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IMPACT ASSESSMENT OF ANTHROPOGENIC ACTIVITIES ON AIR QUALITY OF ULAANBAATAR, MONGOLIA USING LICHEN AS THE BIOINDICATOR

Tsend-Ayush ERDENEJARGAL[1], Enkhtuya OCHIRBAT[2,*], Hosam E.A.F. BAYOUMI HAMUDA[1]

[1]Rejtő Sándor Faculty of Light Industry and Environmental Engineering, Óbuda University, Budapest H-1034, Hungary, bayoumi.hosam@uni-obuda.hu
[2]Laboratory of Flora and Plant systematics, Botanical Garden and Research Institute, Mongolian Academy of Sciences, Ulaanbaatar-13330, Mongolia

Abstract: *Lichen is a composite organism that arises from green algae or cyanobacterium (phycobiont) and fungal partner belongs to the Ascomycota and Basidiomycota (mycobiont), living together in symbiotic relationship. The interaction between lichens and air pollution has been used as a means of monitoring air quality since 1859. The most important pollutant was sulphur dioxide produced by coal burning industry and power stations. City of Ulaanbaatar, the capital of Mongolia was initially designed for a half million residents. Due to intense rural-to-urban migration after transition to market driven economy, the population of the capital is nearly tripled, which resulted in huge area of informal settlements and elevated number of vehicles. Tents and small buildings in above settlements heated by conventional stoves by burning coal and wood, while the most vehicles on the road are imported second-hand cars. During last two decades, air quality of capital city Ulaanbaatar is considered as an emerging issue and above two are primary sources of outdoor air pollution. The most abundant air pollutants are nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO) which have disastrous effects on health when inhaled over prolonged periods of time. Due to the quantities of these pollutants would be far more abundant and thus cause the catastrophic effects to the air quality that is seen in Ulaanbaatar. Various techniques have been developed to monitor air quality, including biomonitoring using lichens. In this study, we monitored types of epiphytic lichens covering sensitive to air pollution fruticose type and relatively tolerant foliose type of lichens. Unlike air quality index, lichens clearly show negative impact of poor air quality on surrounding ecosystems. We examined lichens on Larix sibirica, the most abundant coniferous tree of the area. Both foliose and fruticose types of lichens are abundant in Larix sibirica dominated forests located to the northern areas of Ulaanbaatar. It indicates the area is free of pollution. In contrary, fruticose type lichens, especially representatives from the genera Usnea, Cladonia and Vulpicidia are absent in coniferous forest to the southern areas of Ulaanbaatar. These results clearly show downwind ecosystems have been badly affected by poor quality air of the capital. Additionally, there is none of those bark dwelling lichens are observed on the three along the crowded roads, parks and residential areas which indicates the extreme pollution of the air. Finally, biomonitoring using lichen as the bioindicator is discussed, and future recommendation is provided in the end of the study.*

Keywords: *Anthropogenic activities, air quality of Ulaanbaatar, Mongolia, lichens, bioindicator*

INTRODUCTION

Lichens are mutualistic associations of a fungus and an algae or cyanobacterium. In nature, they occur on rocks, bare grounds, and trees, the latter known as epiphytic lichens. Due to their dependence on airborne nutrients, lichens are very sensitive to air pollution especially to sulfur dioxide. They do not bear defensive tissue, therefore quickly absorb, and accumulate sulfur dioxide in their tissue, which subsequently leads to a damage of chlorophyll in phycobiont algae so that photosynthesis is inhibited. Because of this sensitive characteristic, lichens are widely used as environmental indicators or bio-indicators. Depending on their degree of tolerance, some species may present with certain concentration of pollutants, while all species may vanish with extremely poor air quality. On this ground, lichens provide a relevant, sensitive, and measurable indicator for long-term monitoring (Das *et al*., 2013; Giordani, 2007).

One of the places where lichens could be used as bio-indicator is city of Ulaanbaatar, the capital of Mongolia. The city is characterized by its high elevation (1350 meters above sea level), low precipitation (200-300 mm), and its location in a basin (Hauck, 2008). The city was initially designed for a half million residents. However, due to 1990s intense rural-to-urban migration, population of the capital was far more exceeded than its infrastructure capacity and ended up with informal settlements or huge ger areas (Figure 1).

