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The relationship between soil geochemistry and die back of montane forests in Sri Lanka: a case study

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Abstract Tropical montane forests of Sri Lanka form a unique ecosystem with more than 50% of endemic plant species. It has been noted that trees, belonging to different size and age classes of these forest, have been dying due to a yet unknown factor. This phenomenon was first observed in the Horton Plains National Park, which is a high plateau, composed of tropical montane forests. Later dying of forests were observed at several areas including Hakgala montane forest.

Physical parameters trace nutrients as well as toxic element concentrations in soils, were studied in order to identify the possible geochemical factors behind the forest die back. Systematic soil sampling was carried out covering the entire Horton Plains National Park and random samples were collected from Hakgala montane forest. Samples were analyzed for available Fe, Mn, Zn, Cu, Ni, Cd, Al and Pb using standard colorimetric and atomic absorption spectrometric procedures. Physical parameters such as pH, moisture content, and conductivity of the samples were also measured.

Among extractable micro-nutrients Cu and Zn, and Ni show no deficiency or excess levels. However, the recorded available high concentrations of Fe, Mn and Al can be toxic to certain montane plant species. Acidic moist soil of the area may enhance the toxic effects of these elements. Possible source of these elements should be the underground lithology of the area.

According to the results obtained, there is a relationship between forest die back and high Pb concentrations. The same phenomenon was also observed in the Hakgala forest. The distribution pattern of Pb in the Horton Plains coincides well with the die back distribution pattern. The observed Pb values at Horton Plains and Hakgala are almost similar to values observed at Pannipitiya and Dombagaskanda locations, which are located close to main roads carrying heavy traffic. It is quite possible therefore, that Pb toxicity may be a significant factor behind the forest die back even though other factors should not be completely ruled out at this juncture. Strong monsoon winds, bringing Pb from the polluted southwestern part of the country, can be the most possible source of soil Pb. Further studies however are indeed necessary to confirm the conclusion.

Introduction

Forest die back in some parts of the world has been identified as a phenomenon occurring as a result of nutrient imbalance or soil toxicity. It has frequently been ascribed to Al toxicity and Al induced nutritional disorders due to increased acidification of forest soils (Keltjens et al. 1989). Nutrient deficiency is considered as a contributory factor to canopy die back in montane forests in Hawaiian islands (Balakrishnan and Muller Dombois 1983; Gerrish et al. 1988). Lyon (1909, 1918, 1919) found that soil toxicity developing with soil aging and poor drainage is the cause of dying back of native trees in Maui.

A forest patch with dead and dying trees was first observed in Sri Lanka by Perera (1978), Werner (1982) and Hoffman (1988) in Thotupolakanda mountain rising up from Horton Plains which is covered with biologically as well as hydrologically unique tropical upper montane rain forests. Werner (1988) reported the forest die back from tropical upper montane forests from Pidurutalagala ridge and Knuckles mountain range. Wijesundara reported another case from Hakgala ridge (1991).

Although several hypotheses such as air pollution, disease, and sambur damage were put forward to explain this phenomenon, later studies could not prove any relationship between forest die back and the above hypotheses (Gunawardhana et al. 1998; Adikaram and Mahaliyanage 1999; Ranawana 1999).

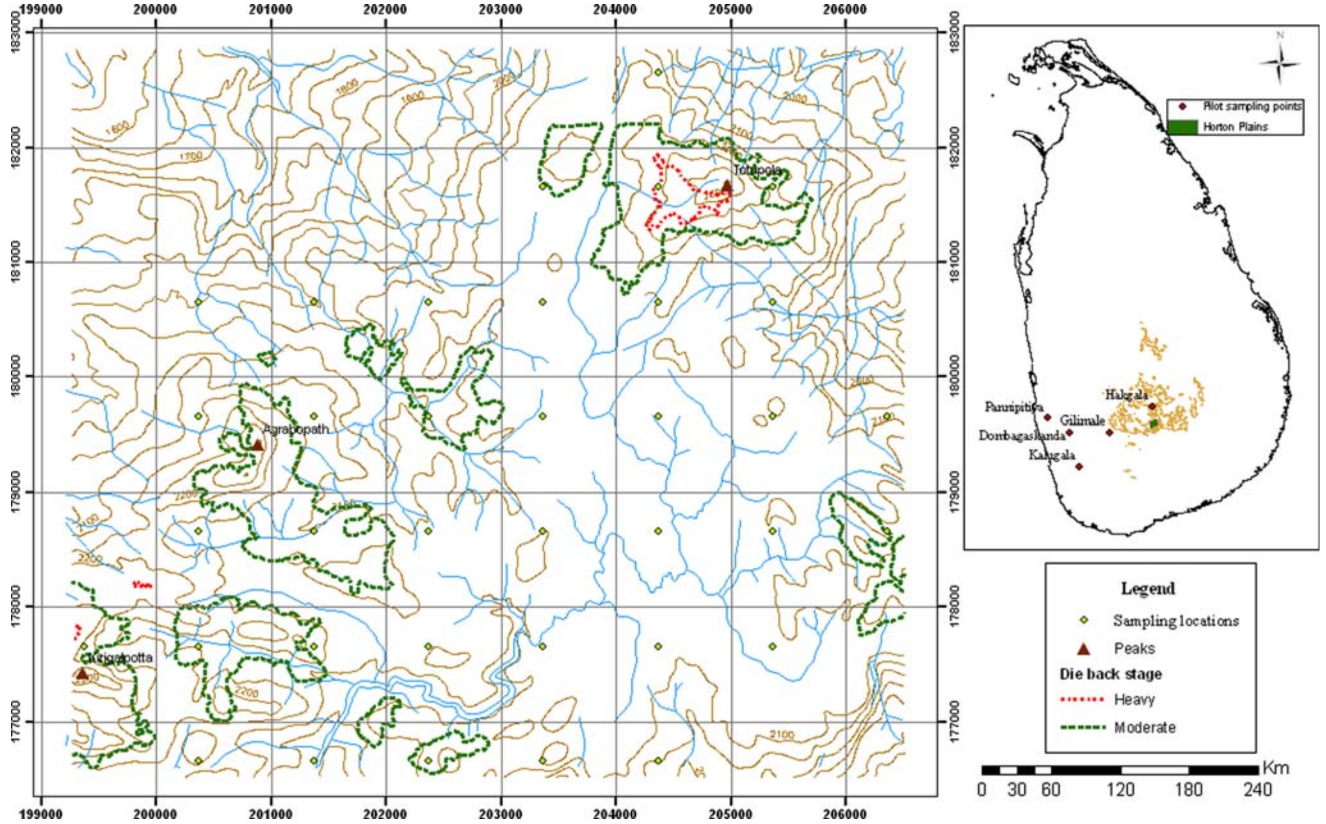
Wijesundara (1991) revealed that total nutrient content was high in die back forest areas of Sri Lanka while available forms were in low concentrations. However study on major soil nutrient levels by Ranasinghe and Dissanayake (1999) could not identify any such relationship between forest die back and major nutrient levels of soils.

