sensitive indicators of the biological effect of pollutants. Presence/absence or dominance of a species or a group of species may provide valuable information about the alterations in the air quality of an area due to air pollution or due to microclimatic changes (Bajpai et al., 2016a). The historical data of the species also provide valuable information in the selection of indicator species for long term monitoring of an area. Common indicator lichens found growing in different areas of India is given in table 1.

2.1.1.2 Identification

Lichen identification is the most important factor in terms of environmental pollution monitoring and climate change studies. The identification of specimens starts at the time of the collection itself. During collection, we need to find out their substratum i.e. lichens growing over bark/twigs (corticolous), rock (saxicolous), mosses (mossicolous), on cloth (fabricolous), lignin (lignicolous), vehicles (vehicolous) on other lichens (lichenicolous) (refer Figure 1).

The morphological and anatomical identification of the specimen collection can be done in the laboratory using microscopes. The chemistry of lichens also plays an important role in identification of taxa. The spot test, thin layer chromatography and microcrystallography are common methods for initial identification.

Figure 1: Lichens growing over different substratum a. Natural b. man-made

Table 1: Common indicator lichens found growing in different areas of India (after Shukla et al. 2014)

Climatic zones	Bioindicator species
Tropical areas	*Dirinaria consimilis* (Stirton) Awasthi; *Rinodina sophodes; Pyxine cocoes* (Sw.) Nyl.; *Lepraria lobificans* Nyl.; *Cryptothecia sp.*
Subtropical areas	*Phaeophyscia hispidula* (Ach.) Essl.; *Pyxine subcinerea* Stirton; *Parmotrema praesorediosum* (Nyl.) Hale; *Parmelinella wallichiana* (Taylor) Elix & Hale
Temperate areas	*Cladonia praetermissa*. A. W. Archer; *Heterodermia diademata* (Tayl.) Awasthi; *Candelaria concolor* (Dicks.) Arnold; *Dermatocarpon vellereum* Zschacke, *Usnea sp.*
Alpine areas	*Rhizocarpon geographicum* (L.) DC, *Aspicilia* sp., *Xanthoria elegans* (Link) Th. Fr, *X. fallax* Arnold, *Lecanora muralis* (Schreb.) Rabenh.
Mangrove area	Species of lichen genera *Dirina, Dirinaria, Arthonia, Lecanora, Opegrapha, Rocella*
Arid area	*Phaeophyscia hispidula* (Ach.) Essl.; *Parmotrema praesorediosum* (Nyl.) Hale, *Caloplaca* sp., *Graphis* sp. *Phylliscum* sp. *Endocarpon* sp.

2.1.2 Zone mapping

The zone maps of common and sensitive lichen species are a relatively simple and inexpensive method of air quality monitoring. The method distinguishes areas with varying degrees of pollution. The studies can be in relation to point emission sources such as power plants and smelters, a general source area such as an urban area or industrial complex, automobile exhaust or as a means of producing baseline data of a previously unsurveyed site or in pre-development appraisals. The occurrence of each species can be GPS tagged and plotted on a map to provide an idea about the overall picture of the lichen distribution in the area. Such distribution map helps to determine the distribution of a species that has changed in the area, in the course of time. A sufficient number of reliable distribution data collected in the past help to assess the changes more easily.

Lichen zonation is a method used to indicate the severity of pollution with reference to distance from sources reflected by the number of species present or absent. The detailed physical investigation of epiphytic vegetation of cities or of larger areas around factories can be used to segregate the area into three, four or more major lichens zones (Herzig et al., 1989) (Figure 2).

