

**NUTRIENTS AND METALS IN SOILS AND VEGETATION OF ARAKU,
ANDHRA PRADESH, INDIA**

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BHARATHIAR UNIVERSITY, COIMBATORE



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DEGREE OF DOCTOR OF PHILOSOPHY
in Environmental Sciences

by
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(An autonomous centre of the Ministry of Environment & Forests, Government of India)

CERTIFICATE

This is to certify that the thesis, entitled “Nutrients and metals in soils and vegetation of Araku, Andhra Pradesh, India”, submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy in Environmental Sciences** is a record of original research work done by **Mrs. Rachna Chandra** during the period from 2006 to 2010 of her research in the Division of Environmental Impact Assessment at Sálím Ali Centre for Ornithology & Natural History, under my supervision and guidance and the thesis has not formed the basis for the award of any Degree/ Diploma/ Associateship/ Fellowship or other similar title of any candidate of any University.

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DECLARATION

I, **Rachna Chandra** hereby declare that the thesis, entitled "**Nutrients and metals in soils and vegetation of Araku, Andhra Pradesh, India**", submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy in Environmental Sciences** is a record of original and independent research work done by me during 2006 to 2010 under the supervision and guidance of Dr. P. A. Azeez, Division of Environmental Impact Assessment at Sálim Ali Centre for Ornithology and Natural History (SACON), and it has not formed the basis for the award of any Degree/ Diploma/ Associateship/ Fellowship or other similar title to any candidate in any University.


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List of abbreviations used in the text

APMFC	Andhra Pradesh Forest Development Corporation
APMDC	Andhra Pradesh Mineral Development Corporation
ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CSIR	Council of Scientific and Industrial Research
GLM	General Linear Model
GSI	Geological Survey of India
GBH	Girth at Breast height
GUIDE	Gujarat Institute of Desert Ecology
LSD	Least Significant Difference
MECL	Mineral Exploration Corporation Limited
OM	Organic Matter
ORP	Oxidation Reduction Potential
PCA	Principal Component Analysis
SACON	Sálim Ali Centre for Ornithology and Natural History
SAR	Sodium Absorption Ratio
SOM	Soil Organic Matter
TAP	Total Available Phosphorous
TAS	Total Available Sulphur
Ti	Transportation Index
TN	Total Nitrogen
TOC	Total Organic Carbon
TOM	Total Organic Matter

1 INTRODUCTION

1.1 Background

As an outcome of globalization and liberalization of our economic policies mining and exploration of minerals have become one of the recent lucrative trades in India. Although aimed at improvement of the socio-economic well being of the people in the country, the flourishing mining industry has diverse environmental implications (Muthreja and Paithankar 1994) and repercussions. The socio-economic and cultural repercussions in several cases in India were also unwished-for. The first and foremost important effect of mining is on the land use pattern, vegetation and environment associated thereof, and changes in distribution of nutrients and minerals in soil. Release of toxic metals in soil is also one of the outcomes of mining. Due to stringent environment legislations, reclamation and reforestation of the mined out sites have become obligatory. Reclamation and revegetation requires detailed information on the soil, its nutrient status and related issues. Information on distribution of nutrients including toxic metals before and after opencast mining would provide valuable insights while developing and executing the strategy for reclamation and revegetation of the mined out sites.

Understanding spatial changes in soil nutrients is important as soil resources can vary markedly among identical sites in areas subject to both natural changes and man-made disturbances. Vertical and temporal distribution of soil nutrients, metals, etc. is controlled mainly by pH (Matschonat and Vogt 1997) in combination with certain other characteristics such as topography of the area and rainfall. Spatial studies of soil help to describe soil properties of a landscape, a function of vegetation and other ambient factors (Agbu and Olson 1990, Prusty *et al.* 2009a). Vegetation grown in the mine areas is expected to accumulate, tolerate or selectively exclude high levels of certain metals. It is also possible that the selected species possess special means of sequestering toxic elements in a manner, which makes their high level biologically innocuous. The strategy of a species in dealing with metal exposure varies with the type of plant (species/ecotype) and micro-environmental conditions such as pH, redox state and ionic strength of the soil (Mogopodi *et al.* 2008).

Heavy metals are among the prominent environmental pollutants, many of which are toxic even at very low concentrations and are a serious threat to soil quality for their persistence after entering into the soil (McGrath 1987). Plants accumulate essential as well as non-essential metals. However, some plant species have the potential to accumulate very high concentrations of toxic metals to levels that far exceed the normal concentrations (Baker and Brooks 1989). The biological function of accumulating heavy metals that are non-essential and hence not directly involved in metabolic processes or structural aspects at any stage of the life cycle is not clearly understood. Certain conjectures such as isomorphic replacement could explain the phenomena (Ernst *et al.* 1992) in certain cases. The ability to tolerate elevated levels of heavy metals and/or accumulate them in very high concentrations can be used as a basis for assessing the bioavailability of metallic elements from soil. Metals present in bulk in soil are moved to the surface of roots and transported to other parts. Plant uptake of mobile fractions is largely determined by the concentration of the particular metal ion. In case of strongly adsorbed ions, absorption largely depends upon the total surface area and the number of roots.

Given that mining projects lead to polluting soil with heavy metals that are toxic, we need to find ways of combating the toxicity to enable the ecosystem to recover. Certain plants are known to change the chemical forms of pollutants as a way of combating toxicity. Studying the levels and spread of toxicity by heavy metals as a result of mining and understanding the way some plants combat this, will help us understand and develop informed potential solutions.

1.2 Objectives

The present study was carried out at Araku (proposed bauxite mine), Visakhapatnam, Andhra Pradesh, India with the following objectives

- Assess the distribution and spatio-temporal variability of nutrients, alkali and alkaline earth metals, and select transition metals in the soils of three proposed mine locations.
- Assess alkali and alkaline earth metals in plant organs to have a baseline characterization of dominant plant species in relation to soil properties.
- Explore the metal accumulation in plants by way of examining dominant plant species seen in the area that may be resistant/or hyperaccumulator for metals.

The above questions are being discussed subsequently under specific chapters in the thesis.

1.3 Significance of the study

The present investigation attempts to create background knowledgebase on soil quality of the three existing hillocks in Araku valley. Being proposed bauxite mine sites, it was felt relevant to examine levels of both alkali and alkaline earth metals, and heavy metals in soil. The metal levels in different plant parts were also examined. As the metal levels in soil are in the form of bioavailable and exchangeable fractions, the study attempts to have first hand information about the likely mobility of the metals from soil to plants. Transportation index (T_i), a measure of mobility of metals from roots to shoots and corresponding plant uptake, helps in understanding the efficiency and uptake rate of different plant species for specific metals. Given an understanding in a situation where, the species are exposed to situations, possibly a post-mining scenario, it was felt vital to examine the T_i of dominant plant species in the area. Hence, the present thesis forms a base document on soil quality of the area and efficiency of existing plant species in the area for metal uptake, which are crucial and imperative for consideration before setting of a mine restoration plan.

1.4 Organization of the thesis

The thesis is organized into 7 chapters. **Chapter 1**, the introduction, briefly brings up the ideas behind the study, and presents the aims and objectives of the study. **Chapter 2** discusses the study area, its climate, geography and related issues. The chapter also briefs

Chapter 1: Introduction

about the sampling strategies adopted for soils and plants and their subsequent analyses. **Chapter 3** presents the spatio-temporal variation in the nutrients across the layers. The spatial heterogeneity was studied at two levels; i) the horizontal heterogeneity (i.e. among the proposed bauxite locations), and ii) vertical heterogeneity (i.e. depth wise distribution of nutrients in the soil at all the locations). **Chapter 4** presents the distribution of alkali and alkaline earth metals (base cations) in the study locations. **Chapter 5** furnishes details of the availability, distribution, mobility and variation of select heavy metals in and across different layers in the soil. **Chapter 6** gives details of the distribution of select alkali and alkaline earth metals and heavy metals in dominant plant species. **Chapter 7** is a combined summary presenting the salient features of the whole study/investigation, followed by a final list of the literature cited in the thesis.

