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Forest Dieback as Affected by Soil Pollution with Special Reference to Montane Forests - A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Authors HKSGG and PIY designed the study and wrote the first draft of the manuscript. Author HKSGG managed the literature searches. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Forest mortality has an upward trend worldwide but has regional aspects as well. Preventive and suppressive measures are based on regional approaches, which address areas of high, medium and low risk mortality. As far as the existence of montane forest ecosystem is concerned, it will be extremely important to eradicate the threats on this delicate ecosystem. One of the most severe threats to montane forests is "dieback". Since dieback dramatically deteriorates the richness of the forest stands, the functions offered by the forest will also be affected.

If dieback is somehow linked with a contamination of the forest soil by various pollutants resulted by vehicle emission, industrial waste, agrochemicals etc., remediation of the polluted soil should mitigate dieback. If the necessary measures are taken to improve the soil quality as a whole in the affected areas, the deteriorated forest stands could be restored. For the execution of a successful soil remediation program aiming at mitigating forest dieback, it would be essential to identify the

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key causes behind dieback first and then, depending on the type of the pollutants and the status of the pollution, the most appropriate soil remediation techniques could be selected. The remediation should be continued until the detectable levels of each contaminant in the soil reaches below the safety levels agreed upon. Finally, the gaps caused by dieback could be filled by a successful reestablishment of trees to bring the affected forest a full recovery.

Keywords: Forest dieback; Montane forest; trace elements.

1. INTRODUCTION

Currently, forests are major contributors to the terrestrial ecosystems that remove about 3 billion tonnes of anthropogenic carbon from the atmosphere every year through net growth, absorbing about 30 per cent of all CO_2 emissions from fossil fuel burning and net deforestation. The 40 million square kilometers of forest ecosystems, almost a third of the Earth's total land area, store reservoirs of carbon holding more than twice the amount of carbon in the atmosphere. Other than mitigating global warming by absorbing CO_2 in the atmosphere, forests offer many other functions to maintain the environmental quality of the globe [1]. Forest also serves as a water catchment. Much of the world's drinking water comes from catchments that are or would naturally be forested. The loss of forest cover and conversion to other land uses can adversely affect freshwater supplies, threatening the survival of millions of people and damaging the environment [2]. Contribution of forest in maintaining biodiversity is widely accepted. Biological diversity of a forest indicates the variability among the living organisms and the ecological processes of the forest that includes diversity within species, between species and of ecosystems and landscapes [3]. As far as the critical role played by the forest for the existence of crucial components of the biosphere is concerned, every possible effort will have be given to protect the forest resource from looming threats such as dieback.

1.1 Montane Forest

Montane forests are found between 500 and 3,500 m altitude with major occurrence between 1,200 and 2,500 m in the tropics [4]. They may occur within the montane and sub- montane floristic zones. Within the humid tropical zone, some vegetation gradients are observed with increasing altitude. Diminishing tree height, simplified stratification, smaller leaf size, more open understory, some floristic changes, and more epiphytes, mosses, and lichens are clearly observed with increasing altitude [5]. Tropical montane forests are usually of low stature [6], whereas submontane forests have greater stature (20-30 m vs. 15-25 m), are richer in species, have more vascular epiphytes, and incorporate species from low and mid-altitude forests [7].

Montane forests are thought to be more vulnerable to the changing environmental conditions because (1) highly specific conditions are necessary to sustain their specialized and often endemic biota, (2) steep environmental gradients are associated with their boundaries, (3) montane biota are extremely vulnerable to invasion and displacement by nonnative plants and animals, (4) diversity and productivity are lower compared to ordinary tropical rainforest, (5) nutrient-cycling rates are lower than ordinary tropical rain forest, (7) montane forest stands have been established on uneven and frequently on steep slopes, and (8) soil is shallow and very often highly acidic [8-12].

1.2 Forest Dieback in Montane Forest

Forest dieback, characterized by the gradual but synchronized mortality of mature canopy trees in large groups [13], occurs world-wide in a great diversity of forests [14-17]. The death of trees cannot be attributed simply to species-specific, pathogens, parasites, pollutants or any other single agent of disturbance but must be induced by a combination of biotic and abiotic factors, which have hardly been explained due to the complex patterns of dieback created by the interactions of several inconspicuous factors [18]. When persistent and extensive, it could be one type of forest decline. Dieback events can exhibit some or all of the following features: dieback can occur as isolated, short term events and on individual trees in response to environmental stress but frequently persistence and progressive development which results in the death of whole trees, and can ultimately extend over much of a forest region. Crown anomalies including tufting of leaves, and immortality of leaves, buds, twigs and branches are characteristic; other anomalies such as early leaf coloration, premature leaf-fall, leaf necrosis, and small leaf size can co-occur but may not necessarily progress to crown dieback. Stem dieback from branch tips inward toward the bole, mortality of the fine roots, and reduced radial growth are characteristic. Symptoms of dieback commonly occur concurrently with one or several diseases and insect infestations. Recovery can occur, dependent on the severity and duration of the injury [19].