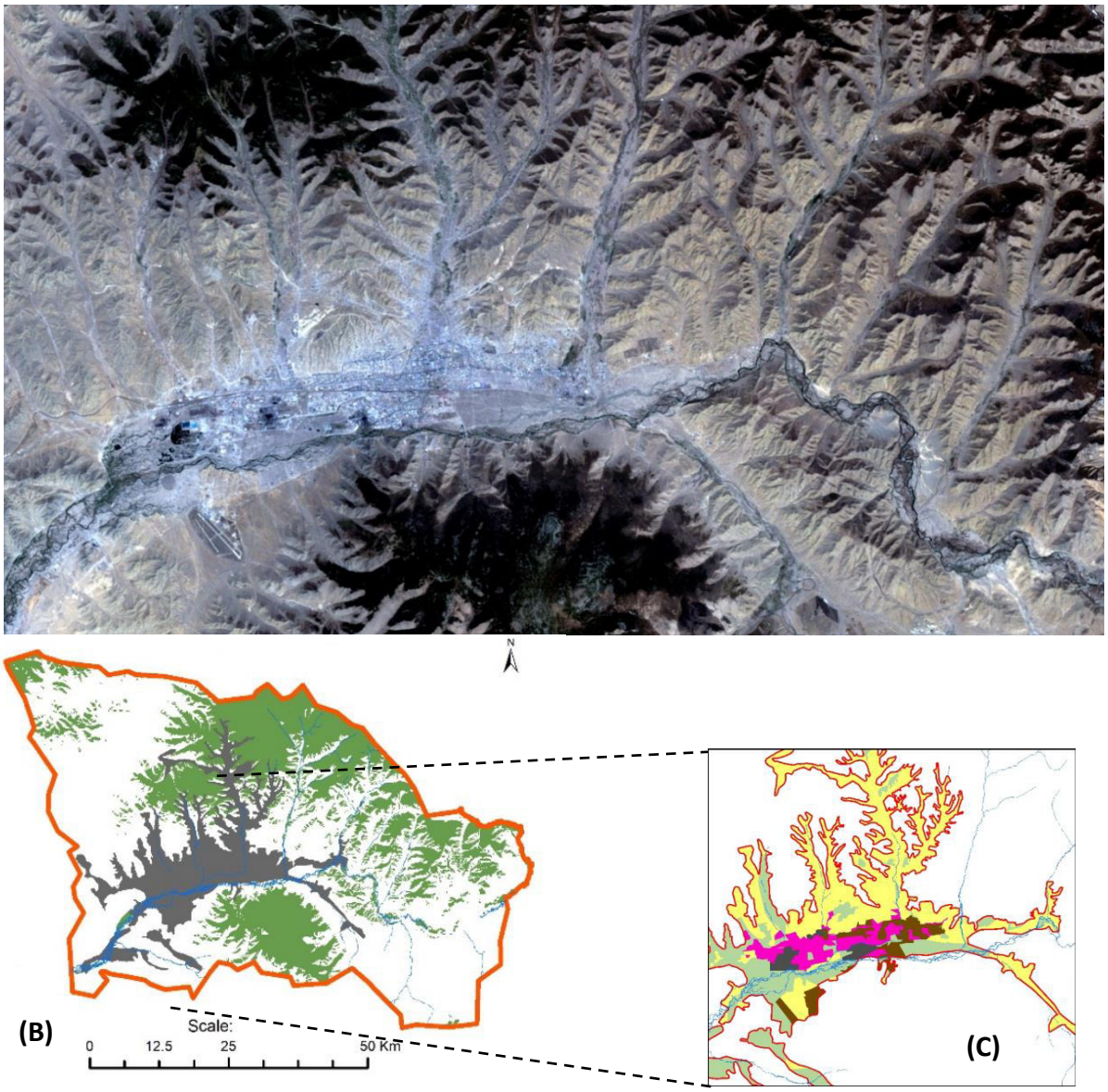


Figure (1): Map of the city of Ulaanbaatar

(A) Landsat image (https://landsat.visibleearth.nasa.gov); **(B)** Settlement areas of the city, where grey - settlement areas, green –forest areas, and blue – rivers; **(C)** Land use map as of 2010, where yellow – ger areas (Myagmartseren et al., 2018)