2 STUDY AREA AND GENERAL SAMPLING STRATEGIES

2.1 Study Area

Araku about 90km north-west of Visakhapatnam city, Andhra Pradesh, close to the Orissa state border, is an important tourist destination in the Eastern Ghats (Figure 2.1). The Eastern Ghats, an important biodiversity area in the country, over 1750 km long has an average width of 220 km in the north and 100 km in the south. Located between 11° 03' - 22° 03' N and 77° 02' - 87° 02' E, the Ghats lie mostly along the east coast of Peninsular India, running through Orissa, Andhra Pradesh, Tamil Nadu and Karnataka states. It covers about 75,000 km² (Pullaiah and Rao 2002), and is cloaked by diverse vegetation types such as evergreen, tropical semi-evergreen, tropical moist deciduous, southern tropical dry deciduous and northern mixed dry deciduous forests. Dry savannah and dry evergreen scrub are also seen in the Eastern Ghats (Pullaiah and Rao 2002). The Eastern Ghats are known to be rich in biodiversity with more than 2500 species of angiosperms, constituting about 13% of the flowering plants of India (Nair and Henry 1983, Pullaiah and Ramamurthy 2000). Reddy *et al.* (2006) reported around 146 endemic taxa occurring in the Eastern Ghats. The Araku valley and its surroundings, located between 82° 51' 40" - 83° 06' 53" E and 18° 12' 34" - 18° 25' 12" N are characterized by undulating terrains and plateaus ranging in altitude from 1090 to 1420 m above mean sea level.

The soil in Araku is finely grained, non clayey, sandy loam and susceptible to erosion. The soil is fertile with the presence of humus on top (SubbaRao and Kumari 2002). The soil type in Araku predominantly is lateritic in the plains, and lateritic and rocky in the hilltops (Chandra *et al.* 2007). The hilltops here are covered by lateritic bauxite capping over khondalite. Moist mixed deciduous forest occurs on the slopes of the hillocks and valleys, while hilltop vegetation is mainly scrub and dry savannah. The forests along the slopes and valleys are largely secondary in origin (SubbaRao and Kumari 2002) as slash and burn/*Podu* cultivation is a traditional and regular practice by the local community in the area.



Figure 2.1. Study Area Map

2.1.1 Geography and Geology

Eastern Ghats, a chain of broken hill ranges in South-East India, is the union of a wide variety of geological formations ranging from the oldest Dharwar schist to the recent plioleistocene (alluvium) and belong to the early proterozoic era (Pullaiah and Rao 2002). The Ghats can be distinguished into four sections (Azeez *et al.* 2008). The first section lies north of the Mahanadi river covering Mayurbhanj district in Orissa and the adjoining territory with Meghasini peak (1165 m). The second section falls between the river Mahanadi and the river Krishna. Deomali peak, Palamkini, Niyamgiri, Mahendragiri and

Chapter 2: Study area and sampling

Kondakamberu of Orissa; Sambarikonda, Chintapalle, Gudem, Sapparla, Lankapakulu, Araku, Anantagiri, Papikonda, and Dummakonda of Andhra Pradesh fall within the second section. The third section lies between the Krishna River and the metropolis of Chennai along the eastern margin of Cuddapah basin. The Nallamalais, Veligonda, Palakonda and the Seshachalam hills whose average elevation is 750 m fall within third section. The hill tract between Chennai and the Nilgiris (where the Eastern Ghats merges with the Western Ghats) falls in the fourth section. Prominent hills of this section are the Javadi, Gingee and Kalrayan, Pachamalai, Shevaroy and Kolli hills of Tamil Nadu, and Biligirirangan and Kollar hills of Karnataka. Araku, falls under the second section of the Eastern Ghats and is also known to be rich in diverse flora and fauna. Araku is underlain, mostly by rocks belonging to Archaean period, which are overlain by laterites of sub recent period and thin alluvial covers in valley portions. The rock types found over the study area are mostly charnockite and khondalite. The generalized stratigraphic succession of the formations present in the area is given in Table 2.1.

Table 2.1. The generalized stratigraphic succession of the formation of rocks

Age	Super Group	Group	Litho unit
Archaean	Eastern Ghat	Younger Intrusive, Migmatites, Charnockite, Khondalite	Quartzo - feldspathic gneisses, Bio Quartz gneisses Charnockite, Khondalite, Calc granulite, Calc granulite quartzite

Source: ICFRE (2007)

2.1.1.1 Archaean formations

The khondalite series belonging to Eastern Ghats Super group consists of garnet – sillimanite - gneisses, garnet – sillimanite - graphite schists, garnetiferous quartzite, calcgranulites and limestone. The garnetiferous gneiss is country rock forming the bulk of the Eastern Ghats. Quartzes form ventricular or isolated bands as at Velagedda limestone is exposed near Borra caves. Calc-granulites are exposed near Bora caves and Kasipatnam. Khondalites can be identified by its spotted grey to red appearance resulting from the weathering and alternations, of grains and clots of garnet mineral. The Archaean consist of

porphyritic granite gneiss and the charnockite series. Pink granites, pegmatites and quartz veins are also associated. Of these, porphyritic granites are noticed at Veduruvada and Pendurthi. Pink and grey granites are extensively exposed in the plains, names at Marripalem, Pinmedeke, Maddilapalem, Juthada and Mushirivada.

2.1.1.2 Structural features

The Archaean rocks are characterized by NE-SW foliation, which aligns with the trend of Eastern Ghats ranges. At places the strikes varies from NNE-SSW to ENE-WSW directions. Large variations in the strike of foliation have been observed in the garnet-sillimanite – gneiss indicating folding and flexuring as seen in the hill ranges around Sabbavaram, Chirupalli and Chandrpalem, three sets fractures/joints are identified in Archaean rocks.

2.1.1.3 Alluvium

Recent deposits at study area are a result of weathering of older rocks and also as alluvial materials, residual solid and in the form of dune/blown sands. The fluvial deposits occur as narrow bands along the margin of coastal plain. This alluvial consists of alternate layers of medium to coarse – grained sand, silty clay gravel, pebbles and pellets of kankar and laterite. They attain a thickness of about 30 m. The intermontane valleys, pediment zones, certain hill slopes and foot hill portions are covered by talus material, which possess high infiltration as evidenced by the losing streams. The central portions of valleys of Paderu and Araku areas are underlain by silty gradational material.

In Araku, three sampling locations (Plate 2.1) viz., Raktakonda (Plate 2.2), Galikonda (Plate 2.3) and Chittamgondi (Plate 2.4) were selected for the present study. The Raktakonda bauxite deposit is situated in Anantagiri reserve forest range near Bisupuram village, Anantagiri mandal. The Galikonda bauxite deposit is situated in Anantagiri and Paderu reserve forest range near Bisupuram village, Anantagiri mandal. The Chittamgondi bauxite deposit is situated in Muliagalugu reserve forest, Araku mandal.



Plate 2.1. Location of Araku in India



Plate 2.2. The hill-top of Raktakonda – a proposed bauxite mine area



Plate 2.3. View of the hill-top of Galikonda – a proposed bauxite mine area



Plate 2.4. A view of the hill-top of Chittamgondi – a proposed bauxite mine area

2.1.2 Climate

The area experiences average annual temperature varying from 10°C during December to 37.8°C during May in Anantagiri and Araku (SubbaRao and Kumari 2002). The annual rainfall in the area is about 800-1000 mm in the plains and 1000-2000 mm in the hills (SubbaRao and Kumari 2002). During the study period, rainfall in the area ranged between 0.8 (Chittamgondi, in December 2007) and 522.4 mm (Chittamgondi, in June 2007, Figure 2.2).

