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Review Paper

Lichen as a Bio-Indicator Tool for Assessment of Climate and Air Pollution Vulnerability: Review

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Abstract

The study of climate change and air pollution is very important in present circumstances throughout the world. Several methods including biological methods are being used for monitoring of environment to assess the climate and air pollution vulnerability. Among the biological methods the use of lichens as a bio-indicator has been very popular for such studies. Lichen, being a natural indicator of climate change and air pollution effects, is very useful for these studies particularly in mountain region. Therefore, a review of the work done in different parts of the world to study the climate change, air pollution and heavy metals using lichen as natural indicator has been presented and the gap areas have been identified for further studies in connection to climate change and air pollution vulnerability using lichen as an indicator.

Keywords: Lichen, bio-indicator, climate change, air pollution, heavy metal, biomonitor.

Introduction

Lichen is a Greek word which means the superficial growth on the bark of olive trees. Lichen is a combination of an alga and a fungus which live together in symbiotic association. During association, the algal component, phycobiont or photobiont and fungus component, mycobiont lose their original identity and the composite organism is called lichen which both morphologically and physiologically behaves as one entity. The three main types of growth forms of lichen are known as Crustose, Foliose and Fruticose. Some intermediate growth forms are Leprose, Placodioid, Squamulose and Dimorphic. Lichens can grow in different climatic conditions and on different substrates. The lichens which grow on other plants are called as epiphytic**.** The lichens can also grow on rocks under the water and on old monuments or buildings. The important parameters required for the growth and abundance of lichens are adequate amount of moisture, light and altitude, unpolluted air and undisturbed, perennial substratum[1]. The different habitats of lichens and associated names of these lichens are listed in table-1.

The lichens form a major component of Indian biodiversity with 2360 species[2]. Based on the 10 dominant families, 10 largest genera and other interesting features of lichen communities Singh and Sinha divided India in to eight lichen ogeographic regions. The eastern Himalaya contains the maximum number of 1141 species and is followed by Western Ghats and western Himalaya with 1136 and 781 species respectively[3].

United Nations Framework Convention on Climate Change (UNFCCC) defines the climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"[4]. As per World Health Organisation "Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide. Outdoor and indoor air pollution cause respiratory and other diseases, which can be fatal" .

Table-1
Habitats and associated names of lichens

Habitat	Lichen
Tree trunk and bark	Corticolous
Twig	Ramicolous
Evergreen leaves	Foliicolous (epiphyllous)
Moss	Muscicolous
Dead wood	Legnicolous
Rocks and boulders	Saxicolous (epilithic)
Soil	Terricolous

Climate change and air pollution are two very important fields to study as they impact not only human beings but also affect flora and fauna throughout the world[5-11]. The researchers have found that animal and plant life is changing due to climate change. It has been reported that two third of butterfly species under study in Europe have shifted their ranges towards north by approximately up to 150 miles[12-13], many species of birds in Britain have moved north by an average of 18.9 km.[14] and plants are flowering eight days earlier on average than they did in the beginning of 20th century (from 1900 to 1920) at Boston's Arnold Arboretum[15]. The climate change has been found to be one of the major factors for declining population of reptiles[16].

The studies on increasing impacts of climate change on plants and ecosystem show that changes in the breeding, flowering, nesting and abundance of biota are significant and these changes follow the expected effects of climate change derived from different models[17-20].

The aim of the present study is to put the work done in various parts of the world on growth and regeneration of lichens under the influence of different climatic, anthropogenic, environmental, edaphic, commercial and political factors. The study also tries to collect the similar work done in India.

Monitoring of Climate Change and Air Pollution

Physical Parameter: The physical parameters such as temperature and rainfall are primary parameters for monitoring the climate change. Temperature functions as an indicator or final product of ecological processes associated with energy budget and its dynamics, such as received solar radiation, evapo transpiration, soil heat flux, and convection[21-24]. Various studies in different parts of world show that the mean temperature of earth and extreme rainfall events has increased considerably in recent time[25-43].

Chemical Parameter: Chemical parameters for monitoring of air pollution include determination of heavy metals such as aluminium (Al), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), iron (Fe), magnesium (Mg), manganese (Mn), zinc (Zn), lead (Pb) and mercury (Hg) etc. and pollutant gases like NOx, SOx etc. Monitoring of heavy metals using plant species and air quality at various places have been studied by researchers[9-11,44-52].

