Assessment of Atmospheric Deposition and Spatial Variability of Trace Metals in Kandy City and Suburbs using Bio-monitoring Technique in Mosses

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Abstract

Deposition of atmospheric Trace metals (TMs) was investigated in this study through the analysis of mosses that have been grown at nine locations within the Kandy Municipal Council area and its suburbs. *Hyophila* sp. moss was selected for TM analysis with referring their common availability. After cleaning, dried mosses samples were digested with conc. HNO_3 in microwave digesting system. Digested samples were analysed for Al, Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb using Inductive Coupled Plasma-Mass Spectrometry (ICP-MS). Average TM concentrations in mosses, were resulted with the order of Fe>Al>Zn>Mn>Cu> Pb> Cr>Ni>Cd. The highest and lowest metal concentrations were recorded for Al and Cd as 12,150 and 0.2 mg/kg respectively. Principle factor analysis suggested two major factors; vehicular emission and geographical location, responsible for the TM concentrations in mosses. Factor analysis indicated that approximately about 73% of the TMs in the atmosphere are by the two factors whereas majority from that to be from the vehicular emission. Apart from that, trans-boundary pollution could identify as one of the major factors for TMs in Kandy. Spatial distributions are not significant for the metals that have identified as geogenic origin and others were reported with clear spatial distribution with having highest accumulations in the areas those experiencing higher traffic activities. The ecosystem risk values are still in the acceptable levels in the means of trace metals in mosses.

Key words: mosses, bio-monitoring, trace metals, atmospheric deposition

1. Introduction

Atmospheric particulates are dispersed into the environment through either natural or anthropogenic origin. In general, natural contributors are volcanic activities, sea salt aerosol, wind born dust, forest fires and crustal minerals (Karim et al., 2014). Power plants, industries, residential heating and traffic activities are some of major anthropogenic activities that rich with particulate emission (Cao et al., 2011, Weerasundara and Vithanage, 2015). As most of the anthropogenic activities are gathered in urban cities, the urban environments are great victims of these atmospheric pollutants (Cao et al., 2011). The atmospheric particulates which

are emitted from various sources are rich with different types of atmospheric pollutants that are able to affect both human and ecosystem quality (Castillo et al., 2013). Among them, trace metals (TMs) are one of the most important pollutants in urban atmosphere (Azimi et al., 2003, Weerasundara and Vithanage, 2015). It is acknowledged that some of these TMs such as Ni, Mn, Cu, Fe and Zn are essential to various biochemical and physiological functions in living organisms (He et al., 2005). However, exceed of the threshold levels would cause different detrimental health effects (Jaishankar et al., 2014). Although the atmospheric pollution by TMs is acknowledged in all over the world, the pollution status has increasing trend due to escalation of emission sources and therefore, monitoring and quantification of TM loads in the atmospheric deposition is a vital need in this era.

The physicochemical methods that facilitate direct collection are the most extensively employed methods to quantification of TMs in atmospheric deposition (Attanayaka and Wijeyaratne, 2013). However, due to high cost and extensively required time and space, the studies on atmospheric deposition quantification were limited (Azimi et al., 2003, Ares et al., 2012). Despite of above limitations, the physicochemical methods are also failed to implement the possible effects of various pollutants on living organisms (Attanayaka and Wijeyaratne, 2013). Bio-monitoring is an inexpensive method that can be used to determine the levels pollution through atmospheric deposition over specific locations (Singh et al., 2017). Common occurrence in the field, the easiness of sampling, the degree of trace element accumulation and no expensive technical equipment is required are some of remarkable advantages on bio-monitors over physicochemical monitors (Singh et al., 2017, Ares et al., 2012). Notably, this concept of bio-monitoring brings an opportunity to assess the effects on pollutants on biotic components in an ecosystem (Attanayaka and Wijeyaratne, 2013).

Although there are several organisms such as ferns, grass, tree rings and pine needles had been used as bio-monitors, their mechanisms are still not fully understood. Lichen, mosses and tree barks have been the most frequent bio-monitoring surfaces for TMs over last few decades (De Bruin, 1990). Moss bio-monitoring has been believed as much advantageous as it is bearing less technical and analytical problems (Barandovski et al., 2008). Most of moss species are capable to grow under different environmental conditions even in urban and industrial areas. Therefore, the sampling of the same species is easy even for geographically disparate areas (Ares et al., 2012). Due to lack of epidermis and cuticle, metal ions can be easily penetrated through cell wall and it enhances the accumulation of metals in a passive way facilitating ion exchange mechanisms (Ares et al., 2012, Onianwa, 2001, Chakrabortty and Paratkar, 2006). As a result of absence of vascular system, the transport of minerals between moss segments is rather confined. The lack of root system promotes the independent nature in the means of mineral uptake and therefore it expedites the accomplishment of nutrient requirements through atmospheric deposition. Hence, the mosses have been identified as one of the most effective organism to assess TM concentrations in atmospheric deposition (Aničić et al., 2009,Onianwa, 2001, Boquete et al., 2014). Table 1 show the selected studies which have been focused on TM bio-monitoring through mosses.

Table 1: Different studies focused on heavy metal bio-monitoring through mosses and their concentrations.

City and Country	Nature of the sampling site	Moss species	Al mg/kg	Cr mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Ni mg/kg	Zn mg/kg	Cd mg/kg	Pb mg/kg	Reference
Eket, Nigeria	High vehicular traffic, airstrip, municipal waste burning	*Racopilum africanum*		5.8	113.2		18.1	6.4	87.7	0.002	16.7	Ite et al. (2014)
Ibeno, Nigeria	Industrial power generation, gas flaring and venting	*Calymperes erosum*		4.4	59.3		9.6	2.1	0.01	0.05	0.001	Ite et al. (2014)
Kosovo, Southeastern Europe	Away from main roads or building, high mountain area	*Pseudocleropodium purum, Hypnum cupressiforme*		2.7	92.7	570	3.12	6.6	37.4	0.3	12.1	Maxhuni et al. (2016)
Albania, Europe	A hotspot for trace metals contamination in Europe	Hypnum cupressiforme, Pseudoscleropodium purum	1800[*]			2000[*]						Lazo et al. (2018)
Alameda, Mexico	Mexican highlands located in Mexican central area, a valley area, High population density, Industrial area	*Fabronia ciliaris*		33.34	172	9332	32.12	10.88	145		112	Zarazúa-Ortega et al. (2013)
Reforma, Mexico	Mexican highlands located in Mexican central area, a valley area, High population density, Industrial area	*Fabronia ciliaris*		27.21	119	6746	40.20	11.08	179		107	Zarazúa-Ortega et al. (2013)
Hipico, Mexico	Mexican highlands located in Mexican central area, a valley area, High population density, Industrial area	*Fabronia ciliaris*		22.32	132	5616	26.17	7.40	151		32.60	Zarazúa-Ortega et al. (2013)
Pila, Mexico	Mexican highlands located in Mexican central area, a valley area, High population density, Industrial area	*Fabronia ciliaris*		19.93	161	6432	20.68	6.20	136		25.31	Zarazúa-Ortega et al. (2013)