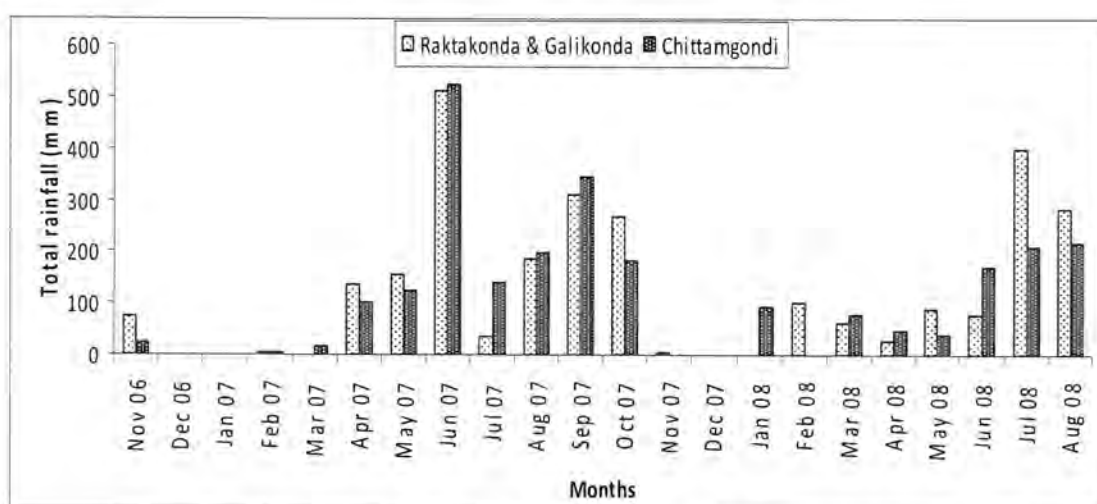


Figure 2.2. Rainfall pattern during 2006 to 2008 in the study area

2.1.3 Vegetation/Habitat

Three major forest types (Champion and Seth 1968) namely moist mixed deciduous, dry savannah and scrub forest are seen in the study area. In general, the Araku valley with rolling terrain, hillocks and valleys, and a favourable climate promotes plant growth. Altogether 655 plant species belonging to 114 families and 442 genera were recorded in the area during the survey (Appendix 1). Of these, having 68 species, Fabaceae was the largest family. A total of 173 trees, 72 shrubs, 254 herbs, 55 climbers and stragglers each, 43 grasses and 03 lianas were recorded during the study. Invasive species such as *Ageratum conyzoides* L., *Chromolaena odorata* (L.) R. King & H. Robinson, *Lantana camara* L. and *Parthenium hysterophorous* L. are growing wide due to the deforestation and other disturbances in the area. Many species of plants occurring in the area are exploited by

Chapter 2: Study area and sampling

tribals and other human communities for several purposes. The bases of the hills are more vegetated than the tops. Some of the tree species recorded in the moist deciduous forest were *Albizzia odoratissima* (L.f.) Benth., *Artocarpus lakoocha* Roxb., *Buchanania lanzan* Sprengel, *Ficus hispida* L.f., *Grewia tiliifolia* Vahl, *Mangifera indica* L., *Phyllanthus emblica* L., *Schleichera oleosa* (Lour.) Oken, *Sterculia villosa* Roxb., *Syzygium cumini* (L.) Skeels, *Terminalia bellirica* (Gaertner) Roxb. and *Terminalia chebula* Retz. Other species commonly seen in the study area are *Anacardium occidentale* L., *Arundinella* sp., *Bothriochloa pertusa* (L.) A. Camus, *Crotalaria* sp., *Desmodium triflorum* (L.) DC., *Eucalyptus* sp., *Heteropogon contortus* (L.) P. Beauv. ex Roemer & Schultes, *Leucas hirta* (Roth) Sprengel, *Mallotus philippinensis* (Lam.) Muell. Arg., *Mitrocarpus villosus* (Sw.) DC., *Murraya* sp., *Paspalum scrobiculatum* L., *Setaria pumila* (Poirlet) Roemer & Schultes, *Stachytarpheta jamaicensis* (L.) Vahl., *Tamarindus indica* L., *Tectona grandis* L.f. and *Tridax procumbens* L. In addition, on the slopes in certain areas the Andhra Pradesh Forest Development Corporation (APFDC, Government of Andhra Pradesh) has coffee (*Coffea arabica* L.) and black pepper (*Piper attenuatum* Buch.-Ham. ex Miq.) plantations interspersed with silver oak (*Grevillea robusta* A. Cunn. ex R.Br.).

A floral survey conducted in the locations during the study period revealed that the Shannon-Wiener index (H') for species diversity for trees, shrubs and herbs in Raktakonda was 1.15, 1.36 and 1.64, respectively. In Galikonda the diversity indices were 1.05, 1.44 and 1.58 respectively. The H' values for shrubs and herbs in Chittamgondi were 1.78 and 2.25 respectively. No trees i.e., GBH (Girth at Breast height) ≥ 10 cm were recorded in Chittamgondi. High herb density, compared to the trees and shrubs, was seen in all the three locations.

2.2 Study Locations

2.2.1 Raktakonda

The vegetation at Raktakonda varies from small evergreen patches in valleys to moist deciduous and dry deciduous tracts towards the heights (Plate 2.2). The hill top is a plateau

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area with scanty vegetation. Raktakonda represents hilly and undulating terrain with intermountain valleys. The Raktakonda mine is a vertical escarpment 400m long partly circumscribed by the road to Araku. The proposed mine areas occur on the plateaus on top of steep hillocks. The peripheries of hill are marked by scarps exposing bauxite and khondalite. The down hill slopes are covered by dense vegetation and rich in floral growth. The Raktakonda mine area, located at a high flat terrain at about 1400 m altitude, is the point of origin for over eight watersheds feeding the Sileru river. Sileru River, a tributary of Sabari River, originates in Andhra Pradesh, flows through Chhattisgarh before merging with Sabari River. Sabari River crosses the border to Andhra Pradesh to merge with Godavari River. The landform is characterised by flat to gentle and moderate topography. The total mine lease area is about 113.192 ha. According to the Geological Survey of India (GSI) and the Mineral Exploration Corporation Limited (MECL), the mineable reserves of bauxite in Raktakonda are 10.8 million tones (GEL 2005a).

2.2.2 Galikonda

A blanket of laterite bauxite in varying thickness occurs on the hill top at Galikonda presenting a characteristic denudate appearance due to the scanty vegetation (Plate 2.3). The region forms a part of the peninsular shield. The other rock types are banded gneiss, composite gneiss and associated migmatites. Granite, pegmatite and quartz veins intrude all the rock types. The formations follow a general strike trend of northeast-southwest and moderate to steep dips to southeast. The bauxite zones are 520 to 700 m long with 320 to 600 m width. The deposits are exposed to surface with little over burden and topsoil. The deposits are low in silica (3%) and titanium (3%), and its iron oxide content varies between 7 and 28%. The total mine lease area is about 93.886 ha. The MECL and the GSI have estimated the mineable reserves of bauxite in Galikonda as about 13.60 million tonnes (GEL 2005b).

2.2.3 Chittamgondi

At the top of Chittamgondi hillock the landscape is barren (Plate 2.4) and slopes and valleys hold dense vegetation. The hilltop is covered by outcrops of laterite/bauxite capping over khondalite. The topographical highs of hill ranges are invariably capped with laterite cover. The total mine lease area is around 152.00 ha. The GSI estimated the mineable reserve in Chittamgondi as 24.57 million tonnes (GEL 2005c).

2.3 Soil Sampling, Processing and Analyses

Soil samples were collected on a quarterly basis from three sampling locations discussed above namely Raktakonda (sites; R1, R2 and R3), Galikonda (sites; G1, G2 and G3) and Chittamgondi (sites; C1, C2 and C3) from November 2006 through August 2008. At each site, soil samples were collected in triplicates from four successive layers, i.e., 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm depth using a plastic scoop (Chandra *et al.* 2007). The samples were then spread over a plastic tray for colour matching with Munsell soil colour chart, and the colour codes and notations were recorded. Subsequently, the samples were packed in pre-treated/laboratory cleaned airtight plastic bags, labeled and transferred to laboratory, stored at room temperature till further processing and analysis (Prusty *et al.* 2009a). In total, 864 soil samples (04 layers x 03 triplicates x 03 sites x 03 locations x 08 seasons) were collected. A portion of each sample was air dried at room temperature (Jackson 1958) in the laboratory and homogenized using an agate mortar and pestle. The homogenized samples were then passed through a standard sieve of 02 mm mesh size (Tandon 2005), and stored in pre-cleaned plastic containers till further analysis. A portion of the air dried sample was hand crushed and analysed for the soil texture and grain size (sand, slit and clay) after sieving through a series of standard sieves of different mesh sizes using a mechanical sieve shaker and the fractions were reported on percentage basis (Allen 1989).

Throughout the experiments and analyses, all the extracting reagents were prepared using metal-free, AnalaR grade chemicals (Thermo Fisher Scientific India Pvt. Ltd, Mumbai, India). Double distilled water prepared using Qualigens quartz double distillation setup, was used for all the analyses. Polypropylene bottles and reagent bottles were subjected to cleaning procedure as prescribed by Laxen and Harrison (1981).