Biological Parameter: Many researchers have measured the environment quality through biological parameters using plants (lichen, moss etc.), animals (fish, spider, larvae of firefly and dragonfly etc.) and microorganisms (virus, bacteria etc.). These are known as indicators of climate change and environmental pollution. It has been observed that the changes in life cycle of plants and animals over time are highly influenced by changes in climate and air pollution in the area. These changes may indicate the response of plants and animals to climate changed world. The effect of climate change on plant phenological cycles is enormous. It may alter the growth, flowering times, production and viability of seed, number of reproductive events per growing season which may result in diversity, abundance and range, morphology, physiology, species composition, mutualisms and accumulation of pollutant etc.[53-57]. The possible feedback effects of such changes in ecological systems can finally change species composition, mutualisms, abundance and range of flora and fauna of that region[58-62].

Lichen as Bio-Indicators: Indicators are required to monitor ecological conditions and used for early warning. Therefore a relevant, sensitive and measurable indicator is required. Lichens have been found to be very much sensitive to environmental parameters like temperature, humidity, wind and air pollutants because they don't have any vascular system and thus absorb water and nutrients passively from their surrounding environment. Lichen species composition and changes in composition is a very powerful tool to get information about changes in climate, air quality and biological processes. The lichens respond to the environmental changes by reflecting changes in their diversity, abundance, morphology, physiology, accumulation of pollutants etc. The main threats such as habitat degradation and loss, habitat fragmentation, overexploitation, air pollution, and climate change which affect biodiversity in general are also applicable for lichens[63]. Lichens are also measurable. Due to these unique features, lichens may be used as relevant indicators for ecosystem productivity and biodiversity. Biological monitoring using lichen as indicator may be considered a very effective tool for early warning system to monitor and detect climate change and air pollution[64]. Loss of the lichen diversity[65] and change in their community due to air pollution, urbanization and changed climate has been witnessed in Bangalore[66] and Kolkata cities[67]. The unregulated harvesting of lichens has become a serious hazard to biodiversity in Himalayas and Western Ghats[68].

Lichens are very important for nutrient cycling[69]. Lichens absorb air and rain-borne nutrients for their use and thus contribute in ecosystems cycling. Researchers have also found that the aerosol and water-borne nutrients would not be intercepted by lichens or other epiphytes and would mainly leached away[70-74]. Some lichen species help in fixing nitrogen through a symbiotic relationship with cyanobacteria which contribute good amount of nitrogen to forest ecosystems[74-77].

Heavy metal deposition: Lichens are very sensitive to pollutants and therefore by measuring changes in community or population of lichens, we can estimate the biological effects of pollutants. Lichens can also be used as accumulative monitors of persistent pollutants by determining the content of trace element within them[44-46,50,78]. The studies from different parts of the world reveals that lichens are being used to monitor metal deposition both as active and passive monitors[79,80]. In case of active monitoring lichens are transplanted in the study sites whereas for passive monitoring lichen live in situ. The lichen thallus accumulates heavy metals by selectively bounding them to the cell wall by an ion exchange mechanism and the cell stake some of the metals. In the cells, these metals are metabolized and eliminated[81].

Lichens accumulate nutrients from their environment using biological processes. They adsorb metal ions through ion exchange process and trap fine particles of rock, soil or any other heavy metal pollutants within their body. This feature of lichens can be effectively used for monitoring the pollution parameters at the study sites. The extent and type of pollutant emissions around industrial installations can be determined by utilizing the chemical analysis of lichen[82]. As monitors of metal deposition, epiphytic lichens have been efficiently used in different countries[83-85]. *Hypogymnia physodes* is being considered to very good bio indicators in the study of bioaccumulation of trace elements due to its high tolerance capacities[85]. *Pyxine cocoes*, a foliose type of lichen, has been proved to be an excellent accumulator of different metals because the metals keep on accumulating in sufficient amounts in this lichen[86]. Shukla et al. observed the accumulation of Polycyclic Aromatic hydrocarbons in the lichens of Garhwal Himalaya[87]. Studies of Saxena et al. showed that crustose lichen *Arthopyrenia nidulans* and foliose lichen *Phaeophyscia orbicularis* had high capacity to accumulate heavy metals[88]. Krishna et al. found high amount of Mercury in lichens near a thermometer factory in Kodaikanal[89]. The lichens which grow on substrate having high arsenic contents also have higher ranges of arsenic. Higher concentration of arsenic was found in lichens growing on site having mining activities[90].