According to [19], dieback cannot be considered as a disorder, but rather a normal phenomenon that is often associated with regeneration of the dying canopy species. A study on forest dieback done by [20] has revealed that the dieback is not correlated with either drought or exceptionally moist conditions in the soil. However, [21] has investigated how the extreme rain fall events in the form of short term droughts and floods affect on dieback in trees that lose vigor due to prior chronic stress (such as nutrient imbalance or advanced age) but, the results were in a disagreement with [22,20]. The effect of polluted rain on forest dieback in industrialized areas has been reported by [23]. There is enough evidence to prove that acid rain as one of the major contributors to the forest dieback [24].

Forest dieback in the Horton Plains National Park (Fig. 1), a tropical montane forest in Sri Lanka, was of significant proportions. As much as 38% of the individual trees sampled were affected by die-back; 13% were dead and 25% showed symptoms, of varying degree [26]. Estimations using recent satellite images combined with ground surveys revealed that about 654 ha, equivalent to 24.5% of the forest in the park has been subjected to dieback. In Thotupolakanda and Kirigalpotta areas, dieback is severe, with over 75% of the canopy trees dead and the rest is in a state of degeneration [26]. One of the worst affected trees was *Syzygium rotundifolium* followed by *Cinnamomum ovalifolium*, *Neolitsea fuscata*, *Syzygium revolutum* and *Calophyllum walkeri* [18]. Also, in these areas, seedling establishment and forest regeneration appear to be at very slow state [17]. When it was first discovered in Sri Lanka in the 1960s, the research community came up with numerous hypotheses such as low absorption of nutrients by plants, the dropping of ground water table, plant diseases, acid rain, damage caused by Sambar (*Rusa unicolor*, climatic change and ultimately lead (Pb) toxicity [27]. Sambar or *Rusa unicolor*, is the largest oriental deer. Seven subspecies occur in varied habitats and elevations from India and Sri Lanka throughout southeastern Asia [28].

Table 1 also shows that the top soils of the areas which are in close contacts with vehicle trafficking have higher Pb levels. Hakgala is a montane forest through which a main road has been constructed and the road is usually busy with heavy vehicle traffic. Pannipitiya is a highly populated urban area with higher levels of industries and vehicle emissions. The results show some direct correlation between vehicle emission and soil contamination with Pb.

Fig. 1. Forest dieback in Horton Plains National park, a typical tropical montane forest, in Sri Lanka Source; [25]

Table 1. 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	0.36-1.63
Hakgala	Montane forest	1.65-3.17
Gilimale	Low country forest	0.254
Kalugala	Home gardens 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 1km from the main traffic road	2

Source [29]

2. FACTORS AFFECTING FOREST DIEBACK IN MONTANE FORESTS

2.1 Natural Causal Factors

Plants are subjected to a wide range of natural stresses, including those induced by changes in water and nutrient levels, light, temperature, and biotic factors. Drought has been suggested as a primary cause of forest decline. Suggestions that upper elevation forests including montane forests experienced drought-triggered declines [30] are based on weather records that do not take into account the contribution of cloud water condensates which constitute over half the total water input into these ecosystems [31]. Trees undergoing nutrient stress may be predisposed to decline upon super imposition of anthropogenic pollution or natural stresses [32]. It is, however, unlikely that montane forests which currently experience extensive forest decline are dying because of uncomplicated, natural nutrient stress. There are many reports on rapid decline of trees presently or previously damaged by insect defoliation or diseases [33]. Over a hundred years of study of insect depredations and diseases has permitted precise evaluation of such damage [34], but the available symptomological and etiological evidence militates against current declines having a unitary biotic cause [35]. Reality is that too many tree species in too many geographical areas of montane forests have been affected by dieback [36]. Where trees have received biotic injuries, they may react more severely to anthropogenic stress factors [37]. Since trees of many species and all age classes are declining simultaneously [38], natural life cycles and forest senescence are implausible as a significant causal factor.

2.2 Anthropogenic Causal Factors

Soil is not only a part of the ecosystems, but also occupies a basic role for animals and plants, because the survival of animals and plants is tied to the maintenance of its quality. Soil has many important and complex functions as filter, buffer, storage and transformation system, protecting the global ecosystems against the effects of pollution. These functions of soil are not unlimited, but are effective as long as soil quality is preserved [39].

Man's impact on the soil has been very broad and complex, and most often has led to irreversible changes. A growing capacity of man to alter his surroundings and to control several natural processes is a source of drastic changes altering the balance of fragile natural ecosystems such as forests. Man-made changes disturb the balance of each ecosystem that has been formed evolutionarily over a long period of time. Thus, these changes most often lead to a degradation of ecosystems. Soil pollution, especially by toxic chemicals is one of the most effective factors in the destruction of many ecosystems including forest. Interactions of pollutants with natural environmental factors augment plant stress [35].