Since Ulaanbaatar is the coldest capital in the world with annual mean temperature of minus 3.7ºC (Hilbig et al., 2004), the major cause (c.a. 80%) of air pollution comes from coal burning stoves which are the sole way to heat ger homes under sub-zero temperatures. There are 130.5 thousand families in ger areas burn roughly 525 thousand metric tonnes of coals, 290 thousand cubic metres of firewood, and other combustible materials each year (http://agaar.mn/static/stove-distribution). As a result, concentrations of the major pollutants far outreached the guideline values provided by World Health Organization (WHO). For example, on the coldest days of the year, daily average of $PM_{2.5}$ level reaches 687μg/m^3, which is 27 times higher than the level WHO recommends as safe (https://www.unicef.org/mongolia/environment-air-pollution). Similarly, sulphur dioxide, the major pollutant from coal burning reaches 170 μg/m^3, which is eight times higher than a national air quality standard. The second major source (10%) of air pollution is 340 thousand vehicles on the road and most of which are (79%) aged more than ten years and with substandard quality. Total of three thermal power plants are responsible for 6% of Ulaanbaatar air pollution, and the rest 4% is windblown dust (Davy et al., 2011).

Supporting reason for dense air pollution of Ulaanbaatar is its geographical location in a basin. The city is located along the Valley of Tuul River. Surrounding mountains reduce vertical and horizontal dispersion of air pollutants, especially during wintertime (Figure 1). Polluted air accumulates in the city area and shows number of negative impacts on human and ecosystem health. Air quality of capital city Ulaanbaatar is considered as an emerging issue and dozens of measures taken during the last two decades; however, no significant improvements have been achieved so far.

Study on lichens in relation with air quality started in mid 90s (Galsan et al., 1995; Enkhtuya, 1999) and further studies examined Ulaanbaatar air pollution effect on lichenous flora of surrounding ecosystems, biochemical and chemical analysis of lichens, bioindicator roles of local lichens and biodiversity of lichens (Ganbold et al., 2007; Hauck, 2008; Baljinnyam et al., 2009; Delgermaa et al., 2016).

In this study, we examined epiphytic lichens on *Larix sibirica*, the most abundant tree of the local forest at four sites close to Ulaanbaatar city. Two sites were chosen from Bogd Khan Mountain to the south and downwind of the city and two were from Chinggeltei Mountain to the north and upwind of the city. Both foliose and fruticose types of lichens were abundant at the sites to the northern areas of Ulaanbaatar. The result indicated the area was free of air pollution and wind flow prevents the area from pollution. In contrary, fruticose type lichens, especially representatives from the genera *Usnea, Cladonia* and *Vulpicidia* are absent in coniferous forest to the southern areas of Ulaanbaatar. Furthermore, relatively tolerant foliose type lichens show morphological changes such as size reduction, shape deformation and colour change or fading. This result clearly shows downwind ecosystems have been badly affected by poor quality air of the capital. Additionally, there were none of those bark dwelling lichens observed on the threes along the crowded roads, parks and residential areas which indicated the extreme pollution of the air within the city. Our result show that lichens could act as reliable and cost-effective bio-indicator which clearly differentiates mild or heavy pollution of the air. On the other hand, from the lichen community and their current biodiversity loss, we could foresee how anthropogenic false activities may effect on other forms of life if pollution exposure lasts further.

MATERIALS AND METHODS

Study sites. Total four sites were selected in this study. Site A and B located in Bogd Khan Mountain area which is to the south and downwind of the city. The Site A located at 1762 meters above sea level, where wind flows mostly from the west, rather not from the city. Site B was just 1.62 kilometers apart from Site A, however 298 meters below and located downwind the emission from Thermal Power Plant III. With this reason, the Site B was suspected as the most polluted site along with other three sites (Figure 2). Site C and D were from Chinggeltei Mountain to the northern side and mostly upwind of the city. The Site C was chosen because its location along the Selbe River. During winter,

when air pollution reaches its highest peak, the polluted air fills up the valley and reaches Site C if wind flow is weak. That is why we suspect this site to expose to mild pollution.