2.4 Plant Sampling, Processing and Analysis

For floral enumeration and quantification the flora line transect method was followed. Transects were laid cutting across the mining locations. Two transects each were laid in each location. Along transects, quadrats of three sizes were laid at varying intervals (Azeez *et al.* 2008). For the study of trees, the quadrats of 20 x 20 m were used. The species growth being stunted, all individuals ≥ 10 cm GBH were included in tree category. Plots of 5 x 5 m and 1 x 1 m were laid within the tree quadrat at each corner to record shrubs and herbs, respectively. A total of 15 quadrats for trees, and 60 quadrats each for shrubs and herbs were laid in each sampling month/season in each location. Additionally, quadrats of 10 x 10 m were laid at each sampling site to measure the dominant species in each season. Samples of dominant plant species were collected from each soil sampling site to explore their likelihood of being potential hyperaccumulators. Seven plant species *viz.*, *Ageratina adenophora* (Sprengel) R. King & H. Robinson, *Eulalia wightii* Hook. f., *Chromolaena odorata* (L.) R. King & H. Robinson, *Lantana camara* L., *Phoenix acaulis* Roxb., *Tephrosia roxburghiana* J.R. Drumm and *Tridax procumbens* L. were collected where they were predominantly distributed. *A. adenophora* is a native of Mexico, *E. wightii* is endemic to peninsular India, *C. odorata* is a native of North America, *L. camara* is a native of American tropics, introduced in tropics, subtropics and sub-temperate, *P. acaulis* is a native of India and Nepal, *T. roxburghiana* is endemic to peninsular India and *T. procumbens* is a native of tropical America. Plant samples were collected by complete uprooting of the individual at each location. Individual plants were then packed in pre-treated, laboratory cleaned polythene bags and labeled. Maximum care was taken to avoid the breakage of leaves or other organs that could lead to loss of metal due to leaching during washing. The plant samples were washed thoroughly under tap water several times followed by rinsing with distilled water, drained, and then chopped/cut and separated as roots, stems and leaves using a plant cutter. The samples were then dried at room temperature. The air dried samples were then kept in a hot oven at 70°C till constant weight (Chandra and Azeez 2009). The oven dried samples were homogenized and passed through a standard sieve of 2 mm mesh size. The sieved samples were stored in pre-treated plastic containers. In total 357 plant samples were collected during the study. The major chemical characteristics of

the soil and plant samples were analysed/determined/estimated following standard procedures and techniques (Table 2.2).

2.5 Statistical Analyses

The Shannon-Wiener's index of diversity (H') for plants was calculated using the software 'Species diversity and richness (version 2.65, Colwell, 1994-2004). Two softwares i.e., Megastat 8.2 (Orris 2000) and SPSS 11.0 (Norušis 1986) were used for analyses of analytical data on soil and plant. Basic descriptive statistics and correlation analysis were performed to assess the distribution and association of different nutrients, base cations and metals along the soil layers, plant organs and months using Megastat 8.2. Multivariate tests to assess spatio-temporal variations in the concentrations of nutrients in soil and plants among the seasons, locations, sites, layers, and among the seasons, locations, species and organs, respectively were performed adopting General Linear Model (GLM-ANOVA). When significant values were found, separation of distinct means was achieved using a Least Significant Difference (LSD) test as a post-hoc analysis at an $\alpha = 0.05$ level. Multiple Regression analysis was performed for heavy metals accumulation in various organs of plant species to identify the influencing factors. The relationships among soil chemical properties and also plants were analysed by multivariate statistical technique, Principal Component Analysis (PCA) using the orthotran/varimax rotation. The parameters were initially subjected to log transformation based on their distribution and were further examined with a PCA using the SPSS 'FACTOR'. The factors were retained in the analyses based on the criterion that each retained factor had an Eigen value >1 .

Table 2.2. Methods used in the analysis of samples collected for the study

Matrix	Parameter	Method	Reference	Instrument/Apparatus
Soil	Soil Colour	Colour Comparison	Allen (1989)	Munsell soil colour chart
Soil	Soil Texture	Standard Sieve Method	Allen (1989)	Mechanical sieves of different mesh sizes
Soil	pH (1: 5, soil: water)	Potentiometry	Tandon (2005)	Digital pH meter (Digisun-7007)
Soil	Electrical Conductivity (EC) (1: 5, soil: water)	Conductometry		Digital Conductivity Meter (Digisun-D1 9001)

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Soil	Total Organic Carbon (TOC, %)	Wet Digestion Method	Walkley and Black (1934)	Titration assembly
Soil	Total Nitrogen (TN, %)	Indo Phenol Blue Method	Kaplan (1965), Raveh and Avnimelech (1979)	Spectrophotometer (Perkin Elmer Lambda 35)
Soil	Total Available Phosphorous (TAP, %)	Olsen's Method	Bray and Kurtz (1945)	
Soil	Total Available Sulphur (TAS, %)	Turbidimetry	Tandon (2005)	
Soil	Available Sodium (mg/kg), Available Potassium (mg/kg), and Available Lithium (mg/kg)	Ammonium Acetate Method	SubbaRao and SammiReddy (2005)	Flame Photometer (Systronics-128)
Soil	Available Calcium (mg/kg), and Available Magnesium (mg/kg)	EDTA Titration Method	Allen (1989)	Titration assembly
Soil	Cation Exchange Capacity (CEC, meq/kg)	Empirical Estimation	Darmody and Marlin (2002)	---
Soil and Plant	Sodium Absorption Ratio (SAR)	Empirical Estimation	Prusty and Azeez (2007)	---
Plant	Total Sodium (mg/kg), Total Potassium (mg/kg), Total Calcium (mg/kg), and Total Lithium (mg/kg)	Mixed Acid digestion	Allen (1989)	Flame Photometer (Systronics-128)
Soil and Plant	Copper (mg/kg), Nickel (mg/kg), and Zinc (mg/kg)	Mixed Acid digestion	Allen (1989)	Atomic Absorption Spectrometer (Perkin Elmer-AA Analyst 200)

3 NUTRIENTS IN SOILS OF ARAKU

3.1 Introduction

The estimation of available nutrients in soil, a complex heterogeneous system, has pedological as well as ecological importance. Understanding spatial changes in soil nutrients is important as they may differ markedly among identical sites subjected to natural and man-made disturbances. Vertical, horizontal and temporal distribution of nutrients in soils is controlled by combinations of the parent material, topography and rainfall in the area. Akin to this, land use patterns and vegetation play important roles in soil nutrient transformation and fertility (Kumar *et al.* 1995). Anthropogenic changes such as fire (Paliwal and Sundaravalli 2002) alter several processes in soil; physical (porosity, soil structure and aggregate stability, water repellency), chemical (soil organic matter, nutrient availability and cycling, pH and C: N ratio) and biological (microbial composition, soil faunal diversity and density, biomass productivity and carbon sequestration). The use of C: N ratio as an indicator of ecosystem stability has necessitated precise estimations on the soil C and N pools worldwide. Several studies (Johnston 1992, Silver *et al.* 1994, Willig *et al.* 1996) show that soil properties, disturbance frequency, topography, and vegetation are interrelated, and therefore a change in one of the properties is likely to have effects on the others.

Study of soils in mountain ecosystems can show patterns in at least four different spatial scales. First, soils may differ among hillocks/mountains. Secondly, soils may also differ among sites within the same hillock/mountain. Thirdly, soils may differ among vegetation types (usually associated with elevation) within hillock/mountain. Finally, soils may also differ among topographic positions within a vegetation type.

Many researchers have attempted examining nutrient variability in different habitat types in India. Sharma and Sharma (2004) reviewed the effect of forest ecosystems on soil properties. Gupta *et al.* (2005) working on the effect of leaf litter on plant growth reported significant improvement in physico-chemical parameters such as pH, EC, organic carbon and other major nutrients (N, P and K) in an amended mine spoil. Various forms of phosphorous

and soil acidity under different land management systems in Meghalaya was examined by Majumdar *et al.* (2007). Prusty *et al.* (2009a) studied the spatio-temporal distribution of nutrients in different habitats in the Keoladeo National Park located in the semi-arid regions of Rajasthan. Notable changes in soil properties can be seen in mining areas and assessing the distribution pattern of nutrients including trace metals before and after mining would provide insights into the likely mobility and bioavailability of these nutrients. Moreover, such information will be of great use during reclamation of the mine sites. The present investigation is an attempt to document nutrient availability and their mobility in soils on a spatio-temporal scale in exploitable bauxite rich areas in a tropical savannah in the Eastern Ghats of India. The information on soil nutrients would be valuable during the reclamation of the area after mining activities have ceased. The broad vegetation pattern being savannah type in all the three hillocks studied, no variation among the vegetation types was examined.