This study aims at identifying possible impacts of soil trace element levels on forest die back of the upper montane rain forests in Sri Lanka. The study was carried out mainly in Horton Plains National Park.

Physiography, geology and soils of Horton Plains

Horton Plains National Park occupies the southern boundary of the anchor shaped central hills of Sri Lanka. Three mountains namely Kirigalpotta (2,389 m), Totupolakanda (2,357 m), country's second and third highest peaks respectively, and Agrabopat rise from the Horton Plains. Because of the prolonged erosion, the Horton Plains could be seen as a gently undulating highland plateau. Being the source region of the three main rivers Mahaweli, Kelani and Walawe, Horton Plains serves as a major catchment area of the country. Drainage pattern of the area is complex since the geology and structure of the area is equally complex. From the aerial photo interpretations, one observes these patterns as being dendritic and rectangular (Fig. 1).

Fig. 1 Physiography of the Horton Plains National park and sampling locations



The Horton Plains area is a part of the Highland Complex of Sri Lanka, which comprises of high grade, lithologically and isotopically distinct, Proterozoic metamorphic rocks, metamorphosed in the Neoproterozoic/early Phanerozoic period (Kroner et al. 1991). In fact, the Horton Plains lie in the eastern part of it. The main lithologies found in the area are quartzite, charnockites, quartzo feldspathic gneisses, hornblende–biotite gneisses and garnet–sillimanite–biotite gneisses (Geological Survey and Mines Bureau 1995) (Fig. 2).

The area consists of simple, overturned folds, well-defined fracture zones and shear zones. Another special feature found in the area is the *''nappe''* structure. Extensive weathering and erosion along a weak shear zone may have resulted in the ''world's end'' escarpment.

Horton Plain area consists of a variety of red yellow Podzolic soils, wet mountain regosols, bog soils and half bog soils (Central Environmental Authority 1997; Fig. 3). Soils of Horton Plains are rich in organic matter in the surface horizons due to slow rate of decomposition. The organic matter content varies from 15 to 25%, and the texture of the surface soil is loam. A large number of earthworms can be seen on the surface soil. Decomposing rock fragment are common in the sub soil.