2.3 Acids and Trace Elements

Montane forests are usually found on the highest elevations which results in excessive exposure to wind, rain and clouds. Also, under humid tropical conditions, these forests receive excessive rain which results the leaching of basic cations in the soil leading to soil acidity. Acids and trace elements, which are transported by the wind for a long distance, are deposited on montane forest ecosystems both as wet deposition and as dry fallout [30]. Sulfuric and nitric acids directly damage plants. High acidity directly damages foliage [40], rendering leaves incapable of normal water relations [41], resisting infection [42], and affecting photosynthesis [43].

Acids accumulating in soils [44] affect nitrogen fixation, nitrogen transformations [45], growth of acid-sensitive moss and lichens [46], microbial activities in soil [47], and stress many other components of forested ecosystems [48].

Lower litter fall and slower rate of organic material recycling in montane forests compared to ordinary tropical rain forest, results relatively poor production of humic matter in the soil. So, the acid ion buffering action in montane forest soils is lower than ordinary tropical forests. Therefore, the development of acidity in montane forest soils is obvious. Soil acidity leads to extensive mobilization of original and deposited trace elements [49]. Contaminated soil solutions with trace elements allow these elements to accumulate in roots [50], to affect seedling growth [51], root development and root function [52], litter decomposition, and they synergistically interact with acids to aggravate damage to plants and to ecosystems receiving acidity [53]. Acids and ions of trace elements also cause stresses of the mineral and organic nutrition of plants [54]. Acidic precipitations intensify leaching of inorganic ions and organic compounds from foliage [55].

2.4 Gaseous Pollutants

A second category of stresses are those imposed by gaseous pollutants on aerial plant parts. Sulfur and nitrogen oxides [56], ozone, organic oxidants [57], hydrogen peroxide [58] and metabolic inhibitors [59] have each been detected in quantities sufficient to cause stress, damage, and forest decline [60]. Sulfur- and N-oxides may affect plants both before and after being converted into acidic ions. Loss of integrity of leaf cutin and waxes, alteration in stomatal control, and other leaf cellular damages repress water movement, cell respiration, and photosynthesis, all contributing to immediate and prolonged stress leading to decline and death [61]. Ozone and other oxidizing pollutants cause a variety of direct injuries and stresses to receiving foliage [62] that, in turn, affect roots [63], litter decomposition [64], soil microbial activity [65], and gas exchange [66]. In general, however, symptoms of uncomplicated gaseous pollutant damage can be distinguished from those induced by other causal factor complexes [67].

2.5 Nitrogen Compounds

A third category of anthropogenic stress factors include a broad range of response to increased ecosystem loadings with nitrogen compounds [68]. Alterations in reduced N/oxidized N ratios in soil solutions in favor of NO_3^- [69] and total nitrogen loading of soils affect soil microorganisms and other processes [65]. Foliar uptake of N [70] may have several consequences. In nodulated plants, high N loadings repress N-fixation, important in agronomic systems and in some forests [71]. Since coniferous foliage has relatively low capability to reduce nitrate [72], its accumulation in leaf cells may be a potential oxidative stress.

3. TRACE ELEMENTS IN THE SOIL AND FOREST DIEBACK IN MONTANE FORESTS

Trace elements are natural components of the Earth's crust but at high concentrations, they are toxic to plants [73] and soil microorganisms as well [74]. As trace elements, some are essential to maintain the metabolism of plants and animals. However, at higher concentrations, they also can lead to poisoning.

High concentrations of trace elements in soils often characterize industrial and postindustrial regions. Sites located in the vicinity of smelting works may have extremely high levels of trace elements accumulated in soil, particularly in the upper layers. Although the levels of toxic pollutants emitted into the atmosphere have decreased, trace elements accumulated in soils may persist and affect terrestrial ecosystems for a long time. The uptake of trace elements by plants depends on soil pH. The uptake of trace elements is higher in acidic soils than in alkaline soils [75].

3.1 Sources of Trace Elements

In plutonic, volcanic and metamorphic rocks, and various minerals crystallized, some can be particularly loaded with trace elements (e.g. chromite, the olivine, garnierite). The contents of trace elements in rocks are transported by rivers to other areas [76]. At present, the anthropogenic contribution of trace elements into the environment far exceeds natural inputs [77]. Potential land-based sources of trace elements include river inputs, local runoff and atmospheric deposition [78]. In most terrestrial ecosystems, there are two main sources of trace elements: the underlying parent material and the atmosphere. The concentrations of trace elements in soils depend on the weathering of the bed rock and on atmospheric inputs of those. Natural sources are volcanoes and continental dusts. Although trace elements are ubiquitous in soil parent materials, the major anthropogenic source of those to soils and the environment are metalliferous mining, agricultural materials, sewage sludge, fossil fuel, industries, electronics waste disposal and warfare. The processing of mineral resources at high temperatures, such as coal and oil combustion in electric power stations and industrial plants, roasting and smelting of ores in non-ferrous metal smelters, melting operations in ferrous foundries, refuse incineration and kiln operations in cement plants result in the release of volatile elements into the atmosphere. Among the volatile pollutants, arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) are widely studied because of the serious health concern associated with them. The emissions of these elements by the above processes alter their biogeochemical cycles in the whole human environment. These pollutants are emitted into the atmosphere continuously through various human activities, especially in large cities where inhabitants and industrial activities are concentrated [79]. Airborne pollutants are depleted continuously from the atmosphere through two major routes: dry and/or wet deposition. The predominant path depends upon the type of chemical species and upon meteorological factors such as the intensity and distribution of rainfall.