The study of Bajpai et al. in Mandav city in central India shows that although most of the metals were absent or present in negligible amount in substrates, yet the thallus of lichens had higher concentration of metals such as Cd, Cr, Ni and Zn. Thus it is evident that the accumulated metals were air borne[91]. The metal accumulation was highest in foliose lichens followed by crustose and squamulose lichens. Maximum concentration of Zn, Ni, Cd and Cr were detected in lichen samples collected from areas adjacent to road while maximum quantity of Fe, Cu and Al were found in lichens samples collected from city centre site. The lowest amount of all the metals was reported in sites which were far from city. Rani et al. estimated nine heavy metals in lichen samples from 12 different sites of Dehradun city by periodic monitoring[92].

Gaseous air pollution

To measure the impact of threats like air pollution and climate change to maintaining ecological health, a number of studies have used lichen communities for long-term monitoring in many parts of the world. In spite of a number of initiatives are being taken throughout the world to reduce airborne pollutants, air quality is still a big problem which continue to be growing with time. It has been reported by Environment Canada that increase in air pollution sources has negated the efforts made in recent years to counter it[93]. As per the recent modelling studies on effect of acid rain impact on ecosystem show that even after 2010 emission targets are reached, approximately twenty five percent of lakes in eastern Canada will be chemically polluted. Cox et al. have reported that high amounts of heavy metals are being found in ecosystems of Nova Scotia due to pollution[94].

Lichens are being used as biomonitors of air pollution[95]. The use of lichens as early warning indicators of air pollution, specially acidifying or fertilizing sulphur and nitrogen-based pollutants, has been reported by various researchers[96-98]. Gombert et al. developed a traffic index with NO_X and NH_3 for an urban area using correlation between nitrogen concentration of epiphytic lichens and the traffic density in the area[97]. Air quality monitoring studies have been carried out in various parts of world such as US, Netherlands and Switzerland through permanent monitoring programs using lichens. Lichens are sensitive to air quality because they absorb airborne nutrients and water but they don't have cuticles which work like protective structures in vascular plants. Although trees and other vascular plants are also affected by pollution but their response to its impacts has been much slower than lichens[98].

Hawksworth and Rose reported that sulphur dioxide (SO_2) was the main factor which affects the distribution of epiphytic lichens in urban and industrial areas and developed a ten-point scale to qualitatively estimate SO_2 by studying the lichens growing on trees[99]. Pitcairn et al. found a positive relationship between the nitrogen and sulphur content of bryophytes and nitrogen deposition[100]. SO_2 concentrations in most industrialized countries decreased after implementation of new policies on emission control[101,102]. Although lichens have recolonized at many urban places in different parts of the world[103-106], the decline in lichen abundance and spatial diversity around urban and industrial areas[107,108] suggests that environmental pollution is still the main factor in their growth. Nitrogen from traffic emissions coupled with unusual climatic conditions plays a major role in influencing lichen growth and composition[109]. The use of lichens as biological monitors of sulphur dioxide pollution over the past 150 years is reviewed by Seaward[110]. Van Dobben et al. found that atmospheric SO_2 and NO_2 were the most important factors for determining lichen biodiversity as almost all species were sensitive to these compounds[111]. There is complex relationship among the variables involved in biomonitoring[112] and hence it is very difficult to develop a model especially for high climatic variability and sharp environmental gradients[113-115].

Giordani carried out a case study from Genova province, Italy and found that the diversity of epithetic lichens had very high correlation with mean annual rainfall and temperature and air pollutants. The study also reported that SO_2 pollution was still the main constraint in urban areas[116]. As harvesting and forest fires had a predominant effect in forest areas, Giordani suggested that more defined sampling protocol should be developed to estimate atmospheric pollution in such type of ecosystems.