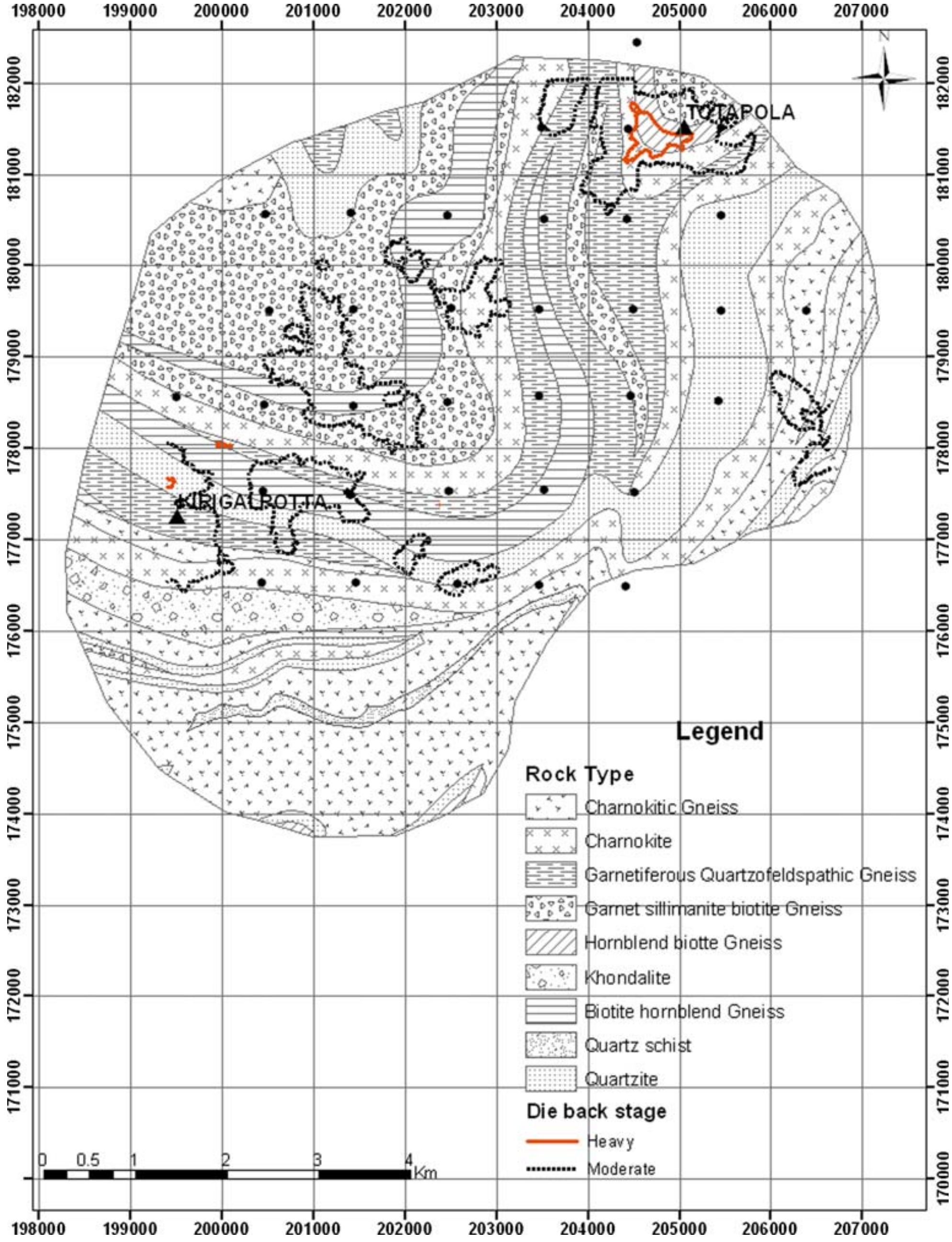


Fig. 2 Geology map of Horton Plains

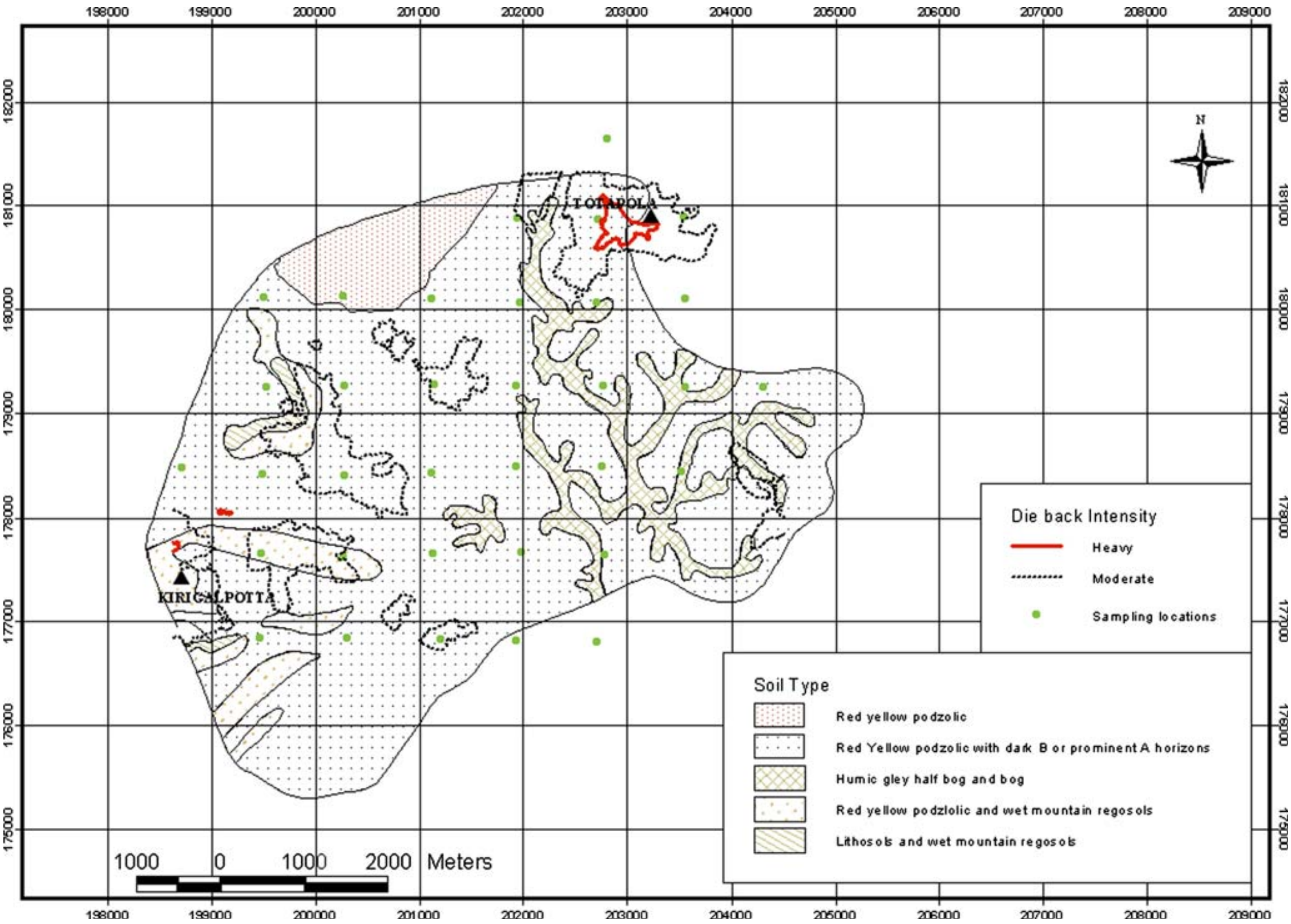


Fig. 3 Soil map of Horton Plains

Climate

Isohyets derived from thirty years of rainfall data from five rain gauge stations around Horton Plains revealed that the mean annual rainfall recorded in the site where the automatic weather station had been established in the park is 2,150 mm (Gunawardena et al. 1998). The study by Gunawardena et al. (1998) has also found that the rainfall is well distributed and a minimum of 100 mm is received each month. Also it has been found that the north-west monsoon brings more rain to Horton Plains than the south-west monsoon.

In Horton Plains fog occurs frequently during the early afternoons and may persist throughout the whole day during the wet season especially during rainy seasons of southwest monsoon. Gunawardena (1998) found that the net rainfall of the area was 2% higher than the actual rainfall and this additional amount was attributed to cloud deposition.

According to Mueller-Dombois and Perera (1971) the mean annual temperature of Horton Plains is 13°C. During the dry months, January and March, the temperature fluctuation is higher than that in other months.