The atmosphere is an important transport medium for trace elements from various sources. Soils are often contaminated for up to 120 of kilometers away from the site of emission [79]. From various air pollution related measurements (air, precipitation, moss, peat cores), Pb and Zn are known to be transported through air in large amounts. Arsenic, Cd, Hg, Sb and Se are also typical representatives of long range transported air masses [80]. The trace elements are usually present in air as aerosol particles with the size range of 5 nm – 20 µm. A high proportion of those in more recent dust deposits are of anthropogenic origin.

Acid deposition aggravates the entry of trace elements into plants. The reason is that the acid deposition on soil reduces the availability of basic cations such as Ca^{2+}, Mg^{2+} and K^{+} leaving larger proportions of metal ions in the soil. So, these changes essentially cause plants to absorb more metal ions [81].

3.2 Aerosol

Long range transport of aerosols occurs mainly via particles with an aerodynamic diameter of a few micrometres or less. If an element is emitted in volatile form from a high temperature source such as coal- fired power plant or a metal smelter it will eventually condense on particles in the emission plume. Since small particles have, a greater surface – to - mass ratio than larger particles preferential concentrations of volatile chemical species occurs on the small-particle fraction. Thus, elements that are entirely or partly emitted as volatile species will be available for long - range atmospheric transport to a greater extent than those that are released in particulate form from the source [82,83].

Elements of volatile character are characterized by high enrichment factor, often 10^2 or more relative to typical “crustal” components such as Al, Sc, Ti etc., (Table 2) which are often used as reference elements. These elements are particularly likely to be deposited far from source region.

Table 2. Classification of trace elements according to their enrichment factor (EF)

Enrichment factor	Trace element
Very high: (EF> 1000)	As, Se, Cd, Sb
High: (100<EF<1000)	Zn, Pb
Medium: (10<EF<100)	V, Cu, Ni
Low: (EF<10)	Cr, Mn, Co

Source; [80]

Certain trace elements (V, Zn, As, Se, Mo, Cd, Sn, Sb, Tl, Hg, Pb, Bi) are subjected to long range atmospheric transport to a greater extent than others (e.g., Be, Ti, Cr, Mn, Fe, Co, Ni, Cu, Ba) [84,85]. Broadly speaking, these elements are the same as those with high enrichment factors in aerosols. Recent monitoring studies in Europe using the moss technique [86,87] shows that the atmospheric deposition is declining not only for Pb, but also for several other elements associated with long-range atmospheric transport.

The forest floor, the organic horizon overlying the mineral soil, is an important and dynamic component of most montane forest ecosystems. Montane tropical forests have large accumulations of soil organic matter due to the “Massenerhebung” effect [88]. Although production is lower at high elevations, large accumulations occur because, the rate of decomposition is inhibited to a greater extent. Though less dramatic, a similar pattern is also seen on mountains in the temperate zone [89-94]. The large organic matter content also provides numerous exchange sites upon which cations of trace elements can be retained on organic exchange sites and in non-labile and weakly labile metal-organic complexes. These give montane forest soils a relatively high cation exchange capacity. In any soil where there is an abundance of organic matter – either in an organic horizon or within the mineral soil-atmospheric deposition of trace metals will result in organic matter – trace element interactions. A major part of the organic matter in soils is comprised of humic substances. The interaction between heavy metals and humic substances can be characterized by chelation, complexation, and adsorption reactions, all of which suggest that heavy metals have a strong affinity for organic matter in general and humic acids in particular [95].

Retention of trace metals in soils is not solely dependent on their stability constants. Another important factor is the degree of incorporation of trace elements in vegetation. Incorporation of those in vegetation will influence elemental retention times in a soil and in the ecosystem. An element that is cycled by vegetation may be repeatedly returned to the surface of the soil in litter fall. This process varies by element and vegetation type. Lead is not incorporated into vegetation to any large degree, while other trace elements are plant – essential micronutrients (e.g., Zn and Cu) and they are readily cycled in vegetation [96].