The sensitivity of lichen species to a range of concentrations of air pollutants have been studied by many researchers[101,111,117-122]. Under conditions of decreasing pollution, indicator lichen species with a known response to pollutant concentrations may be used[101]. Jeron et al. could not establish any relationship between Hypogymnia element concentrations and foliose epiphytic lichen cover in their study area of Slovenian forests[123].Insarov has developed a monitoring scheme using epiphytic lichens over the last decades for several protected areas and regions in Russia and adjacent countries influenced by background air pollution and climate change to detect trends in epiphytic lichen status[124].

Global warming and Climate change

Lichens have been used for climate studies in US and Europe[96,125]. It has been observed that the distributions of some species of lichen depend on moisture and temperature gradients of the region. Climate change effects have been found by long term monitoring of lichens. Many of the lichen species have capability of shifting their habitat, as shown by arrival of some sub-tropical species in a temperate area in recent time[125]. Pisani et al. analysed the content of photosynthetic pigments, chlorophyll degradation and integrity of cell membranes to investigate the effect of high temperature on epiphytic lichens[126].

Rai et al. used multivariate approach in his study for validation of lichen as an efficient bio indicator of changing planets which are now used extensively in interpreting effect of global warming, pollution, change in land use pattern and various other anthropogenic pressures on habitats[127]. Climate warming studies in alpine habitats of Himalaya using lichen based passive temperature enhancing systems was done by Rai et al.[128]. Insarov et al. constructed a trend detection index (TDI) to monitor climate change by measuring epilithic lichens along transects on flat calcareous rocks[129].

Ellis et al. used bioclimatic envelope method for predicting the response of lichen species to climate change scenarios in Britain[130,131]. The projections give broad trends in the response of species placed into contrasting biogeographic groups, and indicate that the spatial distribution of the British lichen flora may significantly change over time. Ellis et al. analysed climate, pollution and landscape-scale habitat structure to study the relative importance of climate compared to other two parameters for controlling species richness and composition. The results describe that these relationships change is dependent on the regional context and the relationship among multiple correlated variables[132,133].

Crabtree et al. found the impact of projected temperature change on species in ecosystem of high Scottish mountains. They used the species interaction combined with wind-speed as an environmental variable[134] to derive that effect of temperature on vegetation decreases with increase in wind speed. The study showed that species of remote arctic and alpine habitats are the most threatened by climate change. As the wind speed is very difficult parameter to be predicted for future, it introduces uncertainty in the climate response of British mountain vegetation. Ellis integrated the parameters of hazard, exposure, and vulnerability within a risk-based social-science to review the biodiversity response to climate change using lichen. They found that climate change impacts might be negated by increasing the long-term continuity of woodlands through habitat protection[135].

Aptroot studied the habitats of vulnerable lichens particularly in the areas of mountain tops in the tropics which are the most likely place for possible extinction of lichens as a result of global warming and discussed the predicted, observed and uncertain effects related to lichen and climate change together[136]. As per his studies, lichens are unequivocally responding to global change. The study by Aptroot and van Herk suggests that many terricolous lichen species are declining while epiphytic lichen species are increasing due to global warming in Western Europe[137]. The response of epiphytic lichens is considerably much faster in formerly highly polluted, generally built-up or open rural areas, as compared to forested areas.

Many lichen species are found to be very much dependent on climate and influenced by small fluctuations in climatic parameters. The distributions of lichen have been highly influenced by climate change[138]. Under long-term biological monitoring programmes, van Herk et al. monitored the lichen distribution in the Netherlands for five-year intervals since 1979to detect the influence of global warming on these organisms and reported major changes in epiphyte distribution independent of pollution[125]. The study suggests that there is significant increase in Warm-temperate lichen species while the species of cold environments have either decreased or disappeared. The statistical analysis found that climate change is possibly the main factor responsible for these patterns in lichen community.

Climate change at high latitudes is expected to be greatest and fastest and more rapid at high latitudes[139], where lichens and bryophytes are greater contributors to biodiversity than vascular plants[140]. Song et al. transplanted epiphyte species over 2 years and stimulated climate change in a montane moist evergreen broad leaved forest in southwest China. They found that even slight changes in climate have shown the significant reduced growth rate and adverse effects on the health of these transplanted epiphytes[141]. In addition, they showed very rapid response to changes in availability of water than terrestrial trees. Their study reveals that *Nephromopsis pallescens*, non-vascular lichen, could be taken as a climate change indicator as it is found to be highly sensitive to changes in moisture and temperature.