Vegetation and forest die back

The forest community in some selected sites of the forest of Horton Plains was represented by 57 species of vascular plants (Balasubramaniam et al. 1993). They belong to 44 genera and 31 families. Among those 57 plant species, 29 (50.87%) species are endemic to Sri Lanka. While 18 species (31.58%) are seen in montane forests of Sri Lanka and India, the rest of the ten species are distributed beyond south India and Sri Lanka. Another study by March for Conservation (1994) reveals the presence of 101 flowering plant species, which include 14 endemics belonging to 20 families.

Ranawana (1999) has found that about 654.3 ha (17.2%) of forested areas in Horton Plains are subjected to die back. It is severe on Thotupolakanda and Kirigalpotta areas where more than 75% of the canopy trees are dead and the remaining trees also showing signs of degeneration. Forest regeneration in these areas is found to be very slow. A study by Adikaram and Mahaliyanage (1999) has identified families such as Lauraceae, Simplocaceae, and Myrtaceae that are highly susceptible for die back. *Syzigium rotundifolium, Ilex walkeri*, *Euodia lunu-ankenda*, *Symplocos bractealis* are some of the dominant plants species susceptible to forest die back. Also it has been noted that susceptibility to die back gradually increases as the GBH class increases. This study reveals that plants on wind-exposed areas are more susceptible than the plants on wind covered sites.

Methodology

Field sampling

The Horton Plains National Park area was subdivided into 1 × 1 km^2 grids. Soil samples were collected from the centre of each grid. Centre of each grid was identified using topographic maps, aerial photographs, and global positioning system.

Soil samples were collected from upper montane forests in the Hakgala mountain range for comparison. At this site plots were located representing different habitats at different die back stages using base maps of 1:25,000 and aerial photographs. Each plot is 50 × 50 m in size. Four soil samples were collected from the corners of the each plot.

Samples were collected from three different depth horizons in each and every location.

Also another four soil samples were collected from four different locations of the country, where different environmental conditions prevail, in order to compare the element concentration levels with that of Horton Plains.

Chemical analysis

All soil samples were immediately analyzed for moisture content, pH and Ec (electric conductivity) at the laboratory, after which they were analyzed for Al, Fe, Mn, Cu, Zn, Ni, Cd, and Pb. The available Zn Cu, Mn, Fe, Ni and toxic elements Cd and Pb were determined by extracting the soil with DTPA- ammonium bicarbonate extract (Soltanpour and Schwab 1977). Extractants were analyzed for the above elements by AAS (Dale and Norman 1982).

KCl is a solution commonly used for the extraction of available Al (Barnhisel and Bertsch 1982). Extracted Al ions were spectrometrically determined by developing colour with Aluminon-acetate buffer.

Quality control

Quality control measures were strictly adopted during chemical analysis to maintain the accuracy and precision.

To cross check the procedural errors ten duplicate samples were prepared following exactly the same procedure. Two sample blanks were prepared for DTPA, amonium bicarbonate and KCl extractant solutions. Their average concentration values were subtracted from sample concentration values to further omit procedural errors. To check the instrumental errors, standard reference samples were analyzed with every sample set. Also a set of selected samples was analyzed with another AAS machine to cross check the instrumental accuracy. It was observed that the variability of results was within 2–3%.

To check the precision of data, repetitions were made at every ten samples.

Data interpretation and representation

Spatial distribution of each element at different depth levels was studied using Surfer 7 software. Element concentrations were girded using 70 m grid line spacing along X and Y directions and with blanking distance of 500 m.

Die back distribution pattern of the Horton Plains National Park was investigated by ground surveying as well as by satellite image interpretation. Main die back plots were demarcated by GPS surveying.

Arc View 3.2 software was used to analyze the correlation between element distribution and forest die back distribution maps in a GIS environment.

Results and discussion

Physical parameters

pH value of the soil indicates that the soil of entire Horton Plains is acidic. It generally varies from 4 to 6 without depending on the depth. Soil is slightly acidic (pH around 5.5–6.0) on ridges such as Thotupolakanda and Kirigalpotta. In grasslands where a peat layer is found on top, the soil is more acidic and there was no relationship between forest die back and soil acidity that could be observed.

Moisture content, which varies from 17 to 52% in top soils, decreases towards the bottom layers and in general top soil of grasslands has high moisture content.

Micro-nutrients

Among DTPA extractable micro-nutrients Cu, Zn and Ni show no deficiency or excess levels. Cu content in top soils varies between < 1 and 2 ppm. A very similar range is found at the middle (30 cm) and bottom (75 cm)

Table 1 Extractable concentrations of Al, Fe, Mn and Pb in soils of Horton Plains

Depth	Al (ppm)	Pb (ppm)	Fe (ppm)	Mn (ppm)
Top				
Max	154	2	609	25
Min	< 1	< 1	< 1	< 1
Mean	73	1	160	6
Middle (30 cm)				
Max	137	8	251	2
Min	5	< 1	12	< 1
Mean	68	1	84	1
Bottom (75 cm)				
Max	180	7	142	21
Min	2	< 1	12	< 1
Mean	55	1	38	2

sampling levels. Zn content varies between < 1 and 2 ppm in top soils. At middle and bottom layers also the range is more or less similar except for two adjacent locations where the value exceeded 10 ppm. Ni, which is a toxic element when found in excess, occurs in concentrations < 1 ppm at all sampling depths except in very few cases. None of these elements show a relationship with the die back distribution pattern.

Iron

Iron is an important micro-nutrient for plants. It exists both as Fe^{2+} and Fe^{3+}. DTPA extractable Fe concentration in top soil is 20–609 ppm, it is 12–251 ppm at 30 cm depth and 12–142 ppm at 75 cm depth levels (Table 1). Depth level variation shows that Fe concentration increases from bottom to top. From the distribution map it is clear that top levels of south-western and northern slopes of the Thotupolakanda ridge where forest die back is prominent, are rich in Fe (200–400 ppm). Top soil in the grasslands has a comparatively low concentration of available Fe (< 100 ppm). This pattern can be observed even at middle levels of the profile (Fig. 4).