3.3 Accumulation of Airborne Trace Elements in Organic – Rich Surface Soils

It has become increasingly evident over the last 2–3 decades that air pollutants from densely populated and heavily industrialized areas are finding their way via atmospheric transport to the most pristine areas on our globe including the areas covered by montane forests. Among these air pollutants, several trace elements are subjected to hemispheric distribution in the atmosphere and subsequent deposition far from their origins. There is increasing evidence that long-range atmospheric transport is particularly significant in studies of organic-rich surface soils [97].

By analyzing aerosols collected at remote sites and either comparing the results with regional element signatures [98] or coupling them to air trajectory data [99,100], it is possible to trace the source regions of pollution aerosols observed at remote sites. It became clear from these studies that metals released from sources thousands of kilometres away are transported in measurable amounts to almost any spot in the world [101].

Accumulation of trace elements in the surface soil depends on several factors, such as (i) supply by atmospheric deposition, from natural or anthropogenic sources, either directly or via forest canopy; (ii) binding capacity of the surface soil material; (iii) uptake in plants from the surface soil; and (iv) transport from the subsurface soil by root uptake in plants and return to the surface with decaying plant material. The most effective accumulation would occur for an element such as Pb, which was one of the first elements shown to be an air pollution problem, is strongly bound to humic materials, and is taken up in plants from the soil to a very limited extent. Therefore, the first studies demonstrating accumulation of trace elements in surface soils from long range atmospheric transport focused primarily on Pb. Gradually other elements were studied, and at present a considerable number of those from the atmosphere are known to accumulate to a significant extent in organic rich surface soils [102].

Montane forest ecosystems appear to facilitate the collection of air pollutants in different ways: geographic locations of these forests are usually the mountain tops which intercept more blowing winds than the low-lying areas, organic matter rich surface soil easily retains cations of pollutants and the extraordinary growth of epiphytes including mosses are some special natural adaptations of the montane forests to capture atmospheric moisture and airborne particles [103]. Mosses are very special in this context. These have no root system and therefore depend largely on atmospheric supply of nutrients. Because mosses efficiently retain ions and aerosols on their surfaces, they normally have higher concentrations of trace elements by orders of magnitude than precipitation samples [97].

3.4 Toxicity of Trace Elements (Cd, Pb and Other Metals) on Plants

Lead and cadmium are not nutrient elements for plants, but Pb and Cd distribution in soils are of great concern because they are major toxic metals in soils to plans and animals [104]. At high concentrations, these metals can act in a deleterious manner by blocking essential functional groups, displacing other metal ions, or modifying the active conformation of biological molecules [105]. Metal toxicity for living organisms involves oxidative and/or genotoxic mechanisms [106]. Based on their chemical and physical properties, three different molecular mechanisms of toxicity by metals can be distinguished: (i) production of reactive species by autooxidation and Fenton reaction (Fe, Cu), (ii) blocking of essential functional groups in biomolecules (Cd, Hg), and (iii) displacement of essential metal ions from biomolecules [107]. Fig. 2 shows the Impact of soil Pb on the mortality of *Syzygium rotunidifolium* saplings in a montane forest.

Accumulation of trace elements in plant tissues varied greatly among plants species. The uptake of those by a plant is primarily dependent on the plant species, its inherent controls, availability of the trace elements in the soil and the soil quality [108,109]. A strong positive correlation between concentrations of Cd in the soil and plant tissues have been reported in an experiment conducted in a montane forest [109]. Impact of soil Cd on the accumulation of Cd in plant tissues is shown in Fig. 3.

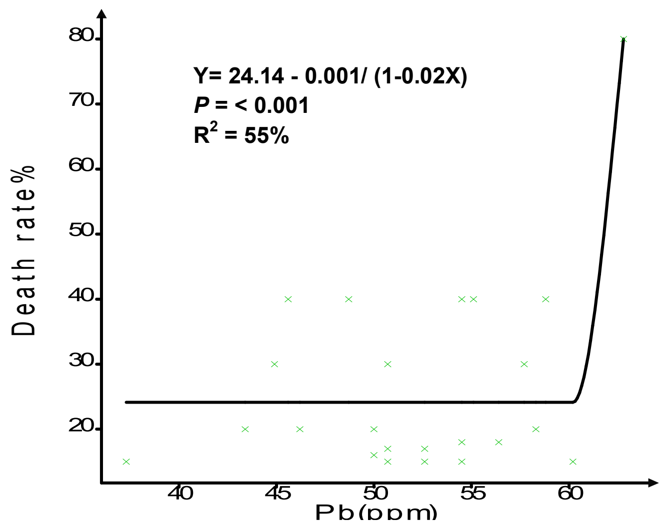

Fig. 2. Pb concentrations in the soil Vs death rate of *Syzygium rotundifolium* saplings

Source: [25]