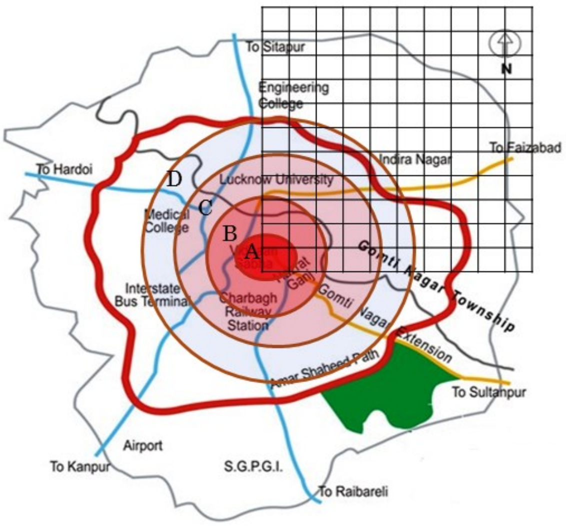

Figure 2: Lichen zone map of Lucknow city and zones categorised as a. no lichens (lichen deserts) b. presence of some calcicolous lichens (Inner struggle zone) c. Scare growth of few crustose & foliose lichens (Outer struggle zone or Transition zone) d. The luxuriant growth of Foliose, Crustose, Folicolous lichens (normal zone)

2.1.3 Quadrate

Quadrate sampling is a basic tool to study population ecology, particularly biodiversity. The passive quadrate sampling can be done in a habitat of interest and the species within those quadrates are identified and recorded. Abundances of organisms found at the study site can be calculated using the number found per quadrate and the size of the quadrate area. The quadrate is a square area of varying size marked off in the studied community for the purpose of detailed study. The quadrate may be List Quadrate (only listing the names of different species growing in the quadrat); List-Court Quadrate (records the number of individuals of each species represented in each quadrate); Chart Quadrate (record the position and areas covered by twigs, mats or tufts of grasses, mosses on the graph paper, these graphs help to compare any change in structure of community in future); Clip Quadrate (record the biomass or weight of each species, all individuals are collected (but when the weight of a particular organ, e.g., twigs or leaf are to be determined only the concerned organ is clipped and its fresh or dry weight is recorded); Nested quadrates (a series of quadrats, laid one over the other with gradually increasing size). The size of quadrates to be used in a given community is determined by constructing a species-area curve.

2.1.4 Community composition

The purpose of quantitative sampling of lichen communities for air quality and climate change assessment is the accurate and sensitive detection of changes in lichen communities through time. The composition of lichen communities is highly sensitive to climate and are strongly correlated to the climatic factors of the area. The community composition provides distinct evidence of the climate-driven effect on species diversity. According to Insarov and Schroeter (2002) the large scale monitoring systems are parts of complex systems usually aimed to study the combined effect of air pollution and climate change on forest ecosystem. The small scale monitoring involves altitude or distances from seashore aims to ascertain the relationship between climatic factors and lichen biodiversity (species diversity and community composition). Because of their sensitive physiology, changes in temperature or water availability lead to shifting in the lichen communities therefore, repeated monitoring of the lichen community indicators provides an early warning of response to climate change. Lichen community composition combined with type of forest vegetation and environmental data suggest causes for variation in the communities. The richness and abundance of species can be correlated with the climate value of the area. Biotic indexes can be developed based on lichen community data along with climate and air pollution gradients.

The lichen communities are also sensitive to landscape structure and land use context and to forest management. The forest lichen communities respond to primary climate variables such as precipitation and temperature and to geographical gradients such as elevation and latitude that integrate climate factors. Some of the lichen bioindicator communities are listed below

Some of the field procedure recommended by McCune (1992) with modification are as follows:

- The area to be sampled (i.e. lichen plot) is a circular area 36.6 m (120 ft) radius or quadrate size 1x1 m or depend upon your study objectives.
- Take a reconnaissance walk through the lichen plot, locating lichen epiphytes on woody plants, and collecting voucher samples and estimating abundances as you go.

- Collect lichen species with fruticose and foliose growth forms (i.e. macrolichens).
- Inspect all trees and shrubs 0.5 m tall within the lichen plot for lichens. Also inspect branches collected for the destructive samples (the same trees used for foliar nutrient analyses, branch and foliage visible symptoms, and tree cores) for lichens.
- Be careful to inspect the full diversity of substrates present: trunks and branches, fallen branches, hardwoods and conifers, large shrubs.
- Be careful to inspect the full range of microhabitats present: shaded and exposed, upper branches and lower branches, and trees in particular topographic positions (for example, in a draw, on an otherwise uniform slope, so long as the draw occurs within the lichen plot)
- Record relative abundances within the lichen plot. Relative abundance for each species is estimated using the following abundance code: Rare (3 individuals in area); uncommon (4-10 individuals in area); common (10 individuals in area but less than half of the boles and branches has that species present); Abundant (more than half of boles or branches have the subject species present
- How to grip doubts during fieldwork, when field worker, not full expert in lichenology for on spot identification of an organism during collections. Some procedures for the field worker are designed to put the responsibility for identification who is not properly trained members. First of all, when you in doubt, assume it is a lichen; when the growth form is in doubt, assume it is a macrolichen; when in doubt, assume that two different forms are different species. The purpose of these doubts is to encourage the field workers to make as many distinctions in the field as possible.
- The overall assessment can be summarized under 3M that is measuring (of pollutants/diversity); monitoring (periodical observations); modelling (to develop indices or models).