Fe toxicity has been recorded for plants even at a level of 30 ppm (Martin 1968). At low pH and water logging conditions toxicity of Fe is thought to be more pronounced. Also when the soil is under continuously poor aeration, high Fe concentration may limit the capacity for absorption of available N. Therefore this high level of available Fe may be a contributing factor for forest die back in the presence of low pH and highly moist soils.

It is of interest to note that such high available Fe contents were suspected to be one of the factors for Hawaiian forest die back (Balakrishnan and Muller-Dombois 1983).

Manganese

This study shows that average DTPA extractable Mn concentrations in top soils of Horton Plains vary from < 1 to 25 ppm. Several locations have values greater than 10 ppm and even 20 ppm. At 30 cm depth it decreases up to < 1–2 ppm and at 75 cm depth the level again increases up to < 1–21 ppm (Table 1). Mn distribution maps show that high Mn concentrations are found in top soil (13.5–8.0 ppm) at Thotupolakanda ridge, Kirigalpotta ridge and surrounding areas where forest die back is extensive. Around Kirigalpotta ridge comparatively higher levels are found at middle (30 cm) and bottom (75 cm) levels (> 1 ppm) as well.

Soils of the grasslands have comparatively low levels of available Mn concentrations at all levels (< 3.5 ppm; Fig. 5).

In Hawaiian forest die back areas NH_4OAC extractable Mn content varies from 1 to 50 ppm and high values are considered as a possible predisposing factor for forest die back. Hoyt and Nyborg (1972) have shown that available Mn concentrations greater than 7 ppm are toxic to certain plant species. As in the case of Fe, impacts of Mn are more prominent in acid soils. Therefore in acidic soils of Horton Plains, Mn may be a contributing factor for forest die back.

Toxic elements

Cadmium

Cadmium is toxic to plants. DTPA extractable Cd levels were initially measured at 16 locations and it was found that all samples contain levels below the detection limit.

Aluminium

Al is not an important nutrient for plant growth. However, high concentrations cause toxicity for plants. Average 1N KCl extractable Al concentrations in top soils of the Horton Plains vary from 5 to 154 ppm. At 30 cm this level varies between 5 and 137 ppm and at 75 cm, 2–180 ppm (Table 1). From distribution maps it is clear that higher available Al levels in top soils (> 100 ppm) are found mainly on plains. In most of the ridges including Thotupolakanda and Kirigalpotta values are less than 80 ppm. Towards the middle (30 cm) and bottom (75 cm) sampling interval levels available Al concentration values are comparatively higher at Thotupolakanda ridge (> 100 ppm; Fig. 6).

Existence of clays, which readily release Al to soil, may cause this phenomenon. Generally montane forests of Sri Lanka contain high Al contents (Werner and Balasubramanium; Werner 1992). Their study has