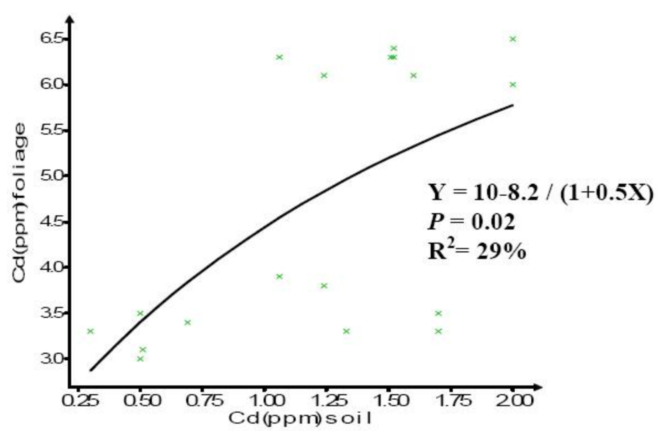

Fig. 3. Cd concentrations in soils Vs Cd concentrations in foliage parts

Source: [109]

4. CADMIUM AND LEAD

Studies done by many researchers [25,110,111] have revealed that Cd and Pb are linked with forest dieback in many parts of the world. A study done by [25] has highlighted the impact of soil pollution with Cd and Pb on a large-scale forest dieback in a tropical montane forest in Sri Lanka. The study has further revealed that by improving the organic matter content of the soil, the toxic effect of the two metals could be mitigated. Soil pollution linking with air pollution and polluted rains have become a common issue across the world as a result of increased vehicle emission, indiscriminate use of Cd contaminated fertilizers and other industries which release Cd and Pb in to the environment. Therefore, as far as the pollution and dieback scenario of montane forests are concerned, these two metals are of great concern [25].

4.1 Cadmium

The toxicity of Cd to plants is well documented. Chemically, Cd is similar to Zn and available Cd in the growth medium is easily taken up by the plants. Although a limited transport of Cd to shoots and binding to cell walls occur in the roots, Cd is relatively more toxic to plants than Pb. Cadmium is phytotoxic to leaves at levels of 5-30 mg kg^{-1} [112]. The strong affinity of Cd ions for sulfhydryl groups of several compounds and phosphate groups involved in plant metabolism might explain the great toxicity. The inhibiting effect of Cd on growth, uptake of nutrients and physiological and biochemical processes is well documented at higher Cd concentrations in the growth media.

4.1.1 Sources of cadmium

Industries linked with metal plating and battery release significant amount of Cd to the environment [113]. Cadmium is a component of diesel fuel, gasoline, and lubricating oil as well. In addition, it is present in vehicle tires and consequently in the particles resulting from tire wears [84]. The abundance of Cd in phosphate rocks and phosphate fertilizers and their impact on soil pollution, accumulation in plants and effects on human health have been documented by the researchers [114,115]. Therefore, the dust particles originated from farm soils, which enters into forest ecosystems may be another source of Cd to forest soils.

4.1.2 Cadmium transportation and accumulation

The geographical distribution of Cd in Norwegian surface soils according to the 1977 survey was shown to be quite similar to that of Pb [84]. Since the Cd deposition in southern Norwey in 2000 had declined to about 15% of the 1977 value [116], the leaching from the humus layer may have exceeded the deposition during the intermediate period. Appreciable surface enrichment of Cd was also reported from Germany [117] and France [118]. The same may be the case for Cadmium readily taken up in the green parts of higher plants such as other elements. Under certain circumstances, the moss may even be supplied with Cd directly from the substrate, although it lacks a root system [119].

4.1.3 Growth responses and seed germination

Plants treated with higher concentrations of Cd usually become stunted in growth. The leaves are smaller, curled and chlorotic and leaf margins and veins show a red-brown coloration. Increased root biomass was significantly positively correlated with increasing metal levels in Cd studies with woody species [120].

The volume of the roots was also significantly affected [121]. According to [122], the critical tissue concentration of a heavy metal, at which the metal causes a biomass decrease, is fairly independent of growth conditions.

4.2 Lead

Like Cd, Pb is considered to be a nonessential metal to plants, although at lower Pb concentrations, a stimulation effect has been observed in many studies, especially older ones. Among heavy metals, Pb could be considered as the least mobile. Lead accumulates in the surface horizons of soils and is not usually leached out [123]. Its concentration in solution is low and this limited amount is available for plant uptake [123]. Compared to Cd, the phytotoxicity of Pb to plants is relatively low, due to a very limited availability and uptake of Pb from soil and soil solutions. However, plant roots are usually able to take up and accumulate large quantities of Pb^{2+} in soil and culture solutions but translocation to aerial shoots is generally limited, due to binding at root surfaces and cell walls. Deposits of Pb, especially as pyrophosphate, in the cell walls of the roots, also similar deposits in stems and leaves and the occurrence of Pb granules, may further explain the low toxicity. Lead toxicity studies, especially at higher Pb levels, are numerous. Depend on species and growth conditions, the toxic effects of Pb may vary considerably and are quite often conflicting [124].