2.1.5 Multi-summit approach (MSA) for long term ecological monitoring

Long term ecological studies not only enhance our understanding of the relationship between vegetation and environment but are a necessity for documenting responses of global climate change. Such continued studies help to distinguish between pathways, causes and mechanisms of vegetation change (Pickett et al., 1987). MSA for permanent monitoring indicate different stages of succession and also generate hypotheses on its pace and causes. The MSA has become an essential tool for monitoring vegetation and presently, there is a renewed emphasis on establishing long term monitoring changes in mountain vegetation that are early indicators of climate change.

Mountain ranges play a significant role in influencing the regional and global climate. Further, being governed by low temperature, high-altitude regions of the world are more responsive to the changing climatic conditions and hence better indicators of the same (Grabher et al., 1994; Grace et al., 2002; Bajpai et al., 2018). The researches prove that the growth and reproduction of plant communities in mountain ranges are mainly controlled by the temperature that gives rise to steep ecological gradients and narrow ecotones and any minor change in temperature may lead to change in tree line and nival zones (Singh et al., 2018). At high altitude regions the lichens and bryophytes are abundantly growing over boulders, shrubs and some time on soil and living without any interruptions. In recent year MSAs, in Indian Himalayan states such as Jammu & Kashmir, Himachal Pradesh, Uttarkhand, Sikkim and Arunachal Pradesh was established with support of Space Applications Centre (ISRO), Ahmedabad for long term climate change assessment under Himalayan Alpine Dynamics Research Initiative (HIMADRI) programme (Singh, 2015). In this programme, permanent plots were established throughout alpine regions and lichen diversity was analyzed (Figure 3). The plot protocol determines the way in which current or future samples are taken. The permanent plots in which no destructive sampling takes place must be distinguished from temporary plots from which material is collected. Designation of sampling areas within temporary plots may be desirable so that the location of disturbance is known. Methods for marking and mapping plots must be identified with current options for establishing coordinates for study sites include topographic maps and global positioning systems.

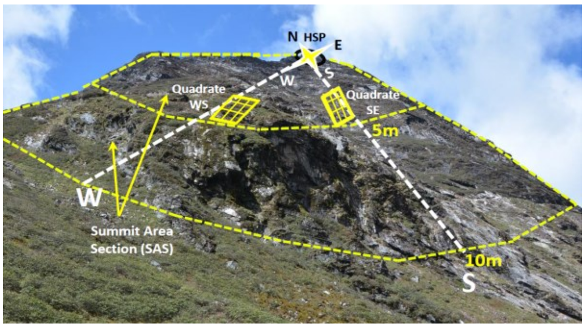

Figure. 3: Long term monitoring setup at Arunachal Pradesh under HIMADRI programme (Source: Bajpai *et al.*, 2016c)

2.1.6 Remote sensing

Remote sensing technologies can be used for long term monitoring due to its nature of revisit in the study area (Melesse et al., 2007). Several types of remotely sensed data are available, which can be used for the assessment of lichen diversity for climate change purpose. The airborne, hyperspectral, and space-borne multispectral remote sensing datasets can be employed to map their distribution patterns at various scales. Remote sensing practices help to map spatial distribution, identifying spatiotemporal changes in the distribution and analyzing the disturbance patterns among the major lichen community (Nordberg and Allard 2002).