Fig. 4 Fe distribution map of Horton Plains

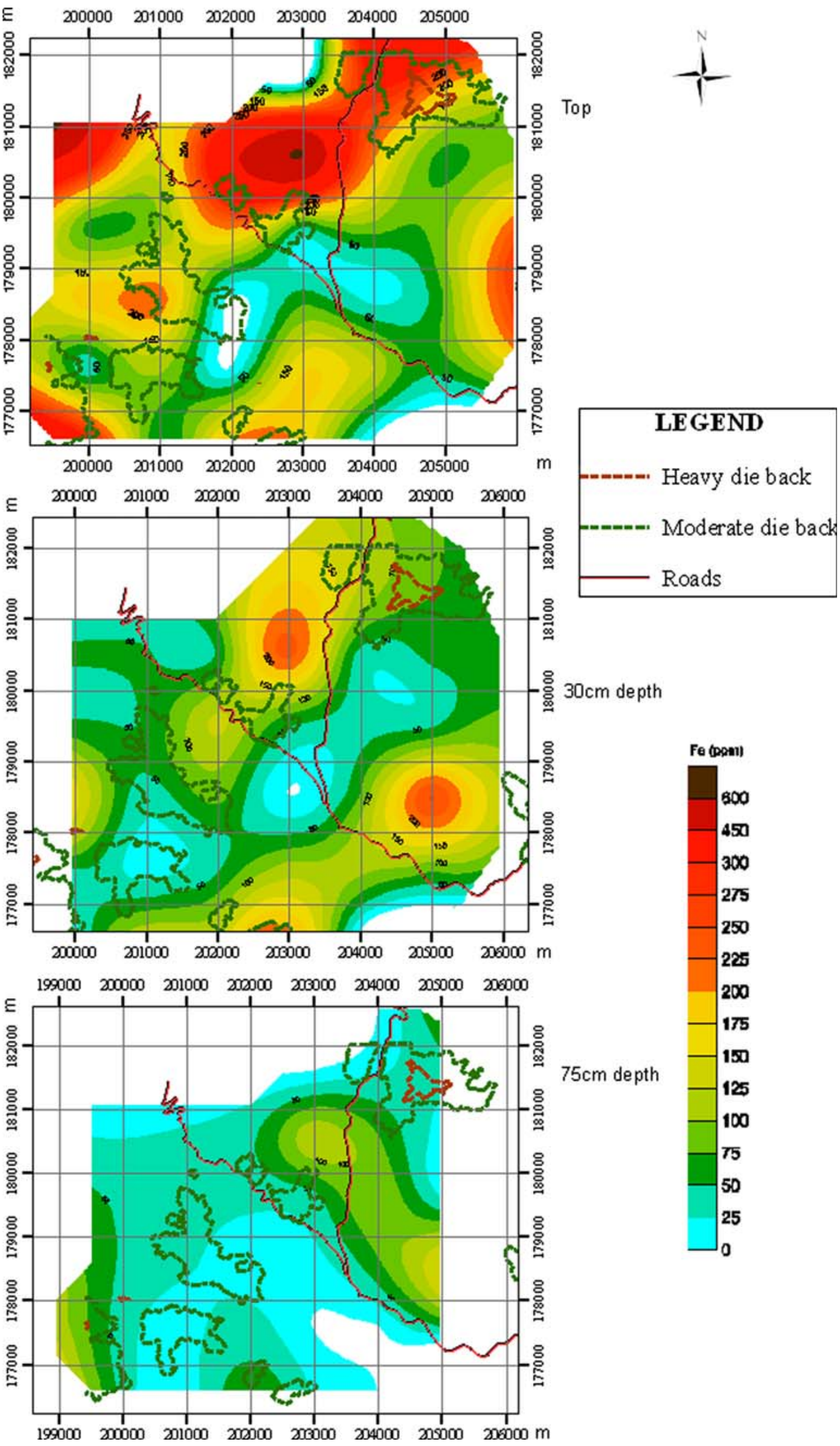
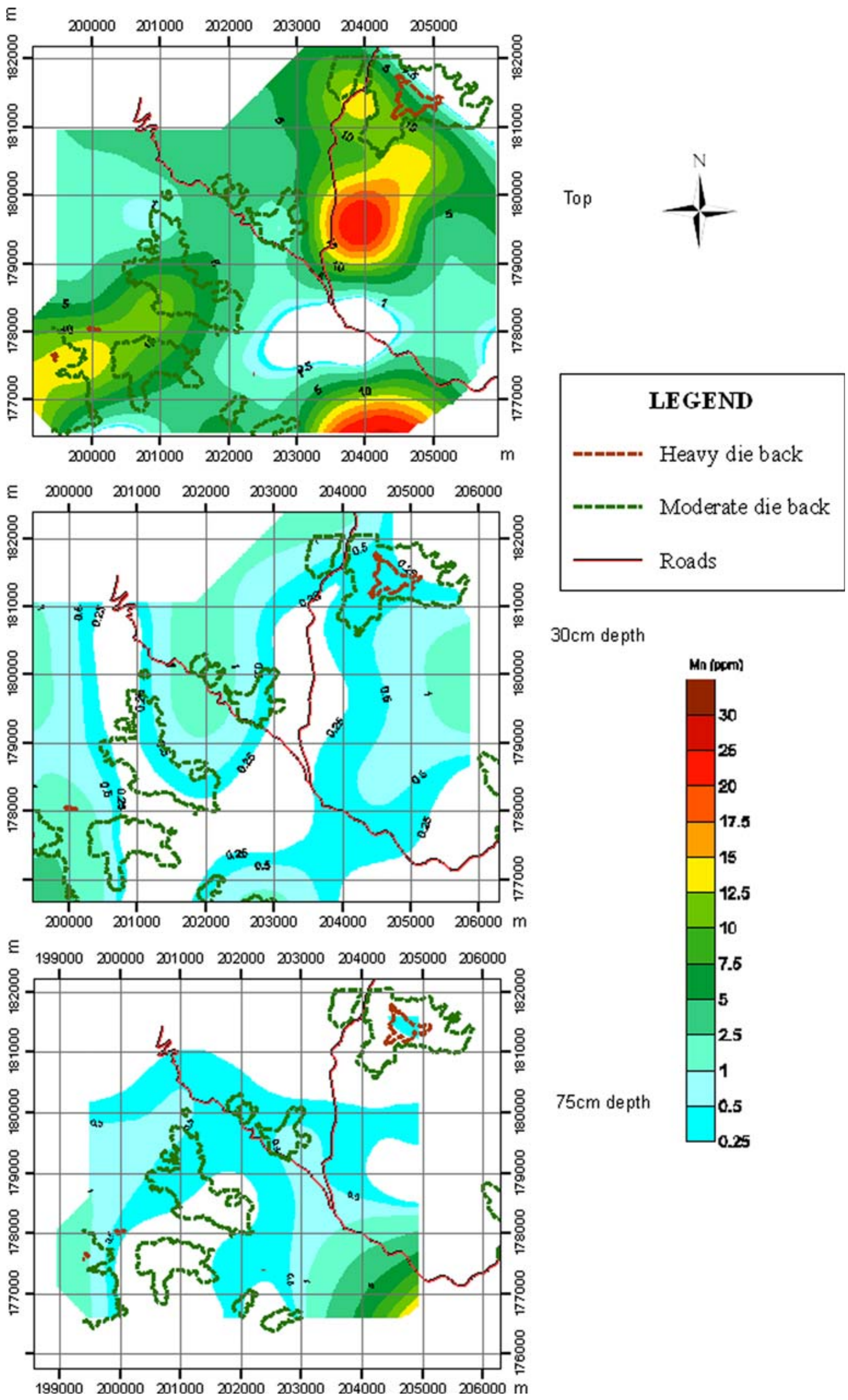


Fig. 5 Mn distribution map of Horton Plains



shown that World's End and Totapola of Horton Plains have 1,180 ppm and 1,014 ppm of total Al. Leaching of Al during intense weathering of quartz feldspar rich rocks of the Highland areas results in the high Al contents in soils. This high value of Al has toxic potential for plants and it has been found that extractable concentrations of 15–20 ppm can also be toxic to certain plants. This toxicity may be more significant when the soil is acidic and water logging (Balakrishnan and Muller Dombois 1983). Therefore, there can be a contribution from high Al levels in Horton Plains (generally greater than 50 ppm) to the forest die back, though there is no significant visible correlation between spatial distribution of Al levels and forest die back.

Lead

Lead is not a nutrient element for plants, but Pb distribution in soil was studied, as it is a major toxic element in soils. Average available DTPA extractable Pb concentration of top soils varies from <1 to 2 ppm. At 30 cm depth it is in the range between <1–8 ppm and at 75 cm depth it varies from <1 to 7 ppm. This shows an increase towards the bottom layers (Table 1).

Available Pb distribution map of Horton Plains suggests a strong relationship between forest die back and concentrations at top level (Fig. 7). At Thotupolakanda, Kirigalpotta ridges where forest die back is prominent, Pb concentrations are significantly high (>1.5 ppm). At middle sampling level (30 cm depth) more or less similar distribution pattern is observed and concentration levels are >1.0 ppm. At bottom sampling level higher concentrations (1.0 ppm) of Pb is found at southern slopes of Thotupolakanda ridge, western slopes of Kirigalpotta and die back areas situated at SE direction of the Horton Plains. Generally grasslands show lower available Pb concentration (<0.5 ppm).