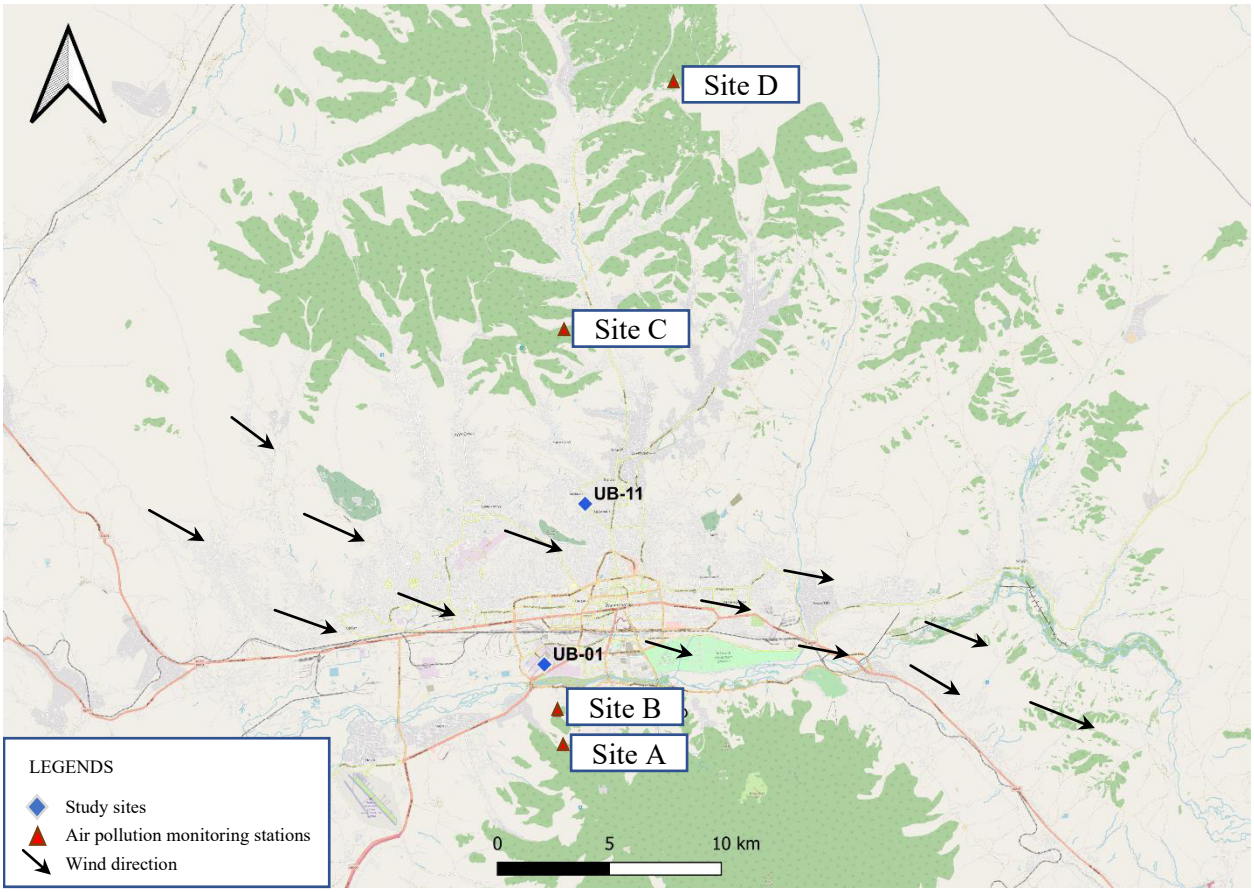


Figure (2): Location of the selected sites

The last Site D was chosen because its distance from the source of pollution. All of the above four sites belonged to the same type of forest or coniferous forest where larch tree dominates (Figure 2). Details of the selected sites were given in Table (1).