The use of Digital Elevation Models (DEMs) and GIS (Geographic Information Systems) technologies help in analyzing the spatial patterns of lichens. The field information collected through the field plots can be visualized and correlated for a better understanding of the relationship of lichens along with its surrounding environment. Predictive modelling provides potentially suitable habitats for the major lichen community and also can be used with various climate datasets to predict the distribution pattern due to climate change. Assessment on large scale patterns of responses with broad species representation like air pollution data, diversity and distribution and community composition towards understanding current and future importance of climate change on species performance and diversity can be done. In the Indian context, few studies are available on use of geographic information systems and lichens to map air pollution (Bajpai et al 2014, Singh et al 2016). Waser et al., (2007) developed several models to predict lichen species richness on soil, rocks and trees in Swiss Pre-Alps following a gradient of land-use intensity combining remote sensing data and regression models. Though the remote sensing techniques cannot replace lichen survey altogether, however, these methods provide information that is remotely similar to field samples and which would allow to considerably reduce extensive field surveys (Cousins and Ihse, 1998).

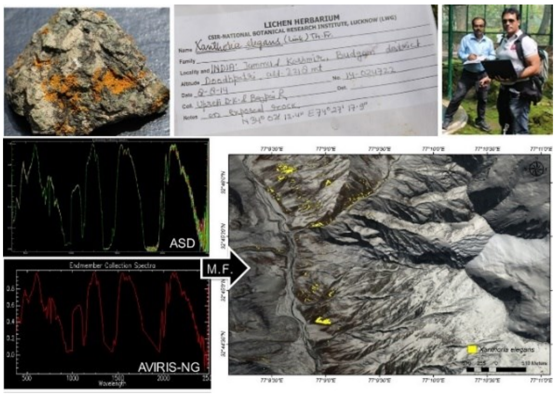

Figure 4: Match filtering technique based classification of Xanthoria elegans lichen using endmember spectra collected from the herbarium records of CSIR-NBRI, Lucknow and AVIRIS-NG data over Lahaul Taluka, Himachal Pradesh (DOA: 18/02/2016)

There is a need to develop a field method to spectrally analyze lichen species and communities that will be able to quantify species composition and cover. The comparison of community structure changes over time, and the correlation of spectral signatures with physiology or toxic element uptake in lichens are the supportive elements for the study. Because of the good development of lichen dominated communities in the Alpine region of Indian Himalaya the potential of mapping their distribution directly by matching image (narrowband) pixel spectra with the reference (hyperspectral) spectra of lichens using a matched filtering algorithm can be used (Figure 4). This is a more appropriate technique, as partial unmixing can detect the presence of a given material (in our case lichens) at a sub-pixel scale. Such techniques have been widely used in mineralogical and lithological studies and recently been applied for the mapping of lichens (Casanovas et al., 2015). Moreover, the concept of spectral species can be explored further, using hyperspectral imageries at high spatial resolution.

2.1.7 Lichenometry

Quantitative estimation of paleoclimate is fundamental for the reconstruction of past environmental and biotic change and that provides a baseline for predicting the effects of future regional and global climate change. Glaciers are recognized as one of the most sensitive indicators of climate change, advancing substantially during climate cooling and retreating during climate warming. Lichenometric technique has been proved useful in dating moraine ridges on recent glacier forelands in alpine regions. Since once attached to the substratum, the position of lichen thallus during the entire life span does not change; therefore, the age of lichen is an alternate for the minimum exposure time of a substrate to the abiotic factors.

The method of lichenometry was originally developed and used by Beschel (1973), and since then it has been widely applied in dating recently exposed rocky substrates in the world (Armstrong, 2005). In the Indian context, Joshi and Upreti (2010); Bajpai et al., (2016b) recently studied lichenometry, to study the glacier retreat in some major Indian Himalayan Glaciers (Figure 5). Based on the methods applied, lichenonometry may be direct and indirect. The direct lichenometry deals with observations on individual lichens at repeated intervals overtime where, indirect lichenometry is a correlation established between the size of the thallus and the surface age, based on lichens growth measurements from surface of known age e.g: Graves's stones, stone wall/ manmade artefacts etc.