A case study on the Chorabari glacier, Garhwal Himalaya, India to observe Climate change and its impact on the Himalayan glaciers based on the dating of lichens has been done by Chaujar[142]. Pearson and Lawrence found that lichens in Northwestern Minnesota showed characteristic patterns of distribution, correlated with height above ground and thus may be used as microclimatic indicators[143]. Buschbom and Kappen studied the role of microclimate for the lichen vegetation pattern on rock surfaces in the subarctic[144]. Anstett measured the extent of lichen coverage on rock faces exposed to high and low levels of wind and light in the White Mountains of California to find the effect of wind and light exposure on the extent of lichen coverage in an alpine environment[145].

Giordani et al. tried to quantify the relationship between distribution of epiphytic lichen and macroclimatic parameters in a borderline area of Liguria, NW Italy. They evaluated the role of epiphytic lichens as bioclimatic indicators for prediction of lichen distribution and reported that abundance of the lichen species in the study sites was related to yearly average temperature and rainfall because 59 species showed highly significant relationship with these macroclimatic variables[107]. They used cluster analysis to select four groups related to warm-humid, cold-humid, mesothermic-humid and warm-dry climatic niches and found that distributional pattern of the groups in the survey is in a good correspondence with the bioclimatic units of Liguria region reported by Nimis[146]. The result of the study of Giordani et al. suggests that a large number of epiphytic lichen species in the study area may be considered efficient bioclimatic indicator which maybe effectively used to monitor climatic changes, in a long-term perspective. Gupta et al. concluded that macro-scale environmental variables such as altitude, relative humidity and temperature have influence on diversity and distribution pattern of lichens in Badrinath valley of Western Himalaya[147].

Table-2 gives an idea for the work done in the past i.e. before year 1991, from 1991 to 2000, 2000 to 2010 and 2011 to 2015on climate change, heavy metals, air pollutions and lichens by the researchers and reviewed in the paper.

Table-2
The chronological distribution of reviewed work

Topic related to lichen and climate/pollution	Before 1991	1991-2000	2001-2010	2011-2015
Global Warming / Climate change	27,31	4,19,21,28-30,32,33, 53, 54,129	22-24,16,34-41,63,77,105,124, 128,130-133, 136,137,139, 142,148,149	5-7,25,42,43, 135, 141
Effect of climate change / pollution on animal and plant life	103	12-14,19,20,61,104	15,17,18	8,9,11,16,47, 48
Air pollution / Heavy metal estimation	98,99	64,96,100,117,119,120	63,80,93,95,97,106,107,116, 118, 121-124	9-11,49,51,52
Lichen to monitor Heavy metal Deposition / accumulation	46,81	83-85	44,45,79,80,87-91,122	50,86,92
Loss of lichen diversity and change in their community due to air pollution, habitat degradation and loss, habitat fragmentation, over exploitation, urbanization and changed climate	103	3,19,104,140	63,65-68,105-109,113,114, 116,125,138	2
Role of Lichen in nutrient cycling and Nitrogen fixing	70-72,75,76	69,73,74	77,97	-
Lichen as indicators to estimate the biological effects of pollutants	-	110	78,82,101,102,111-116,123	127
Lichens as microclimatic / Bioclimatic indicator	143	53,61,62,144	55-60,126,134,145-147	-

Conclusion

The reviewed literature shows that lichens are very useful indicators for long term monitoring of climate change and air pollution and their vulnerability as they are not only very much sensitive to climate change and air pollution but also measurable and thus relevant for such studies. Their response to any change in climate or pollution is much faster than any other biota. So far, the changes are found to be as expected during long term monitoring[125] but comparatively few researchers have taken the lichens studies in connection with global warming[148].Lichens were successfully used to monitor global warming at various places in the world[96,125,149]. Lichens are important components of ecosystems. Although the abundance and diversity of lichen are high in spite of the unfavourable environmental conditions, yet no significant study on lichens has, so far, been reported to known the favourable microclimates for lichen growth[145].

Lichen has been used as natural indicator of climate change and air quality monitoring worldwide including US, Britain, Canada, Netherlands, Switzerland, Italy and Israel etc. but very few such studies have been done in India.

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