3.2 Materials and Methods

The methods of sampling and preliminary processing are discussed earlier in the Section 2.3. The total number of soil samples, collected, after processing and packing in plastic containers, was 864. In these samples, the portion meant for chemical characterization was analysed for several parameters i.e., pH, electrical conductivity (EC, mS/cm), Total Organic Carbon (TOC, %), Total Nitrogen (TN, %), Total Available Phosphorous (TAP, %), and Total Available Sulphur (TAS, %, Table 2.2).

pH and EC were analysed in the soil water extracts (1:5 w/v) using digital electrodes. Total organic carbon (%) was estimated following modified chromic acid wet digestion method of Walkley and Black (1934), wherein the Organic Matter (OM) is oxidized with a mixture of potassium dichromate ($K_2Cr_2O_7$) and concentrated sulphuric acid (H_2SO_4) utilizing the heat of dilution of the acid to accelerate the reaction. The unspent potassium dichromate was back titrated against ferrous sulphate ($FeSO_4 \cdot 7H_2O$) solution. Total Organic Matter (TOM) values were obtained by multiplying TOC with 1.724, as TOC comprises of 58% of TOM.

Total nitrogen (%), TAP (%) and TAS (%) were estimated spectrophotometrically. Total nitrogen was determined following persulphate oxidation method of Raveh and Avnimelech (1979) coupled with indophenol blue method of Kaplan (1965). Total available phosphorous was determined after extracting with ammonium fluoride solution as per Bray and Kurtz (1945). Total available sulphur was determined turbidimetrically following SubbaRao and SammiReddy (2005). Soil was extracted with 0.15% CaCl_2 and turbidity was developed using barium chloride. Concentrations of nitrogen, phosphorous and sulphur in the samples were determined using linear regressions (with zero intercept). The nutrient ratios, C: N, C: P, C: S and N: P, were estimated empirically.

3.3 Results

Soil at all the three locations had low chroma and in general, the soil colour was very dark brown, showing no seasonal changes. In Raktakonda and Galikonda soil colour varied from very dark brown to black, and in Chittamgondi from dark reddish brown to very dark brown (Table 3.1). Hue of soil at all the three locations was yellowish red with few exceptions at Chittamgondi where it was red. Soil in the study area was moderately textured (sandy loam), and was rocky and red ferruginous in nature. Particle size were in the order sand > silt > clay (Table 3.2). Invariably, the soil was acidic, pH ranging from 4.2 to 6.4, characteristic of lateritic soil. The highest and lowest pH at Raktakonda was 6.4 and 4.2 (Figure 3.1A, B and C), at Galikonda 5.9 and 4.7 (Figure 3.1D, E and F), and at Chittamgondi 6.4 and 5.1 (Figure 3.1G, H and I), respectively. Electrical conductivity was found highest at Raktakonda (75 $\mu\text{S}/\text{cm}$) and lowest (10.4 $\mu\text{S}/\text{cm}$) at Galikonda (Figure 3.2A, B, C, D, E, F, G, H and I). pH varied significantly among the months, locations, sites and layers and EC among the months, locations and layers (GLM-ANOVA, $P < 0.05$). Further post-hoc analysis (LSD, $P < 0.05$) revealed that the pH in November 2006, August 2007 and November 2007 differed significantly from each other and other months (Table 3.3). Similarly, EC in February 2008 was found significantly distinct from that in all other months. pH and EC at Chittamgondi varied significantly from that at Raktakonda and Galikonda. Total organic carbon in the soils of Araku ranged between 0.66 and 4.19%. Total organic carbon at Raktakonda ranged

between 1.87 and 4.0% (Figure 3.3A, B and C), while at Galikonda, between 2.33 and 4.19% (Figure 3.3D, E and F) and at Chittamgondi 0.66 to 3.7% range (Figure 3.3G, H and I). Total organic carbon varied significantly among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). The post-hoc analysis showed TOC concentrations of all locations to be significantly distinct. Overall, TOC showed a trend of decrease along the soil layers.

Table 3.1. Colour codes and notations of the soil layers

Location	Layer (cm)	Colour codes	Colour notation
Raktakonda	0-5	7.5YR 2.5/1-2.5/2	Black-Very dark brown
	5-10	10YR 2/2	Very dark brown
	10-15	7.5YR 2.5/2	Very dark brown
	15-20	7.5YR 2.5/3-10YR 3/2	Very dark brown-Very dark grayish brown
Galikonda	0-5	10YR 2/1-2/2	Black-Very dark brown
	5-10	10YR 2/1-2/2	Black- Very dark brown
	10-15	10YR 2/2-3/2	Very dark brown-Very dark grayish brown
	15-20	10YR 2/2-3/1	Very dark brown-Very dark gray
Chittamgondi	0-5	5YR 2.5/2 10YR 2/2	Dark reddish brown – Very dark brown
	5-10	5YR 2.5/2 10YR 2/2	Dark reddish brown – Very dark brown
	10-15	7.5YR 2.5/2 10YR 2/2	Very dark brown
	15-20	7.5YR 2.5/2 10YR 2/2	Very dark brown

Table 3.2. Soil texture along the layers in Araku proposed mine locations

Location	Layer (cm)	Sand (%)	Silt (%)	Clay (%)
Raktakonda	0-5	95.2	3.1	1.5
	5-10	93.8	4.1	1.9
	10-15	91.3	4.9	3.6
	15-20	89.7	5.3	4.7
Galikonda	0-5	94.8	3.1	1.8
	5-10	93.5	3.9	2.3
	10-15	90.1	5.4	4.3
	15-20	90.4	4.8	4.5
Chittamgondi	0-5	92.3	5.3	2.1
	5-10	91.7	6	2.1
	10-15	92.1	5.6	2.1
	15-20	91.4	5	3.2