[*] Approximate values

Since Kandy City of Sri Lanka is the second largest of the country and the vehicle traffic is significant, in Kandy City due to touristic and geographic nature and hence the traffic influence is crucial for emission of TMs into the atmosphere (Weerasundara et al., 2017). In accordance with the results shown in Weerasundara et al. (2017) both geogenic and anthropogenic metal have been found in the Kandy environment whereas the geogenic metal concentrations showed elevated concentrations than that of the anthropogenic metals. However, it has been stated that the traffic activities are the foremost reason for emitting both of those metal types into the atmosphere either as primary or secondary emission. Thus, the monitoring of TM concentrations in atmospheric deposition is a need in order to identify the present status, mitigation strategies and control policies. Hence, the present study was conducted to monitor and assess the atmospheric TM deposition in Kandy City through mosses as bio-monitoring tools. Weerasundara et al. (2017) has depict the data for atmospheric deposition through deposition collection and it facilitates the understanding of present status of the Kandy area in the means of atmospheric TM deposition and the present study facilitates the understanding of amount of TMs which been accumulated with the surface area of the living organisms for a long time period.

2. Materials and methods

2.1 Study area and sampling sites

The sampling sites were located within and the suburbs of the 26 km^2 Kandy City which is centrally located in a small valley facilitating thermal inversions within the city atmosphere (Weerasundara et al., 2017). Four main entrances are allowing more than 106,000 of vehicles as daily traffic flow. Due to significant vehicular volume within a small area, it always creates immense traffic congestion especially in office hours and weekends. The permanent population in Kandy is more than 170,000 people and the daily transient population is around 100,000 people (Wickramasinghe et al., 2011). The city is located at ~500 m above mean sea level. The average day time ambient temperature is in the range of 28-32 ℃, monthly rainfall is in the range of 52-398 mm and the day time relative humidity is in the range of 63-83% (Weerasundara et al., 2017).

Twelve sampling sites were selected for the collection of mosses samples However, only nine sample sites were consisted with the selected moss species. Both inner City and suburbs were considered while selecting of sampling sites. These sites were designated as Good Shed station (S_1), Railway station (S_2), Market place (S_3), Children's park (S_4), Kingswood college (S_5), Pushpadana College (S_6), Trinity College (S_7), High school (S_8), National Institute of Fundamental Studies (NIFS) (S_9), Thannekumbura (S_{10}), Lewalla (S_{11}), Peradeniya (S_{12}) (Fig. 1). Lewalla is a site far away from main road and the vehicular activities. Therefore it was selected as the control site.
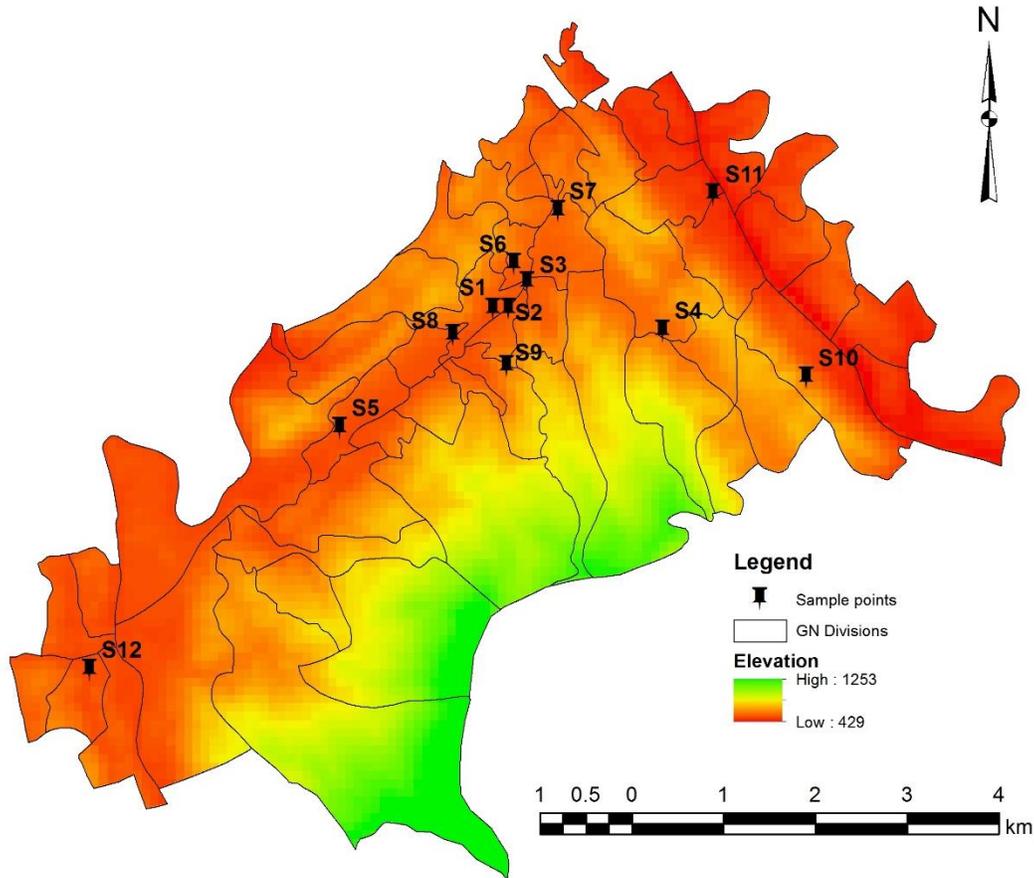
Figure 1: Map of the study area and locations of the twelve sampling sites.
S_1=Good Shed Station; S_2=Railway Station; S_3=Market Place; S_4=Children's Park;
S_5=Kingswood College; S_6=Pushpadana College; S_7=Trinity College; S_8=High School;
S_9=National Institute of Fundamental Studies; S_{10}=Thannekumbura; S_{11}=Lewalla;
S_{12}=Peradeniya