Figure 5: Lichenometry with lichen a. *Xanthoria elegans* b. *Rhizocarpon geographicum*

The percentage of lichen cover is also used as a growth index. Innes (1988), provided a list of micro-and macrolichens that can be used in lichenometric studies. Mainly the species having more or less typical centrifugal pattern of growth are recommended for dating purpose. The most often used species in lichenometric studies is *Rhizocarpon geographicum*, because of its bright colour easy to recognized in field, circular growth and worldwide distribution in alpine areas. In alpine environments, *R. geographicum* attains slow growth rates of 0.2 mm/year (Hansen, 2008) and lives up to a considerable age. Morphologically, this lichen comprises discrete areolae that contain algal cells of *Trebouxia*, located on a fungal medulla, which is attached to the substratum and extends into a black algal-free marginal zone around the thallus called hypothallus. Primary areolae near the edge of the hypothallus may develop from free-living algal cells on the substratum that are trapped by the hypothallus whereas secondary areoles may develop from zoospores produced within the thallus, thus ultimately resulting in the radial growth of *Rhizocarpon*.

Due to their slow growth rate and uniform growth size, lichens help in dating the exposure time of the sequences of the rock-forming glacier moraines due to retreat of the glacier thus providing the approximate time of glacier retreat. The lichenometry appears to be superior to many other techniques; it attempts to date glacial deposits in the most accurate way. The technique is easy, cheap and can be applicable to date surfaces less than 500-years-old where radiocarbon dating is least efficient.

2.1.8 Lichen biological soil crust (BSC) assessment

The biological soil crusts are a complex community of primaeval organisms that flourish worldwide in harsh, arid, semi-arid and cold desert regions. The bare ground is not an abiotic ground, truly, the soil surface in areas free of higher vegetation is often covered by a casing made up of a community of cryptogams, like lichens, bryophytes cyanobacteria and algae forming a complex structure known as biological soil crusts (BSCs). They are also the first colonizers of disturbed soils and have major influences on the soil properties through stabilization, erosion limitation, and facilitation of colonization by higher plants. The BSCs plays a crucial role in stabilizing bare soil, stemming erosion from wind and rain, trapping moisture, fixing carbon and nitrogen in the soil, and providing shelter for the seeds of vascular plants (Lehnert et al. 2018).

The spectral characteristics of BSCs or their species components were investigated by a certain research study (review Ager et. al. 1987, Chongfeng et al. 2013). Chen et. al. (2005) recognized that mapping BSCs by relying on remote sensing images was feasible, and they effectively-identified lichen crust in the Namibia desert using Landsat Thematic Mapper 3 data (TM bands 4, 5,and 7) and compared both true colour air-photos and hyperspectral imagery at around 10 m spatial resolution to identify BSCs, and successfully assimilated BSCs patterns. Further to detect cyanolichens BSCs, the crust index (CI) was established by Karnieli and Tsoar (1995) using aerial photograph and Landsat TM data. After CI the biological soil crust index (BSCI) was proposed to identify lichen-dominated BSCs which allowed more accurate separation of BSCs from the background (Chen et al. (2005). The composition and stage of BSCs significantly affect its spectrum and found that BSC index can serve as a good indicator during the early years after a disturbance when relatively few microphytes are established in the soil surface (Zaady et al. 2007). However, despite the important information attained from mapping indices and reflectance spectroscopy, specifically, the ability to spectrally monitor BSCs functional response to climatic change is increasingly important, as these organisms will experience significant shifts in both function and composition, resulting in large scale changes to soil stability, soil fertility, and biogeochemical cycling in future climate. Further to understand the roles of BSCs in carbon and nitrogen fixation and monitor their distribution patterns in the region by remote sensing technology, and to evaluate the roles of carbon and nitrogen fixation in the whole ecological system may definitely open a new path for further researches in the country.

2.2 Active methods

2.2.1 Transplantation

The lichen transplants are used to assess air quality in an area where lichens are absent or sparse. Richardson (1992) reviews the use of transplants to assess air quality in the urban environment and to monitor contaminants in air and water. The healthy lichens are transferred from an area where they occur naturally to test area. The changes in physiology, morphology and element accumulation provide data that can be correlated with extend and impact of pollution in an area. Most of the transplantation experiments have been performed with corticolous lichen and particularly with foliose lichen because they are generally more tolerant of gaseous or airborne pollutants. The twigs having lichens or lichen bearing bark are fixed in 20x20 cm cardboard with any fixative (Araldite), are placed or hanged on trees and if trees are absent, the electric pole or other objects are used for hanging the board. The observations on morphological, anatomical changes and the health status of lichens together with physiological changes provide important data related to the degree of pollution prevailing in the area.