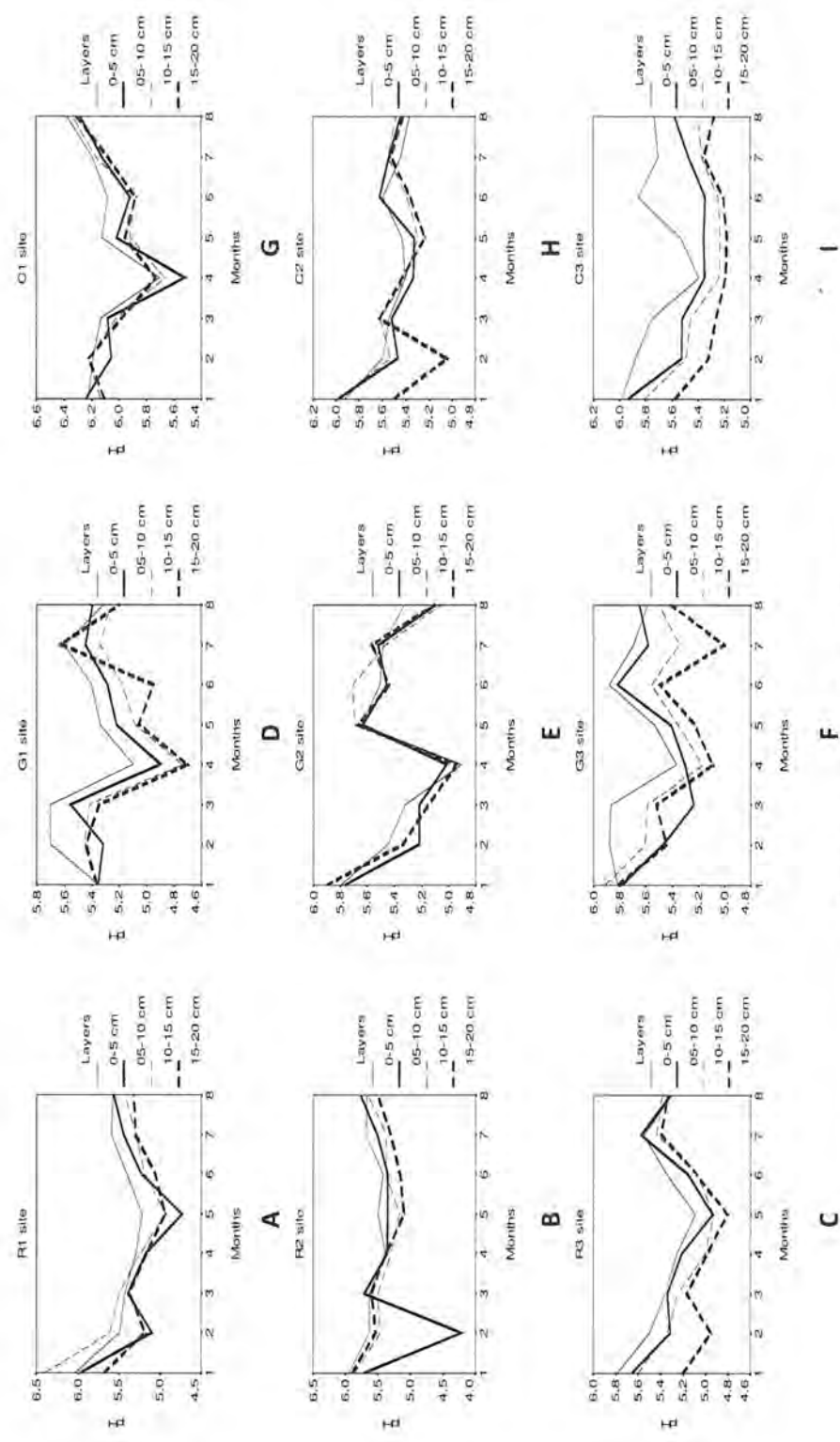


Figure 3.1. pH in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

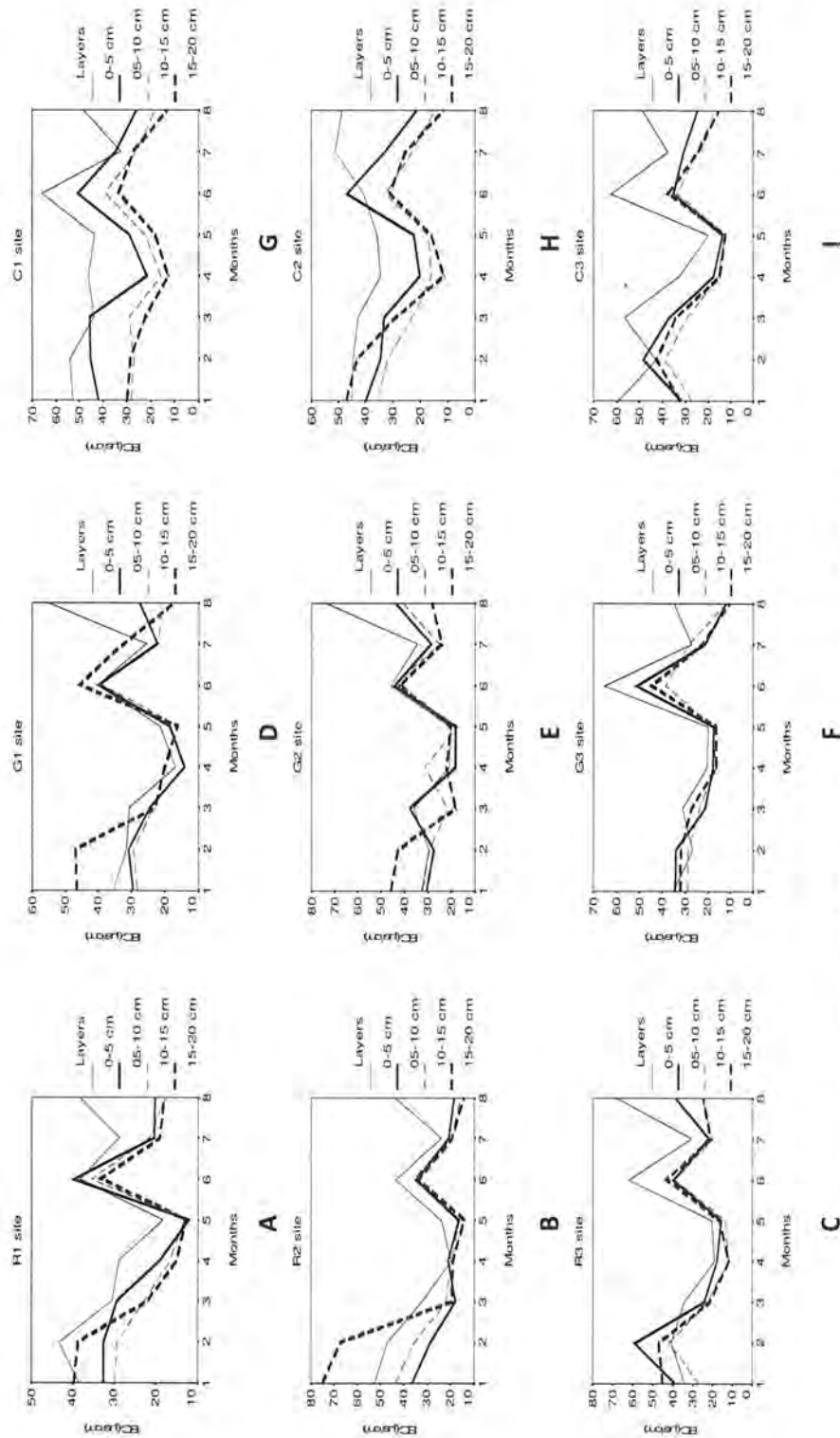


Figure 3.2. Electrical Conductivity in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

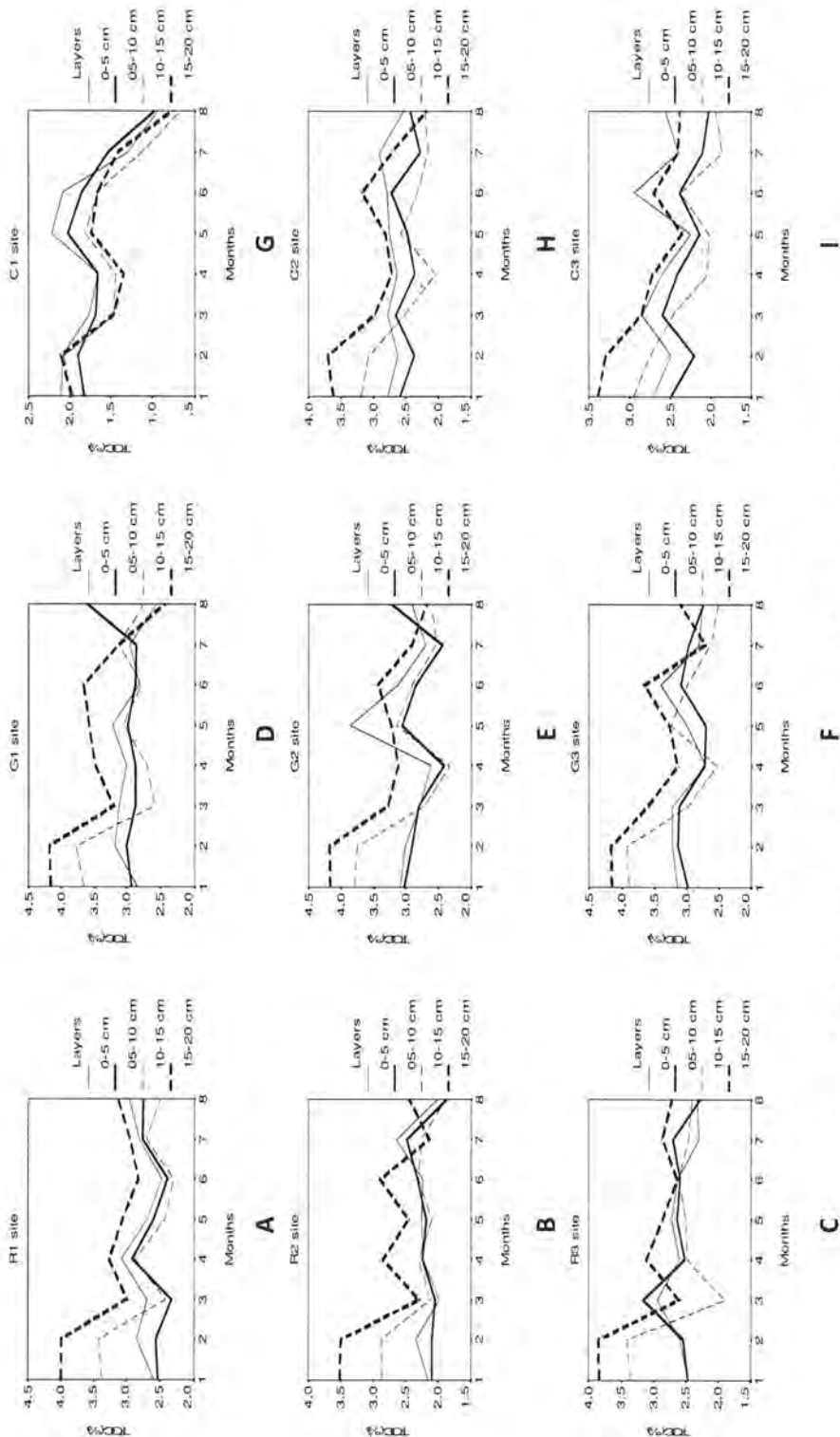


Figure 3.3. Concentrations of Total Organic Carbon in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