2.2 Sampling of mosses

Hyophila Sp. moss (Fig. 2) samples were collected from nine sampling sites. Only top portion was collected, discarding the basal portion with adhered soil or impervious surfaces. In each location, sampling was done at 2-3 individual places and mixed to form a common sample. These moss samples were collected into clear paper bags and sealed immediately and brought into the laboratory and stored in a refrigerator until analysis. At the laboratory, the mosses samples were cleaned by carefully removing any adhered particles. Then those were further cleaned with deionized water and magnetic starrier. Same procedure was followed for three times to clean the mosses to the greatest extend. After cleaning, the mosses samples were oven dried for 24 hour at 40 ℃ and they were ground to a fine powder using a pre-cleaned mortar and pestle.

Figure 2: *Hyophila* Sp. Moss.

2.3 Laboratory analysis

Powdered moss samples of 0.2 g were acid digested with 5 ml of Analytical grade Conc. HNO_3. It was conducted with a MARS6 microwave digestion system (CEM cooperation). All the digestion vessels were cleaned with Conc. HNO_3 before every digestion circles. After completion of a digestion, the vessels were allowed to cool and opened under a fume hood. The entire sample was transferred into a 25 ml volumetric flask and the volume was adjusted with de-ionized water. The sample was then filtered with a 0.45 μm membrane filter and kept in a refrigerator under 4 ℃ until the metal analysis has been taken placed. The digested samples were analyzed for TMs namely, Al, Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb because those metals are commonly present in the urban environments. Since Al is a crustal element, it was selected as an identifier of geogenic metals (Weerasundara et al., 2017). The TM concentrations were determined using as Agilent 8800 Triple Quadruple Inductively coupled plasma mass spectrometer (ICP-MS) at Queensland University of Technology (QUT), Australia. All the quality assurance and quality control (QA/QC) samples were prepared and tested as specified in US EPA method 200.8 (USEPA, 1994). Calibration curves were setup and ensured that the residual mean square (R^2) was greater than or equal to 0.98. Consequently, certified reference material (CRM) recovery was compared against values given in standard certificate. Multi-element standard solution V for ICP-MS prepared by TraceCERT® was used as the CRM. Calibration blank was a volume of deionized water acidified with the same acid matric as the calibration standards. Internal standards were prepared according to the US EPA method 200.8 (USEPA, 1994). The diluted internal standard was spiked into the samples at 5 μg/L prior to the ICP-MS analysis to ensure all the samples are above the method detection limits as described in US EPA method 200.8 (USEPA, 1994).

2.4 EnricTMent Factor (EF) analysis

The EF analysis was conducted to determine either anthropogenic or terrestrial influence upon TMs for their enricTMents using Eq. (1) developed by Zarazúa-Ortega et al.(2013). Iron was selected as conservative element to determine the enricTMent of TMs. The values for reference soil, coming from a site that far away from anthropogenic activities.

$$EF = \frac{(C_s / Fe_s)_{moss \; or \; lichen \; value}}{(C_o / Fe_o)_{reference \; soil \; value}} \qquad (1)$$

Where, M_s is concentration of one particular metal in moss sample, Fe_s is concentration of selected conservative reference element (Fe) in moss sample, M_o is concentration of same metal in reference soil, and Fe_o is concentration of conservative reference element in reference soil. In order to assess the enricTMent level by metal, following criteria in Table 2 were applied.

Table 2: Criteria for evaluated moss enricTMent factor.

EnricTMent Factor value	EnricTMent level
≤ 2	Conservative
3–5	Slightly enriched
6–9	Moderately enriched
≥ 10	Highly enriched

2.5 Ecological risk assessment of trace metals

Accumulating coefficients of TMs in mosses samples taken from different sampling sites were computed and applied to indicate the accumulating status of TM in the mosses samples. The computing equation for accumulating coefficient C^i_f is as follows

$$C^i_f = \frac{C^i_m}{C^i_n} \qquad (2)$$

Where, C^i_m is the value of TM concentration in the samples, and C^i_n is the background values (mg/kg).

The potential ecological risk index method developed by Hakanson was applied in this study (Zhu et al., 2012) to assess the ecological risk. According to this method, the potential ecological risk coefficient E^i_r of a single element and the potential ecological risk index, R_i of multi-element were computed via the following equations (Equation 3 and 4)

$$E^i_r = T^i_f \times C^i_f \qquad (3)$$

$$R_i = \sum_{i=1}^{n} E^i_r \qquad (4)$$

Where, C^i_f is the accumulating coefficient of a particular element and T^i_f is the toxic-response factor of that particular element (which reflects its toxicity levels and the sensitivity of bio-organism to it). E^i_r is the potential risk of individual TM and R_i is the sum of potential risk of individual TM. The indices and grades for E^i_r and R_i as follows.