4.2.1 Lead transportation and accumulation

A significant amount of anthropogenic lead (Pb) was deposited on soils and surface waters in the northeastern United States throughout most of the 20th century. The dominant source of this Pb was the combustion of gasoline containing lead additive in automobile engines (1). Lead was emitted to the atmosphere associated with aerosols and introduced to terrestrial ecosystems via rainfall and dry deposition. Researchers have documented the forest floor as a net sink of atmospherically deposited Pb and suggested that Pb leaching from the forest floor to the mineral soil and thus to ground waters and streams may be negligible [4,6,7]. These studies have also estimated Pb residence times in the forest floor to be on the order of hundreds of years due to the high affinity of Pb to organic complexes. Therefore, the organic matter rich surface soils in montane forest may be hot spots of Pb [125].

Reports of Pb pollution in natural organic top-soils also emerged from different countries. Between 1950 and 1987, [79] found appreciably increased Pb contents in forest soils located about 120 km away from the most industrialized region in Scotland. Results from a nationwide survey of natural surface soils in Sweden had increased by a factor of 5 -10 compared with estimated pre-industrial values. Studies of natural soils in Finland [126], France [127], Latvia [128], and Switzerland [129] confirmed that surface soils in large areas in Europe are affected by long-range transport of Pb. A study conducted about a dieback incidence of a montane forest in Sri Lanka has revealed the impact of vehicle emissions on the accumulation of Pb in the forest soil (25).

4.2.2 Growth responses to Pb toxicity

Visible symptoms of toxicity, though unspecific to Pb, are smaller leaves and a stunted growth. Leaves may become chlorotic and reddish with necrosis and the roots turn black. Thus, presence of anions as phosphate and sulfate may reduce Pb uptake. The initial liberation of Pb into the soil solution by increasing soil acidification is one of several possible contributing factors in forest decline [130].

Comparatively low levels of Pb in a soil solution affect growth. However, the concentration of free Pb^{2+} will rarely exceed 5 μgL^{-1} even in greatly acidic forest soils, due to complexation with organic matter. Lead supply to soil, as used in many Pb toxicity studies, is also of limited interest when predicting the influence of Pb on plants growing in natural ecosystems. Soil type and other growth conditions must also be considered to assess the toxicity of Pb on plants [131].

The great influence of environmental factors on availability, uptake and toxicity of Pb to plants brought [132] to omit Pb in their review on critical tissue concentrations of heavy metals. The contribution of Pb from direct aerial pollution of leaf surfaces compared to that taken up by the roots is usually great. Although entering of smaller Pb particulates through stomata and cuticular cracks into the leaves cannot be excluded, most foliar applied Pb has proved to be effectively immobilized at the leaf surface [133]. Like other heavy metals, Pb is a little toxic to seed germination [134].

4.2.3 Physiological responses to Pb toxicity

Lead is well known from numerous studies, to interfere with and inhibit various physiological processes. Exposed plants show decreased photosynthetic and transpiration rates with increasing supply of the metal. The responses are suggested to be, indirectly or directly, related to changes in resistance of the stomata to CO_2 and diffusion of water [135]. Lead ions are also shown to inhibit chlorophyll biosynthesis [136] leading to lowered chlorophyll contents. Thus, the inhibited photosynthesis could partly be related to reduce chlorophyll contents of the leaves. As roots are effective barriers against further transport of Pb to the shoots, usually very high Pb concentrations in the growth medium are needed to affect photosynthesis in intact plants.

4.2.4 Biochemical responses

Several biochemical processes are affected by an excess of Pb. As the metal reacts with important functional groups, the activity of several enzymes is influenced, some of which are of fundamental importance in the photosynthesis and N metabolism. The activity of hydrolytic enzymes and peroxidase is shown to be altered too, indicating an enhanced senescence in plants presence with Pb [137]. Probably, due to the limited transport of Pb from roots to shoots, the biochemical, like the physiological responses, is often more pronounced in the roots. The activity of phosphoenolpyrovate carboxylase (PEPC) in the leaves, however, proved to be very sensitive to Pb.

4.2.5 Cytological responses

Various forms of Pb may cause cell disturbances and chromosomal lesions in plant tissues. Included in these are the effects by the highly toxic organic Pb compounds, as tri- and tetraethyllead, discussed as a possible factor in forest decline [89]. With increasing concentration of Pb and time of exposure, tetramethyl-Pb inhibits the cell division and damaged cell organels, the mitrochondria, proved to be the most sensitive [138].