3.3.1 Soil nutrients

In the study area, TN varied from 0.01 to 3.3%. Total nitrogen at Raktakonda was found between 0.05 and 3.3% (Figure 3.4A, B and C), at Galikonda between 0.04 and 1.7% (Figure 3.4D, E and F) and at Chittamgondi between 0.01 and 1.8% (Figure 3.4G, H and I). Significant variation of TN was observed among months, locations and sites (GLM-ANOVA, $P < 0.05$). Total nitrogen values in November 2006 and August 2008 were significantly distinct from each other and from the rest of the months (LSD, $P < 0.05$, Table 3.3). Total nitrogen at Chittamgondi was found to be distinct from other two locations. Total available phosphorous levels ranged between 0.000004 and 0.0007% during the months (Figure 3.5A, B, C, D, E, F, G, H and I). In general, TAP decreased along the depth profile in all the locations, except a few sites at Raktakonda. Total available phosphorous concentrations varied significantly among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Total available phosphorous concentration in November 2006, February 2008, May 2008 and August 2008 were distinct from each other and from the rest of the months (LSD, $P < 0.05$, Table 3.3). Of the three locations, Galikonda was significantly distinct from others with respect to TAP levels. However, in each of the locations, no-significant variation in TAP levels was seen among sites. Total available phosphorous content in the upper two layers (0-5 cm and the 5-10 cm) differed from each other as well as from rest of the layers. Total available sulphur at the study area ranged from 0.00007 to 0.01743%. At Raktakonda the TAS ranged between 0.00007 and 0.00574% (Figure 3.6A, B and C), at Galikonda between 0.00009 and 0.01743% (Figure 3.6D, E and F), and at Chittamgondi between 0.00025 and 0.00525% (Figure 3.6G, H and I). Total available sulphur was high in 0-5 cm layer and low in 15-20 cm and varied significantly among locations (LSD, $P < 0.05$).

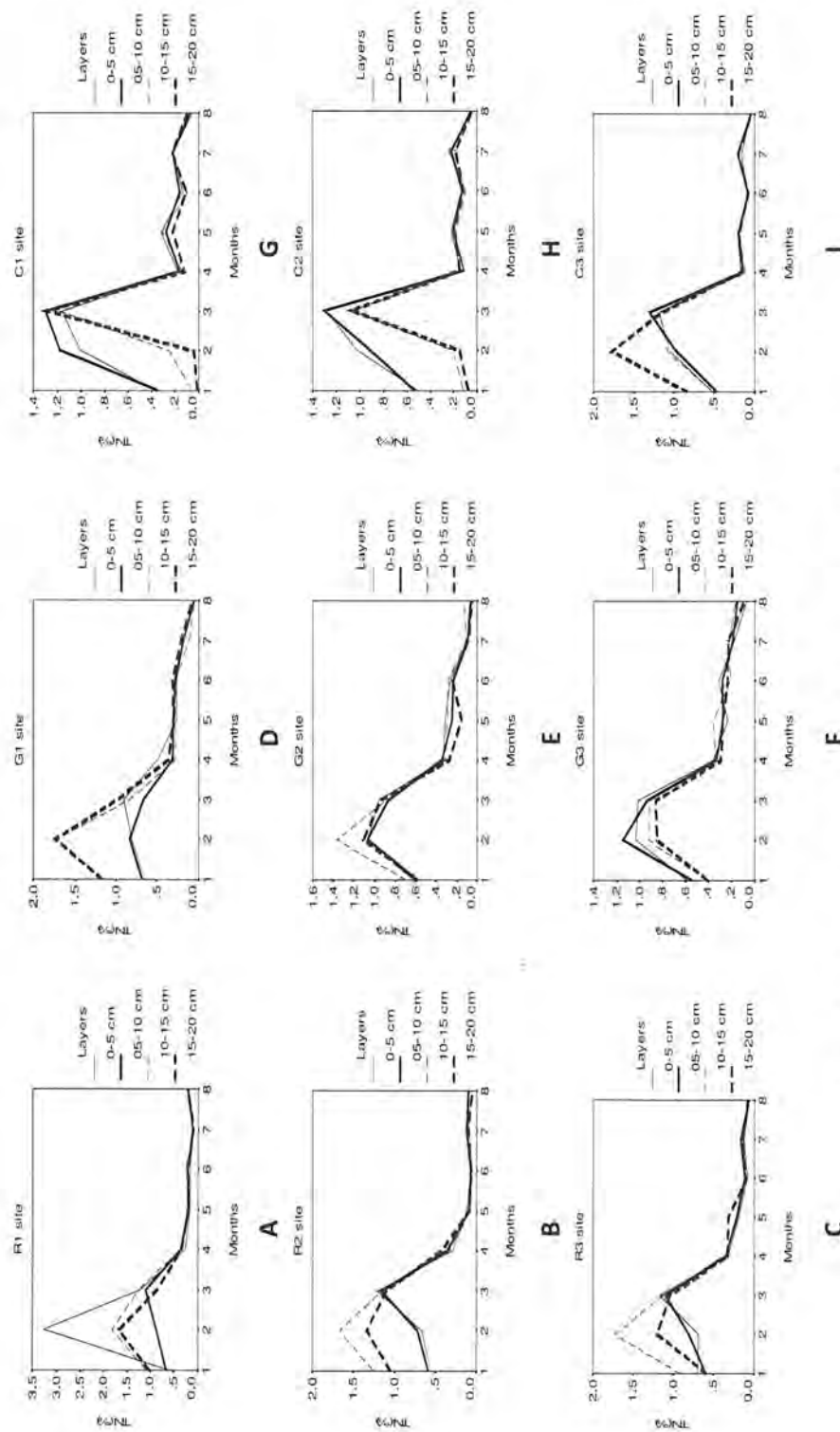


Figure 3.4. Concentrations of Total Nitrogen in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