01. For E^i_r,
    a. $E^i_r < 40$:   = Low risk
    b. $40 \leq E^i_r < 80$ = Moderate risk
    c. $80 \leq E^i_r < 160$ = Considerable risk
    d. $160 \leq E^i_r < 320$ = High risk
    e. $320 \leq E^i_r$ = Very high risk
02. For R_i
    a. $R_i < 150$ = Low risk
    b. $150 \leq R_i < 300$ = Moderate risk
    c. $300 \leq R_i < 600$ = Considerable risk
    d. $600 \leq R_i$ = Very high risk

3. Results and discussion

3.1 Metal concentrations in mosses

It was not found the *Hyophila* sp. moss was not found in all of 12 sampling points and therefore, TM concentrations in mosses are available only for sampling sites namely, S_1, S_2, S_5, S_6, S_7, S_9, S_{10}, S_{11} and S_{12}. The mean TM concentrations, SDs and ranges reported in moss samples are illustrated in Table 3. The wide range variation and higher SD values are also reported with mosses. The metal concentrations in mosses for twelve sample sites are presented in Fig. 3. Al and Fe are the mostly found TMs in moss samples over nine sampling sites. Kandy district is mainly consisted with Reddish Brown Lateritic soil. In this Reddish Brown Lateritic soil, all of the all soil profiles are consist with clay; A1 - 0–6 inches, fine gravely clay loam; A3- 6-10 inches, fine and coarse gravelly clay loam; B2t – 10–37 inches, fine and coarse gravely clay (Moorman and Panabokke, 1961). The clay minerals in soil are layered alumino-silicate (Tennakoon, 1987). Therefore, the sources identification for Al and Fe would be geogenic origin with the presence of Alumino-silicate based earth crust in Kandy area. Mn and Zn also reported in significant concentrations in moss samples. Other TMs namely Cr, Ni, Cu, Cd and Pb are in comparatively lower concentrations while Cd showed lowest concentrations in moss samples.

For mosses the Pearson's correlation coefficient values were found to be in higher values for most of TM pairs indicating significant relationships among them (Table 4). The similarity for of their sources of origins would be the reason for this increased coefficient values. The PCA applied for grouping of separate statistically significant associations for mosses. From the nine analyzed variables, the matrix of dominant rotated factor loadings for mosses is presented in Table 5. Two major factors were identified and interpreted as Factor 1 and Factor 2, which include 83% of the variability of tested elements.

Factor 1 (Al, Cr, Mn, Fe, Ni, Cu and Pb)

The factor 1 associates TMs indicate anthropogenic influence in the studied area. As Kandy city having high traffic activities due to historical and economic importance, these vehicular activities would be the major anthropogenic source for these metals. The city is lacking with significant industrial activities and any other significant anthropogenic activities such as mining the vehicular activities play a major role for the emission of anthropogenic metals into the atmosphere. Except for Pb all other metals in this factor have factor loadings more than 90%. The major source for emission of Pb is leaded gasoline. However at present, the leaded gasoline is banded and the emissions have been limited. However it may not completely removed from the urban environment as previously emitted Pb are still persistent and circulating through the atmosphere. This fact would be the reason for Pb has such low but significant factor loading within this factor.

Factor 2 (Zn, Cd and Pb)

The metals associated in this factor are not generally originated from geogenic sources. Therefore this factor cannot be indicated as a geogenic factor. The outside factor such as trans-boundary pollution through wind activities would be the sources for this metals in mosses collected in Kandy area.

Table 3: Descriptive statistics for metal concentrations in mosses

Metal	Concentrations in Mosses (mg/kg)		
	Mean	**SD**	**Range**
Al	11181.6	5770.7	5836.3 – 25869.1
Cr	41.6	19.3	25.3 – 89.8
Mn	348.5	178.8	186.4 – 806
Fe	21745.9	14021.8	12150.5 – 58.84.2
Ni	23.9	24.4	12.9 – 88.8
Cu	58	26.9	35.1 – 123.8
Zn	357.3	162.1	198.1 – 666.4
Cd	0.9	0.8	0.2 – 2.8
Pb	26.2	11.1	12.8 – 45.8