Vehicle emissions where Pb containing gasoline is used contributes to toxic metal and soil pollution. For busy roads, Pb levels in soil and vegetation indicated a significant level of Pb pollution in the areas nearby [139]. [140] in one of their studies have proved the presence of many trace metals in both leaded and unleaded petrol, diesel oil, anti-wear substances added to lubricant, break pads and tyres and emission of them through vehicle exhaust pipes. A great part of metal pollutants are deposited in adjacent soils, where they may be transformed and transported to other parts of the environment - e.g., to vegetation. In addition to soil, forest vegetation in particular acts as a sink for atmospheric pollutants because of its capacity to act as an efficient interception to airborne matter [123]. An experiment in Spain by [141] showed the significant increase of Pb on petunia leaves in urban areas in Madrid compared to suburban areas.

A study by [142] in Kandy, Sri Lanka, revealed that the air pollution levels is two to three times higher than Colombo, the capital, depending on the weather patterns. The study revealed that the NO_2, SO_2 and O_3 in Kandy exceed the Sri Lankan standards of about 34%, 38% and 33% respectively. Unusually higher levels of NO_2 and SO_2 result acid rains. There is a great chance that this polluted air is blown away to the sky above Horton Plans, the montane forest, causing acid rains. Studies done by [143] showed the contamination of the soils in the area with Pd and Cd which are highly toxic heavy metals to plants.

5. INFLUENCES BY SOIL ACIDIFICATION FOR THE MOVEMENT OF Pb AND Cd IN SOIL

The impact of metal concentrated in the surface soil strongly depends on their mobility within the surface layer as well as their transfer to deeper layers and eventually to surface or ground water. Soil pH is a key factor for the chemical speciation of metals in soils, and hence for the ability of metals to be fixed in the surface horizon [144]. Organic-rich surface soils often show pH values of 5.0 or less, which means that really strong metal binding depends on complex formation with humic matter. On the other hand these soils also have a high cation exchange capacity, which offers a considerable amount of weaker binding sites [145].

Metals, which are subjected to long- range transport, are frequently accompanied with acidic and acidifying chemical substances (SO_2, HNO_3, H_2SO_4, NH_4^+). Acidic precipitation may weaken the chemical bonds of metals with humic substances and reduce the cation exchange capacity by adding protons to negatively charged sites. The resulting soil pH may therefore determine whether there is a net accumulation or a net loss of a given metal in the humus layer, and thus the retention time of the element. Metals predominantly present in exchangeable form (e.g., Zn, Cd) are particularly susceptible to minor pH changes [146]. Enhanced soil acidification may also affect the sub-surface horizon by increased weathering of the natural soil material and further downward movement of metals previously released from the humus layer. Metals strongly bound to humic substances, such as Cu and Pb, may be leached from the humus layer associated with organic matter and precipitated in the upper B horizon whereas other metals such as Zn and Cd tend to be more easily removed from the root zone by further downward leaching [147].

Acidification is a natural process occurring in all organic-rich surface soils. It is obvious however that the additional acidification caused by air pollutants may considerably change not only the chemical speciation of metals in the soil, but also their plant availability, toxicity to soil biota, and residence time in the surface horizons. The widespread accumulation of toxic metals in the forest floor may not be considered as a great risk factor to the ecosystem in the first case. The simultaneous deposition of acidifying substances, however, has enhanced soil acidification and the damage potential of the metals by making them more bio available. Furthermore, the progressive acidification of deeper soil layers with less binding capacity for metals may constitute a risk for contamination of drinking water resources [148].

6. CONCLUSION

Soil pollution in forests at high altitudes in particular (e.g. montane forests), are strongly linked with air pollution. The chief agents of the damage include trace elements such as Cd and Pb resulted mainly by industry and industrial agriculture. These trace elements fall to the soil directly or with rain and finally ended up in plant tissues as well. The continual damage caused by these elements will result in continual dieback and deterioration of the ecosystem as a whole.

Dieback linked with soil pollution inflicts a major threat to the existence of montane forests. The impact of pollution is much higher on montane forests because the vegetation of this specific ecosystem has to survive under many unfavorable conditions – e.g. shallow acidic soils, steep slopes, strong wind, low litter fall etc. The dramatic decline of montane forests as a result of forest dieback is well understood though, knowledge appears to be restricted to a few well-known reasons such as drought, insect pests attacks, diseases, parasitic and semi parasitic epiphytes, increased populations of herbivores, acid rains etc. Less understood is the impact of soil pollution on extraordinarily sensitive montane forest vegetation in particular and the long term effect of forest dieback on the montane forest ecosystem itself and on the other ecosystems which are benefited by the montane forests ecosystem.

The incidences of soil pollution and air pollution should not be taken as separate entities. Therefore, measures should be taken to reduce air pollutants from impacting soil nutrition and forest health. Air pollutants from stationary and mobile sources are frequently transported over great distances and across national borders. Therefore, the focus of a conservation program should go far beyond the regional boundaries to achieve the goals. Without collaborative efforts at regional, national and international levels to control air and soil pollution, forest dieback problems will not be solved and the existence of montane forests cannot be assured. Further studies are urgently required if we are to provide useful guidance on potentially dangerous levels of soil contamination, remediation options, and effective forest conservation and reforestation programs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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