This bottom enrichment of Pb, found on eastern and south-eastern parts and surface enrichment, found in northern and south-western parts, are significant. Surface enrichment is generally associated with ridges located in the Horton Plains while bottom enrichment is associated with plains and undulating topography.

In Hakgala tropical upper montane forest, where forest die back is extensive, and situated about 20 km north of Horton Plain, average DTPA extractable Pb value in the top soil is 1.65–3.17 ppm (Table 2). Concentration of DTPA extractable Pb levels at different parts of the island was also measured during the study to identify whether there is any Pb anomaly in the Horton Plains area. It shows that Pb values at Horton Plains and Hakgala are almost similar to values at Pannipitiya and Dombagaskanda locations, which are close to the main roads. Other locations, situated away from main roads, have significantly lower (<0.5 ppm) Pb concentrations.

This result clearly shows that in soils of Horton Plains, available concentration of Pb, which is a toxic element, is similar or even higher than essential micronutrient (Zn and Cu) levels of the soil. Further, levels of DTPA extractable Pb are similar to the levels recorded in soils on heavily polluted traffic congested roads.

Studies have identified surface enrichments of Pb in most Scottish soils and elsewhere. This phenomenon has been described as a plant accumulation rather than an atmospheric pollution or fertilizer contamination. Surface enrichment of Pb in high elevated areas and bottom enrichment in low elevated areas of Horton Plains is difficult to understand based on this hypothesis.

As the underlying rock assemblage is restricted to high-grade metamorphic rocks such as quartzite, quartzofeldspathic gneiss, charnokitic geneiss, and chrnokokites, source of Pb cannot be attributed to the underground geology. Extensive expansion of forest die back since it was first record in 1960s is also a strong evidence to rule out the contribution from a natural source such as underground geology.

Therefore the most possible source of high Pb levels can be the wind bringing polluted air. The south-western monsoon winds, which sweep the industrialized south-westen part of the country, yielding heavy precipitation at south-western part of the central mountain massif may bring Pb to this area. Occurrence of DTPA extractable Pb in soils at the montane forests found in this south-western part of the central massif at levels similar to polluted areas close to traffic laden roads may validate this hypothesis.

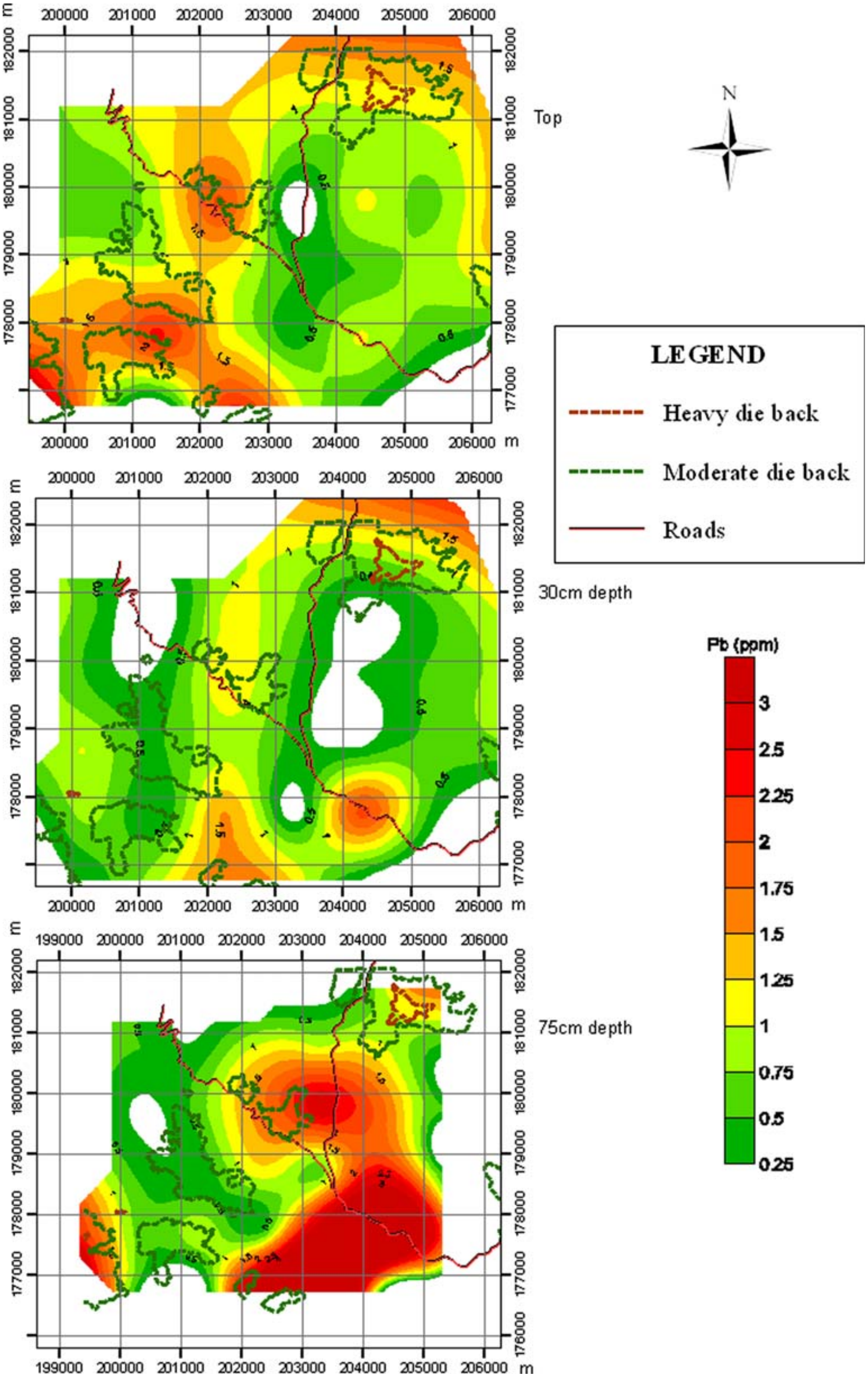
As discussed above more than 70% of the dying plants are endemic to Sri Lanka and many of them are restricted to high altitudinal tropical montane forests of the country. They may be highly sensitive to high Pb levels in soils. Therefore Pb may be a strong contributory factor for forest die back in this region

Conclusions

Results of this study show that the soils of Horton Plains is acidic and no direct relationship between forest die back and physical parameters such as moisture content, pH and conductivity could be identified.