SD=Standard Deviation

The special distribution of metals reported in moss samples are showed in Fig. 4. As Al is mainly from geogenic sources, the distribution pattern is common for all of sampling sites. Therefore Al has not sharp spatial distribution except for S_6 site. In S_6 site, the Al concentrations have huge increase rather that all other sampling sites. Not only for Al but also for Cr, Mn, Fe, Ni and Cu, S_6 site has been showed quite high concentrations indicating the site S_6 is highly affected with atmospheric deposition. For Zn, the concentrations are comparatively high in sites S_{10} and S_{11}. Zn is highly concentrated in site S_2, S_7, S_9 and S_{12}. Regarding Pb, the depositions do not depict sharp spatial variation.
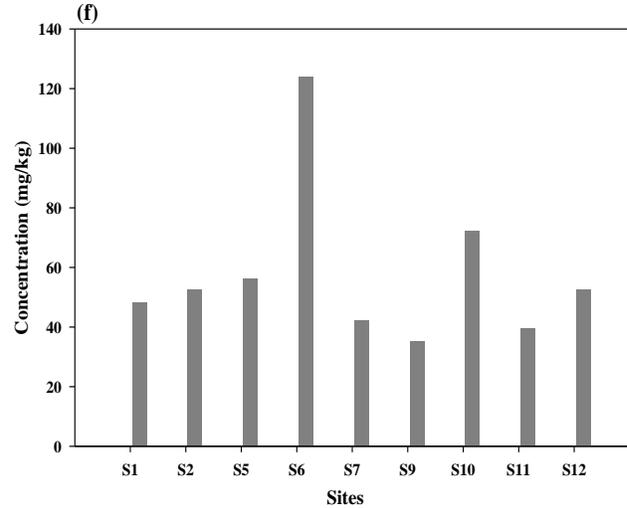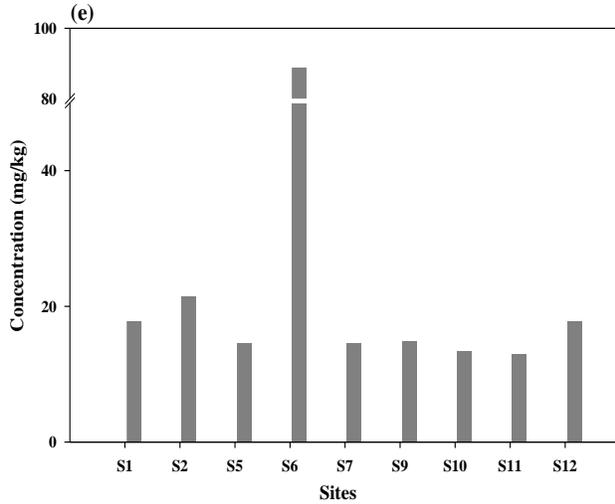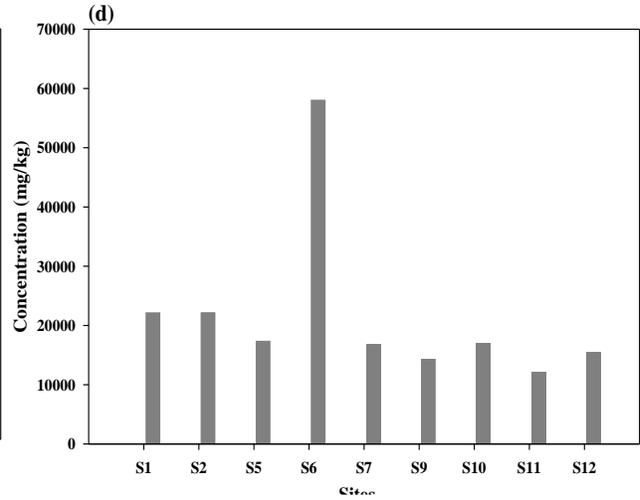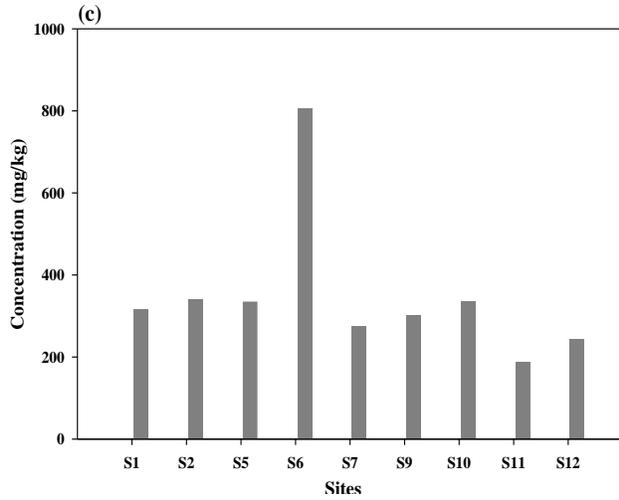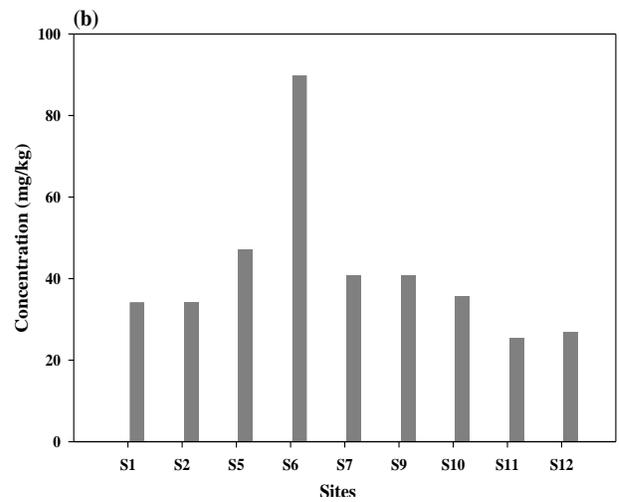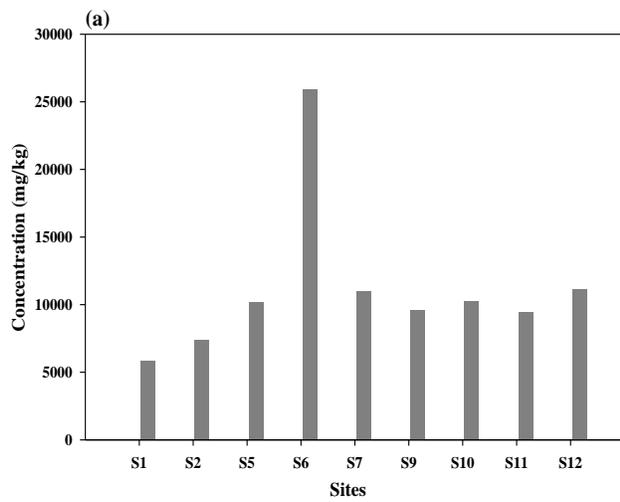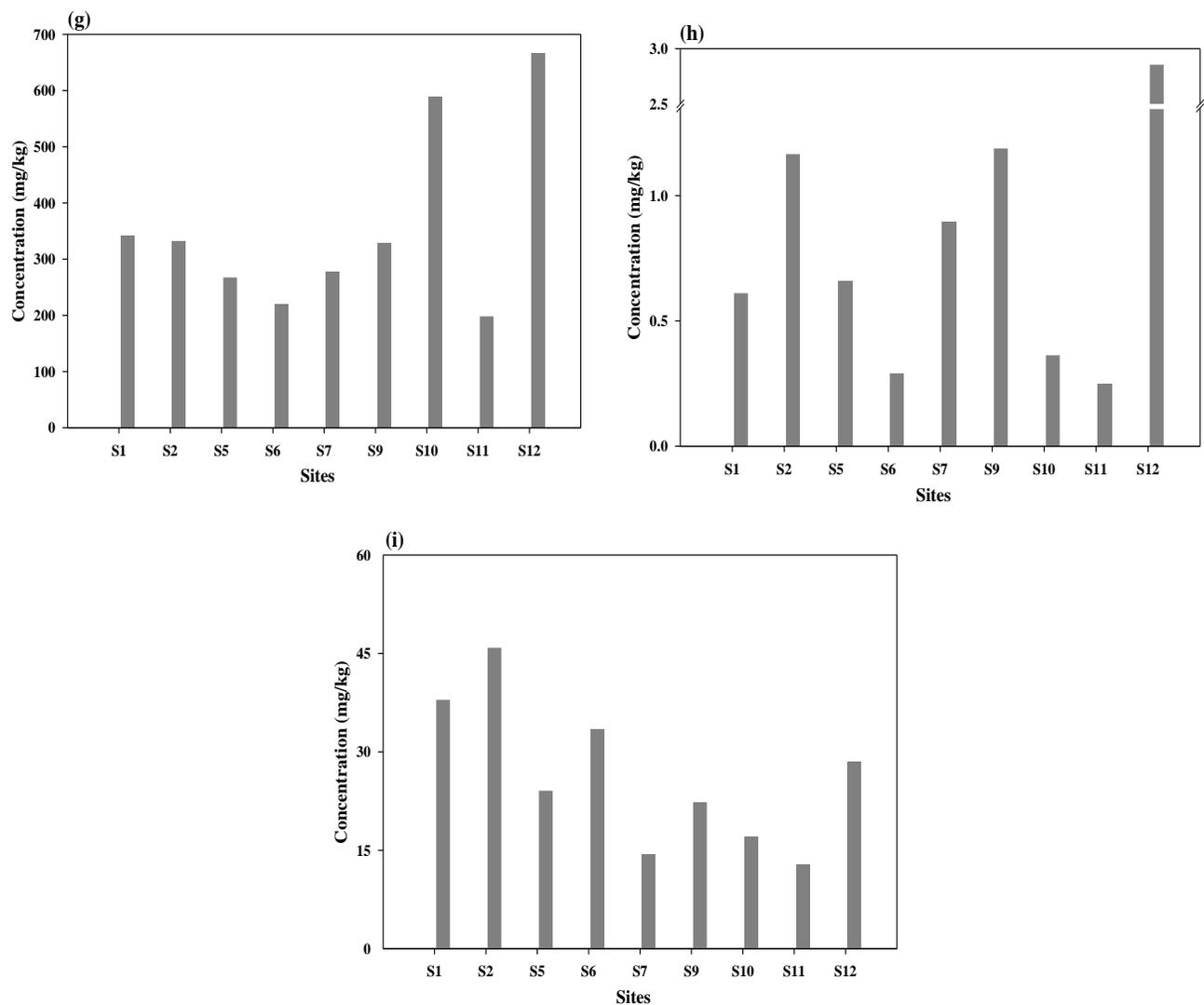
Figure 4: Metal loads in mosses samples. (a) Al, (b) Fe, (c) Zn, (d) Cr, (e) Mn, (f) Ni, (g) Cu, (h) Cd, and (i) Pb at nine sampling locations