2.2.2 Open top chambers (OTC)

Open-top chambers used in the field duplicate the ambient environment as closely as possible while allowing control of pollutant concentration within the chambers. Appropriate experimental designs for using open-top chamber systems include pollutant-free and ambient chambers as well as non-chambered control plots to estimate any chamber effects. The open-top chambers are the best currently available experimental technique for developing functional relationships useful for predictive purposes (Shriner et al., 1990).

Figure 6: Open Top Chamber (OTC)

The OTCs are made-up of polyvinyl chloride (PVC) plastic film enclosed by hexagonal frame constructed by aluminium (Figure 6). The OTC approach for long-term climate change monitoring with lichens in Indian Himalayan region is also initiated recently. Due to the unhurried growing rate and sensitive nature of lichens can be utilized as an indicator of climatic changes, on which they are growing as well as kept in OTC for continuous observations. Other parameters like lichen diameter, qualitative and quantitative estimation of secondary metabolites in high altitude lichens may perform in OTC and their comparison with control may also lead to correlate with rising temperature as well as against high UV radiations.

2.2.3 Dust load

Dust may also be secondary stress like drought, insects and pathogens. Effects of dust on natural communities may alter the competitive balance between species in a community. The dust interception and its accumulation in different plant species not only depends upon the sources and amount of pollutants in the environment but also depends on morphological characters of plants too. The most extensive evidence for the effects of dust on plant communities has come from studies on epiphytic lichens. Gilbert (1976) studied the effect of dust on lichens and described the effects of limestone on epiphytic lichen communities form distinctive zones around sources of sulphur dioxide pollution. He found zones surrounding a lime dust source and resulted that heavily dusted trees had few lichens, but this was followed by a zone containing lichens that are normally saxicolous i.e. *Caloplaca decipiens*, *Catillaria chalybeia*, *Lecanora Calcarea*, *L. campestris, Lecidella scabra* and some species of *Bacidia* and *Micarea*. In 1980 Kaupii stated that fertilizer factories dust also affect lichens and showed the application of fertilizer dust to *Hypogymnia physodes* and *Cladonia Stellaris* caused a temporary increase in net photosynthesis and an increase in the number of algal cells in the thalli. The measurement of dust is an important parameter to observe the qualitative as well as quantitative particulate matter in the area.

2.2.4 Accumulation assessment

The various heavy metals, metalloids, pesticides, persistent organic pollutants (POPs, radionucliotides are widely accumulated in lichens through active as well as passive methods. These pollutants accumulated in lichen thallus through absorption as well as adsorption beyond their physiological needs. In Indian context the metal accumulation data on different lichens species growing in and around major Indian cities such as Pune, Bengaluru, Lucknow, Mahabaleshwar, Darjeeling, Dehradun, Pauri and Srinagar are available (Shukla et al., 2014).

Apart from metals, metalloids (inorganic) and organic pollutants lichens have an ability to accumulate the radioactive substances like Cesium, Thorium, Cobalt, Plutonium, Radium, Radon, Uranium and Strontium in their thalli in huge amount. The analysis of these radionuclides in the lichen thallus can be done following the procedure of US EPA (1986) and modified by Kircher and Daillant (2002). The radionuclides in lichen samples can be analyzed through gamma-spectrometerically using a large volume reversed electrode high purity germanium detector (Canberra, 55% relative efficiency). Unlike conventional coaxial detectors, this detector has a usable energy range which extends down to 5keV and thus enables to determine ^{210}Pb by measuring its 46.5 keV gamma line.

3. Conclusion

It is assumed that apart from a number of complex and costly techniques available for monitoring air pollution and climate change, the present methods help to familiarize some easy and low cost, practices which would not only reduce considerably the wide-field survey but also help to obtain simple data for developing pollution and climate change models using Geomatics techniques. The methods described in the present communication are ample contribution to the ongoing discussion of global as well as regional pollution and, climate change methodologies assessment in the near future.

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