High concentrations of available Mn, Al, and Fe levels in Horton plain areas may be predisposing stress factors for forest die back. Sources of these elements can be geological and effects might be enhanced by acidic soil of the area.

Fig. 6 Al distribution map of Horton Plains



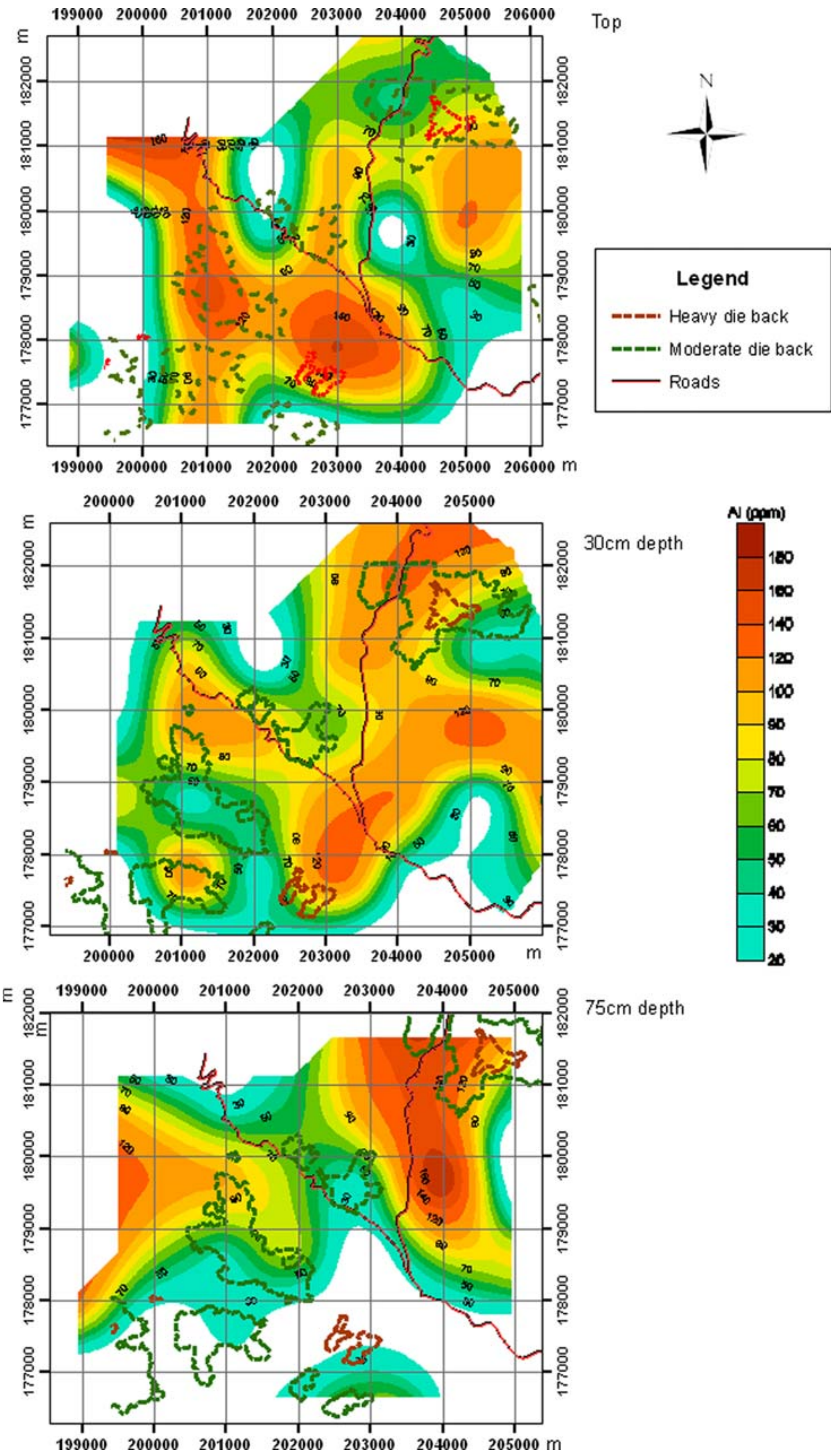


Fig. 7 Pb distribution map of Horton Plains

Table 2 DTPA extractable Pb in top soils of different locations in Sri Lanka

Location	Description	DTPA extractable Pb (ppm)
Horton Plains	Montane forest and wet Patana grasslands	0.37–1.63
Hakgala	Montane forest	1.65–3.17
Gilimale	Low country forest	0.254
Kalugala	Home garden away from main traffic roads and close to a wet zone forest	0.424
Dombagaskanda	Low country forest about 1 km from the main traffic road	2.18
Pannipitiya	Home garden about 1 km from the main traffic road	2

DTPA extractable Pb level shows a good correlation with die back distribution pattern and the levels in concerned areas are more or less similar to the levels in polluted areas of the country close to traffic roads. Source of Pb might be strong south-west monsoon winds carrying Pb particles. Since most of the dying plants are endemic and restricted to tropical montane forests of Sri Lanka, they may be sensitive to elements foreign to their environment as exemplified by Pb. Even though lead appears to be a strong candidate for the cause of forest die back, a further detailed study of other element contents in plant matter is needed to confirm this hypothesis.

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