Table 4: Correlation coefficient values for heavy metal pairs.

	Al	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Al									
Cr	0.90								
Mn	0.88	0.96							
Fe	0.87	0.92	0.98						
Ni	0.93	0.92	0.96	0.98					
Cu	0.88	0.86	0.93	0.92	0.91				
Zn	-0.21	-0.40	-0.27	-0.30	-0.30	-0.05			
Cd	-0.18	-0.36	-0.32	-0.29	-0.24	-0.29	0.64		
Pb	0.02	0.20	0.36	0.42	0.34	0.26	0.01	0.20	

Table 5: Matrix of rotated factor loadings for trace metals in mosses (F>0.5).

Metal	Factor 1 (%)	Factor 2 (%)	Communality (%)
Al	91	-12	84
Cr	94	-25	94
Mn	99	-10	98
Fe	99	-8	98
Ni	98	-8	97
Cu	95	-1	89
Zn	-21	82	71
Cd	-21	87	80
Pb	40	47	37

Enrichment Factor analysis in mosses

Table 6 depicts the EF values for moss samples collected from nine sampling sites. Regarding Al, Cr and Mn most of the sites are in conservative and slightly enriched levels and therefore, those TMs may primarily coming from the geogenic origin. However, the vehicular activities may have some effect re-suspension of those TMs. The PCA analysis also has proved this fact. Other metals; Ni, Cu, Zn, Cd and Pb have reached moderately to highly enriched levels within the sampling sites. Therefore, those metals may have significant anthropogenic involvement as it has confirmed by PCA analysis.

Table 6: Mosses enrichment factor values from sample sites at Kandy City and suburbs.

| Metal	S_1	S_2	S_5	S_6	S_7	S_9	S_{10}	S_{11}	S_{12}	Mean EF
Al	7E-06	8E-06	1E-05	1E-05	2E-05	1E-05	1E-05	4E-05	4E-06	1E-05
Cr	4	3	6	5	5	4	5	4	4	4
Mn	5	5	7	3	5	4	5	4	5	5
Ni	6	6	6	6	6	6	5	7	7	6
Cu	11	11	15	10	12	11	20	31	12	15
Zn	10	9	9	6	10	8	19	16	14	11
Cd	1227	1096	879	552	1301	1146	876	1931	3446	1384
Pb	22	24	16	18	10	18	12	17	15	17

Ecological risk assessment in mosses

Table 7 shows the average potential ecological risk (E_r^i) values for individual TMs of moss samples. All most all the E_r^i values indicate less than 40, presenting low ecological risk. Therefore the results show that still the ecosystem health in Kandy area is in acceptable levels in the means of atmospheric trace metals on biological organisms.

Table 7: Average ecological risk (E^i_r) values for nine trace metals on moss samples.

Metal	Concentration (mg/kg)		E^i_r value
Cr	Min	9.1	0.6
	Max	47.0	3.3
	Mean	33.2	2.2
Mn	Min	56.3	0.1
	Max	339.9	1.1
	Mean	226.1	0.7
Ni	Min	5.8	3.0
	Max	21.3	11.0
	Mean	15.2	7.7
Cu	Min	35.1	0.4
	Max	72.2	0.8
	Mean	47.9	0.6
Zn	Min	136.9	0.4
	Max	530.5	1.0
	Mean	290.5	0.7
Cd	Min	0.2	0.4
	Max	1.2	2.3
	Mean	0.5	0.9
Pb	Min	7.4	0.5
	Max	45.8	3.6
	Mean	24.6	1.9