Table (1): Details of the selected sites

Site of study	Bogd Khan Mountain (downwind the city)		Chinggeltei Mountain (upwind the city)	
	Zaisan	Khiimoriin ovoo	Yargait	Khandgait
Latitude	47º86′26.2″N	47º87′61.5″N	48º02′93.9″N	48º12′71.2″N
Longitude	106º88′28.6″E	106º87′91.7″E	106º88′90.8″E	106º95′85.8″E
Altitude	1782 m	1464 m	1545 m	1731 m
Distance from city center by road or path	8.6 km	7.0 km	14.7 km	26.9 km
Forest type	Coniferous	Coniferous	Coniferous	Coniferous

Lichen sampling. Siberian larch *Larix sibirica* was used in this study because of its abundance and morphological characteristics of bark that is rough and suitable for lichen settling. Lichen colonies were collected with the help of forceps, placed in sample bags and transferred to a laboratory.

Identification of lichens
Lichen specimen was collected in polyethylene bags and transferred to a laboratory. The samples were air dried and identified using light microscopy with the help of chemical tests (Orange et al., 2010).

Total lichen coverage. Total fifteen individual larch trees, whose diameters ≥20 cm were selected at each site. Quantification of lichens was done by placing a lichen grid (20X20 cm) on the tree at 0-20 cm and 130-150 cm heights from ground level (Enkhtuya, 2007).

RESULTS AND DISCUSSION

Lichen diversity. Currently there are 225 species of lichen recorded in Bogd Khan Mountain (Enkhtuya, 2007). However, in this study, we recorded collectively 12 lichen species at the A and B sites selected from Bogd Khan Mountain area (Table 2); 10 and 8 species from the Site A and B, respectively. Most lichens observed from Bogd Khan Mountain belonged to foliose and crustose growth types which are relatively tolerant to air pollution. For example, according to Hawksworth, 1970, foliose type lichen *Hypogymnia physodes* could tolerate 70µg/m^3 mean winter SO_2 concentration and appear around the basis of the trees, but do not extend up the trunks. In our study, mostly all sensitive species from fruticose type lichens were vanished and foliose type species - *Hypogymnia physodes, Flavopunctelia soredica and Parmelia sulcata* were observed as dominant lichens mostly around the basis of the trees. Especially, two tolerant species *Flavopunctelia soredica* and *Parmelia sulcata* comprised more than 90% of the total lichen coverage at the Site B.
From fruticose growth type, only one species - *Evernia mesomorpha* was observed in this area. To note, only one colony of *Evernia mesomorpha* was recorded among fifteen larch trees used at the Site B.

Table (2): Lichen species recorded at each study site

Species	Morphology	Bogd Khan Mountain		Chinggeltei Mountain	
		Site A	Site B	Site C	Site D
Cladonia coniocraea	Fruticose			+	+
Cladonia fimbriata	Fruticose			+	+
Evernia mesomorpha	Fruticose	+	+	+	+
Usnea fulvoreagens	Fruticose			+	+
Usnea hirta	Fruticose			+	+
Usnea lapponica	Fruticose				+
***Usnea* sp.**	Fruticose				+
Flavopunctelia soredica	Foliose	+	+	+	+
Hypogymnia bitterii	Foliose	+		+	+
Hypogymnia physodes	Foliose	+	+	+	+
Melanelia exasperatula	Foliose	+			+
Melanelia olivacea	Foliose			+	+
Parmelia soredica	Foliose		+	+	+
Parmelia sulcata	Foliose	+	+	+	+
Vulpicidia pinastri	Foliose				+
***Buellia* sp.**	Crustose			+	+
Lecanora piniperda	Crustose	+			+
Lecanora symmicta	Crustose			+	+
Lepraria sp	Crustose	+			+
***Rinodina* sp.**	Crustose			+	+
Trapeliopsis flexuosa	Crustose	+	+	+	+
Trapeliopsis granulosa	Crustose		+		+
Hypocenomyce scalaris	Squamulose	+	+		
Total		**10**	**8**	**15**	**22**

+ present

For the two sites C and D from Chinggeltei Mountain area, upwind the city, the most sensitive fruticose type lichen species were observed as abundant lichens (Table 2). Well known bio-indicator species from a genus *Usnea*, which exist when mean winter sulfur dioxide concentration is below 40μg/m^3 only were observed at both Sites C and D. Furthermore, golden-coloured foliose type lichen *Vulpicidia pinastri*, which is extremely sensitive to any type of air pollution, was recorded at Site D. This result indicated an excellent air quality at this site. We collected and identified total 22 species of lichens from Chinggeltei area; 15 and 22 species from the Site D and C, respectively. Some of the lichens were photographed and shown in Figure (3).



Hypogymnia physodes



Parmelia sulcata



Flavopunctelia soredica



Hypogymnia bitterii



Vulpicidia pinastri



Evernia mesomorpha



Usnea fulvoreagens



Usnea hirta



Trapeliopsis granulosa



Lecanora symmicta



Cladonia fimbriata



Cladonia conicraea

Figure (3): Lichen species observed near Ulaanbaatar city

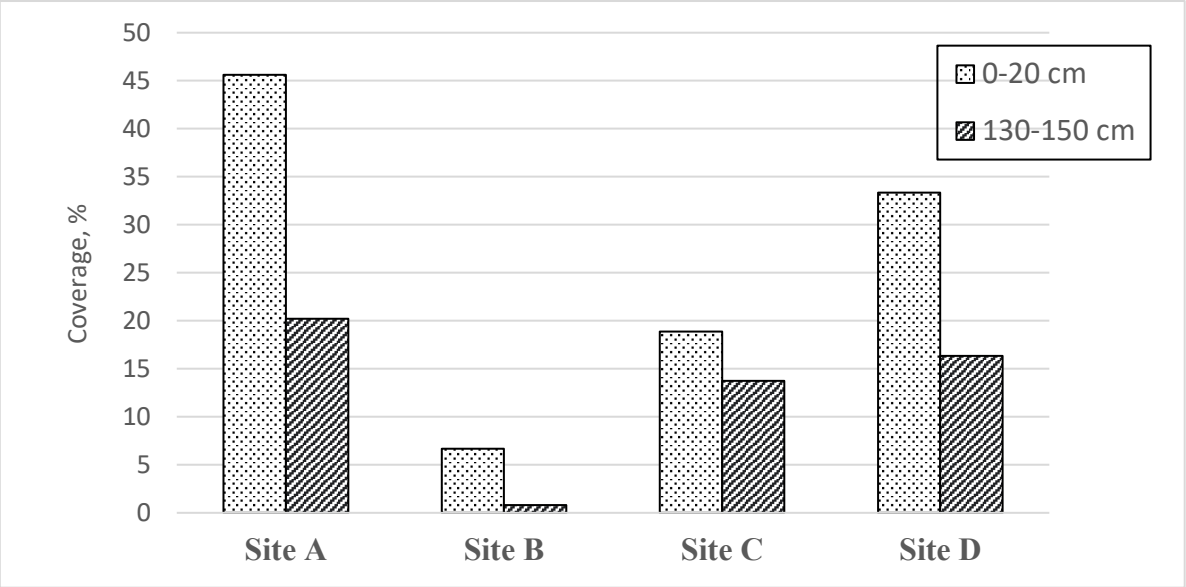


Figure (4): Total lichen coverage at the selected study sites

Lichens as bioindicator of air quality

Sulfur dioxide level in the air can be estimated qualitatively by studying the epiphytic lichens growing on trees (Hawksworth, 1970). In contrary, higher vascular plants and trees respond to air pollution at much slower rate (Muir et al., 1988). We observed lichen diversity within and outside of the city of Ulaanbaatar. All species of the trees and bushes near roads, parks and residential areas of Ulaanbaatar city do not bear any of the species of lichens. This result simply suggests a disastrous amount of air pollution that is mean winter sulfur dioxide concentration is around or exceeded 170μg/m^3. This finding also meets measurement results from the air quality monitoring stations.
Bogd Khan Mountain area, downwind of the city bear only lichen species tolerant to mild pollution, but size, colour and morphology are already changed, and this result indicate plant stress under polluted conditions.

CONCLUSION

In this study we observed clear change in lichen diversity downwind and upwind of the capital city Ulaanbaatar. The results suggest that polluted air generated from conventional stoves from ger areas transferred to the southern part of the city and show its negative impact to Bogd Khan Mountain ecosystems. Lichens are the first organisms respond to environmental pollution and warn us; but if such anthropogenic false activity still remains for the future, many other important life forms may degrade in term of prolonged exposure time.

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