4. Conclusions

 Hyophila sp. mosses were collected from selected nine sampling sites within Kandy City and its suburbs and analysed for a range of TMs. As for TMs Al and Fe, from geogenic sources, were found to be in significantly higher concentrations in mosses samples compared to the other TMs. As the Fe and Al are mainly from geogenic origin the increased concentrations suggest the influence of soil particles to the atmospheric deposition in Kandy and its suburbs. Zn and Mn have ranked in next two highest concentrations. Zn can be originated from various anthropogenic sources. The traffic related activities are always promoting Zn emission to the atmosphere with galvanized automobile parts. Galvanized roofing materials are another possible source for this increased Zn concentrations since galvanized roofing materials are common in Kandy area. The other TMs investigated, namely, Cr, Ni, Cu, Cd and Pb, were attributed to being primarily originating from anthropogenic sources, mainly from traffic activities as confirmed by the PCA analysis undertaken. The trans-boundary pollution may have some influence on low concentrated TMs in Kandy area in particular for Cd. The special distribution showed similar patterns for the TMs that identified as geogenicaly originates and the TMs which have significant anthropogenic influence showed clear special variation among sampling sites. Most importantly, the areas that have considerable traffic activities showed elevated metal concentrations. As Kandy City has historical and religious importance, large numbers of tourists and devotees visit the City. Therefore, the traffic conditions are higher. Within the City, at different locations, there are variations in metal concentrations and the major contributor for this special variation could be the traffic intensities. However, still the city in in acceptable ecological risk levels in the means on trace metals.
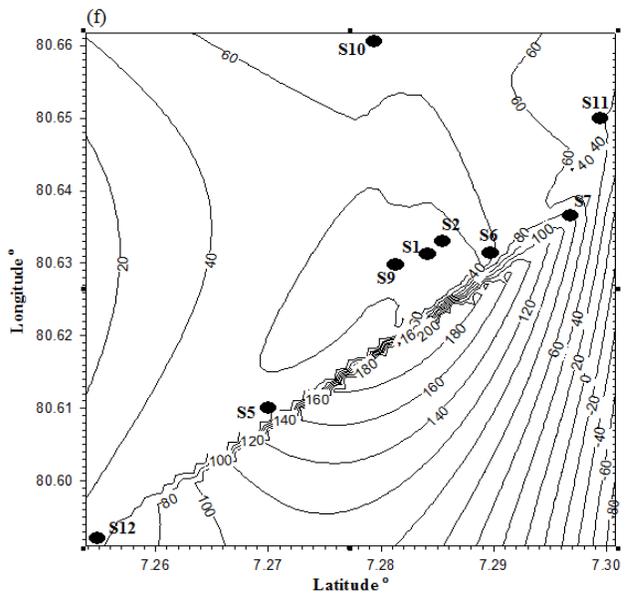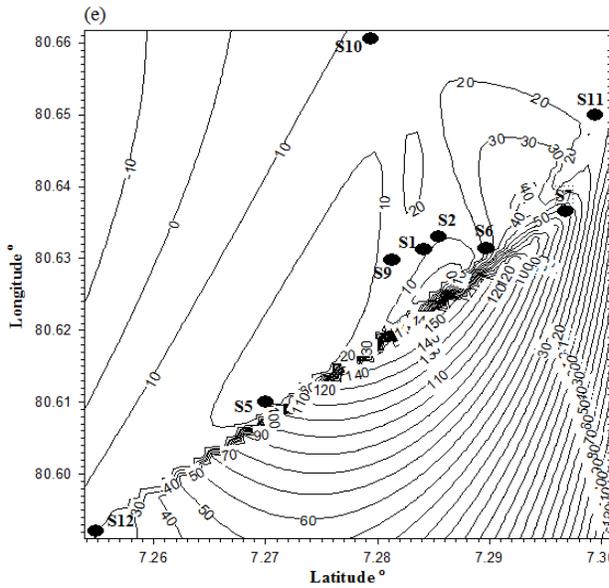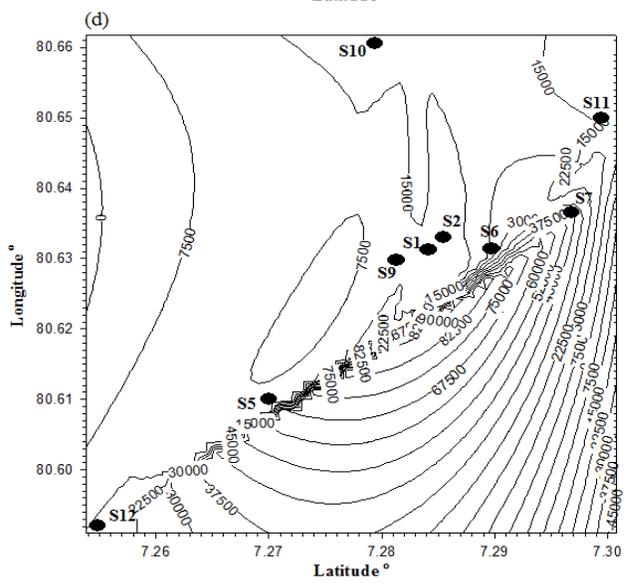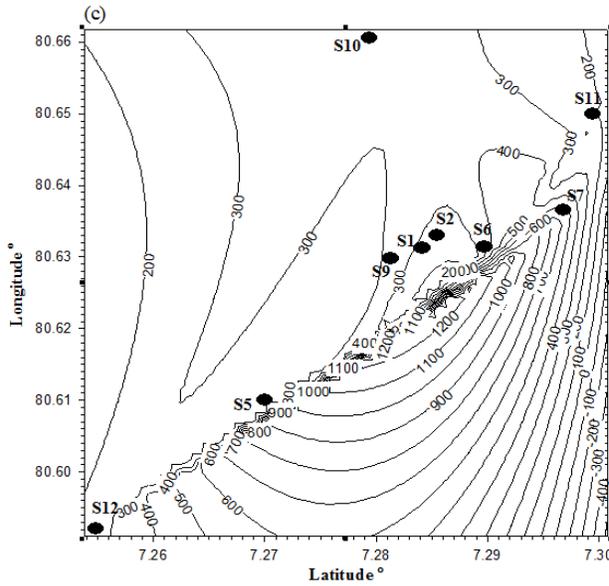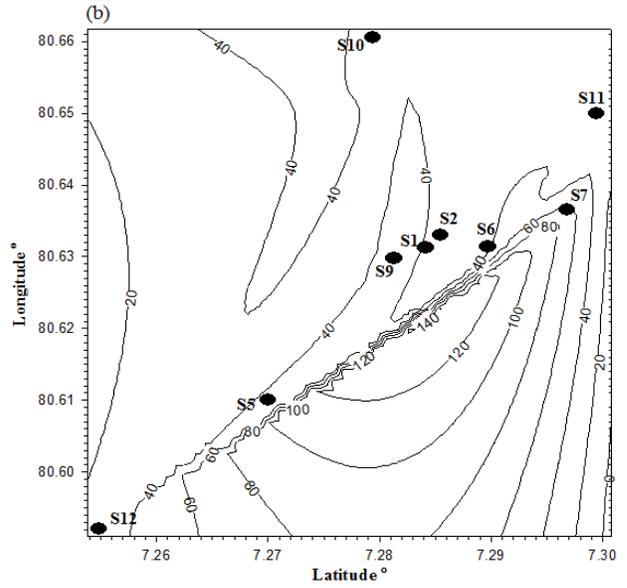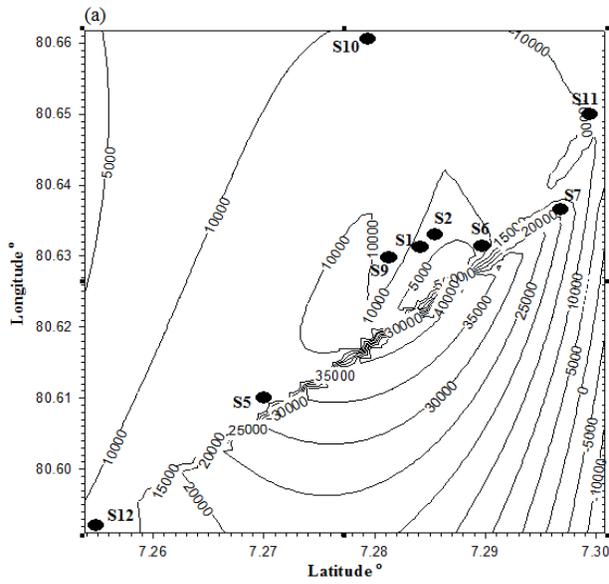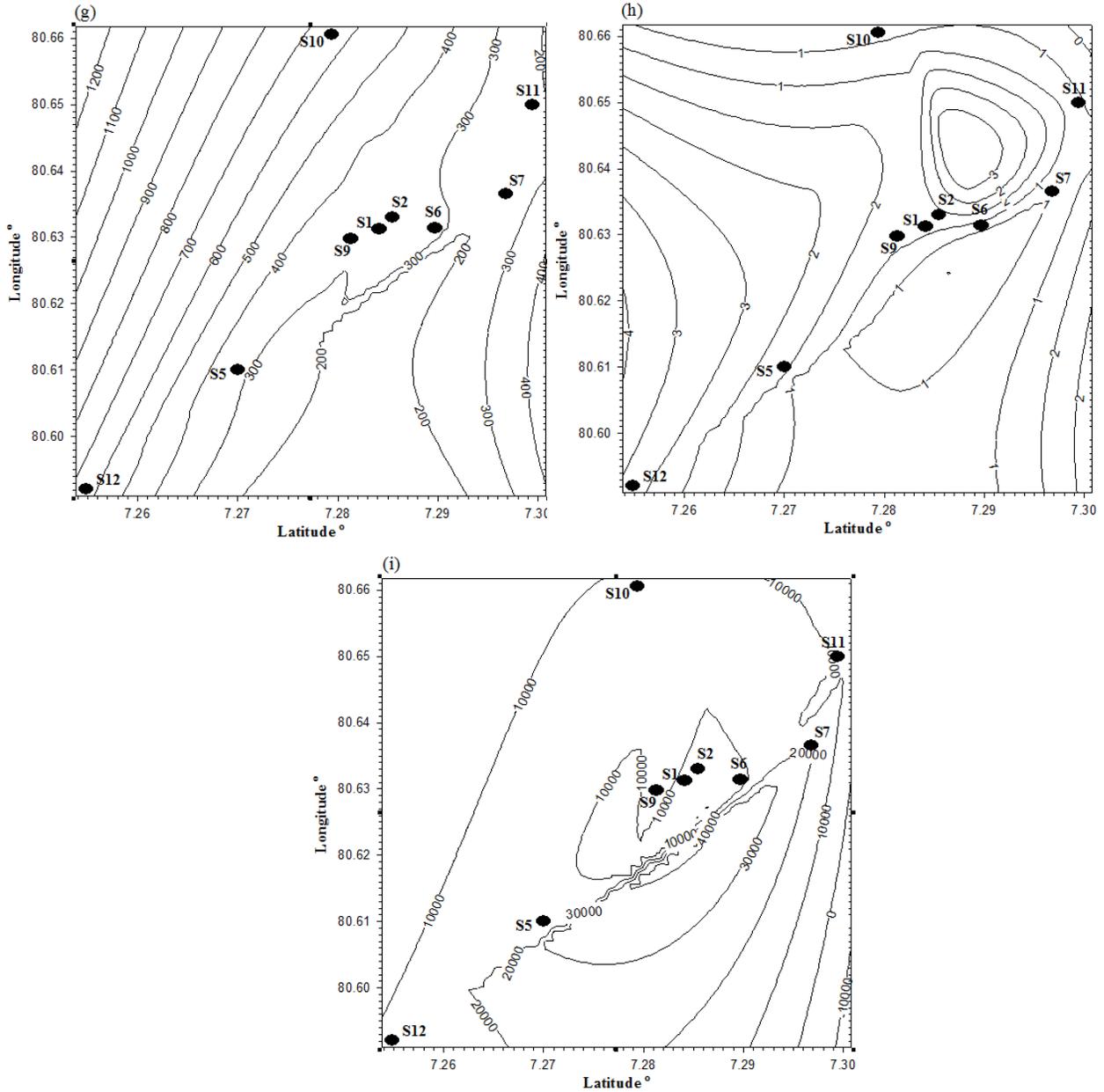
Figure 4: Spatial distribution of heavy metal for moss in Kandy and its environs.
(a) Cr, (b) Al, (c) Mn, (d) Fe, (e) Ni, (f) Cu, (g) Zn, (h) Cd, and (i) Pb; Good shed station (S_1),
Railway station (S_2), Kingswood college (S_5), Pushpadana College (S_6), Trinity College (S_7),
National Institute of Fundamental Studies (NIFS) (S_9), Thannekumbura (S_{10}), Lewalla (S_{11}),
Peradeniya (S_{12})

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