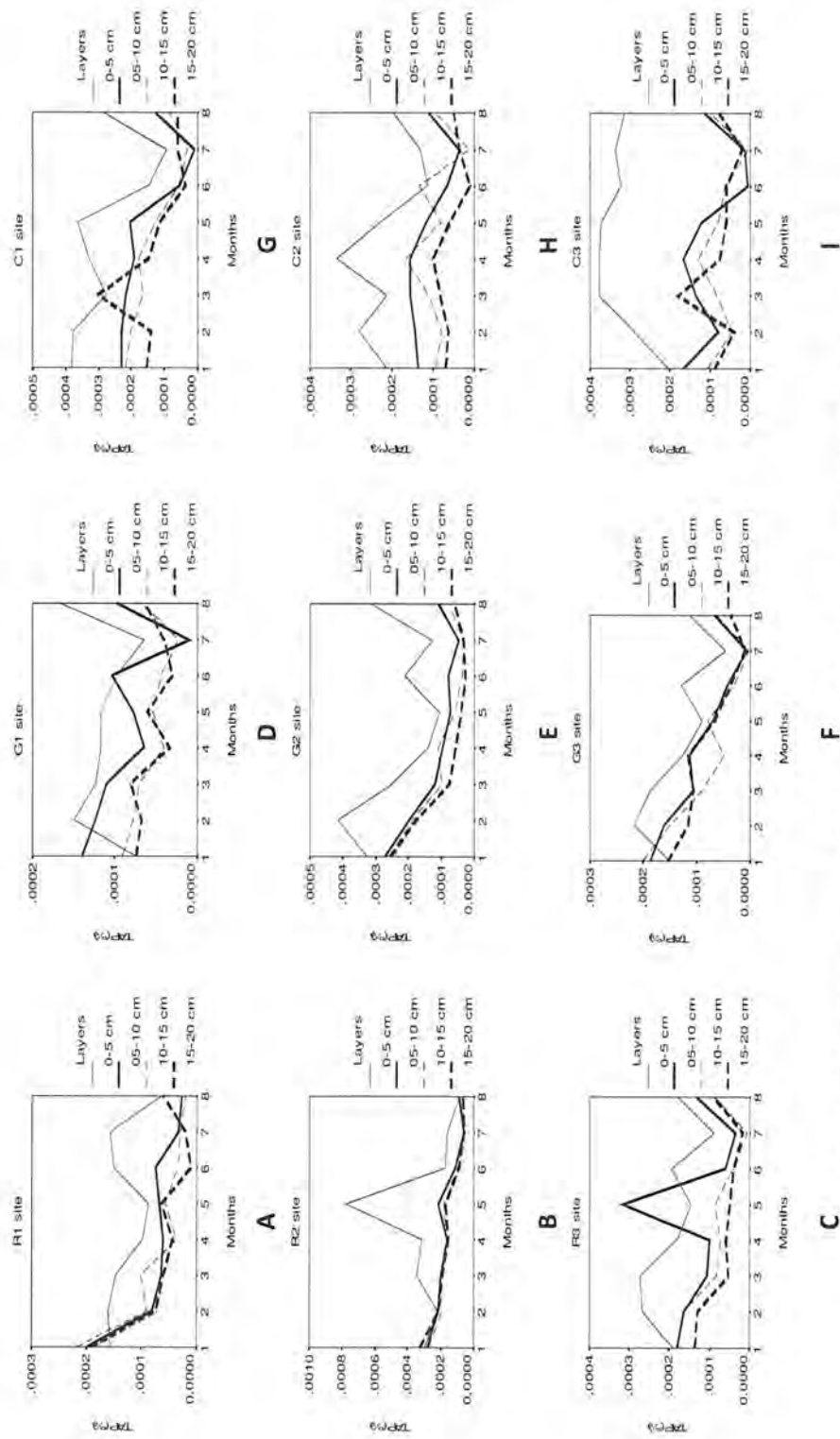


Figure 3.5. Concentrations of Total Available Phosphorous in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

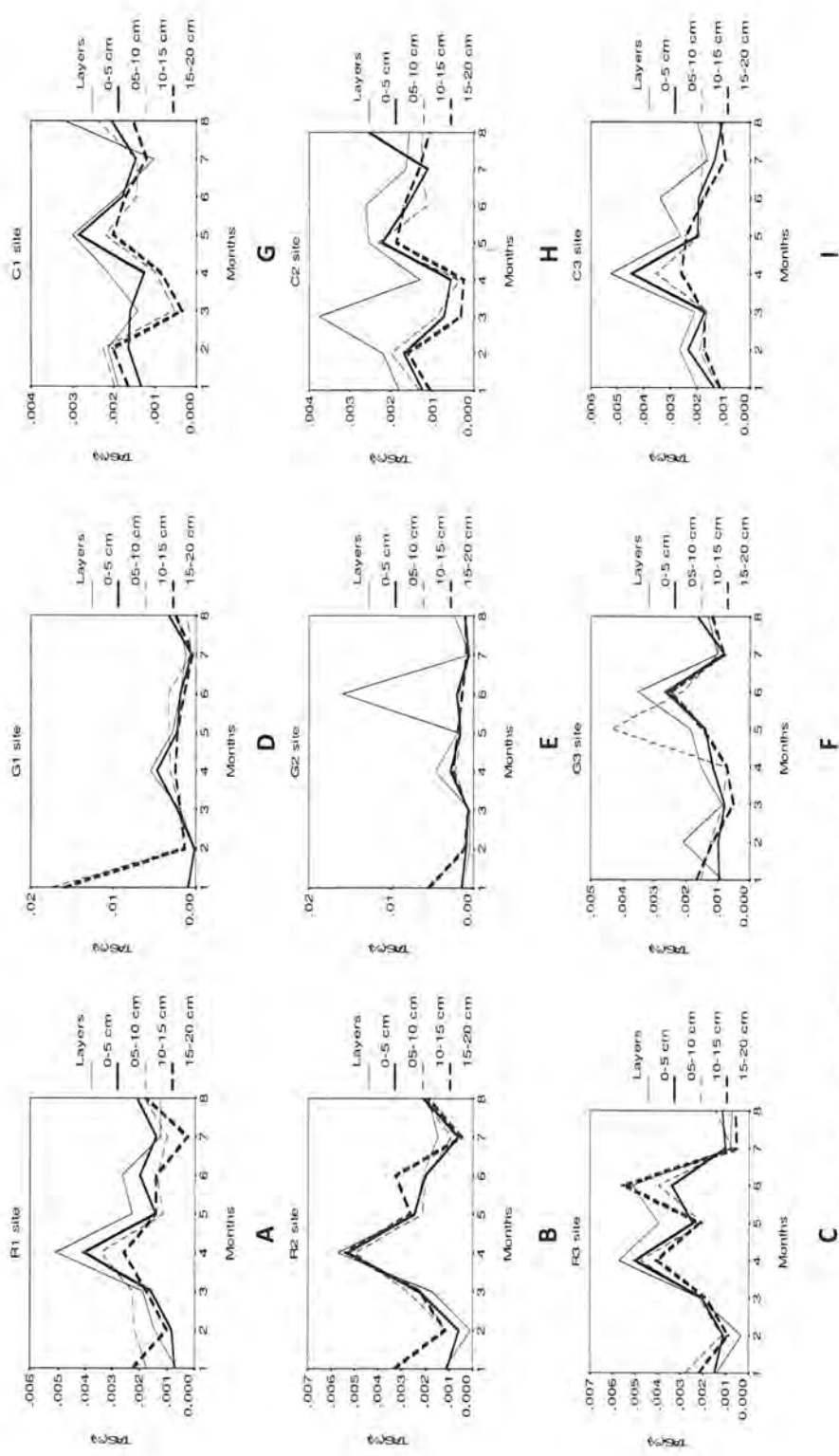


Figure 3.6. Concentrations of Total Available Sulphur in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

3.3.2 Elemental ratios

Overall, C: N ratio was found ranging between 0.86 and 71.9 in Araku; at Raktakonda the ratio was between 0.86 and 47.2, at Galikonda between 2.2 and 68.1 and at Chittamgondi between 1.1 and 71.9. The ratio of C: N varied significantly among the months, locations and layers (GLM-ANOVA, $P < 0.05$) and the post-hoc analysis (LSD, $P < 0.05$) showed C: N ratio in August 2008 to be distinct from others. Among locations Chittamgondi was distinct and differed significantly from others. Among layers 15-20 cm layer was distinct from rest others. The ratio of C: P ranged from 2908-649691; at Raktakonda between 2908 and 404752, at Galikonda between 7292 and 649691, and at Chittamgondi between 3260 and 313538 and varied significantly only among the months (GLM-ANOVA, $P < 0.05$). The post-hoc analysis showed (LSD, $P < 0.05$) C: P ratio in May 2008 to be distinct from all other months.

The ratio of C: S in overall Araku soil samples ranged from 197 to 35487. At Raktakonda C: S ratio ranged between 389 and 35487, at Galikonda between 197 and 34063, and at Chittamgondi between 277 and 11063 and varied significantly among months (GLM-ANOVA, $P < 0.05$, Table 3.3). February 2007 was different and distinct from all other seasons (LSD, $P < 0.05$) with respect to C: S ratio. The ratio of N: P ranged from 86 to 53626. At Raktakonda N: P ratio was between 150.3 and 28614, at Galikonda between 147 and 53626, and at Chittamgondi between 86 and 43233 and the ratio in May 2008 was distinct from the other months and 0-5cm layer was distinct from rest all layers (LSD, $P < 0.05$, Table 3.3). pH was positively correlated (2-tail test, $P < 0.05$) with EC and TAP, and negatively with TOC. Electrical conductivity was positively correlated with TOC, TN and TAP. Total organic carbon was correlated with TN and TAS. Total nitrogen was positively correlated with TAP. Total available phosphorous was positively correlated with TAS (Table 3.4). Principal Component Analysis (PCA) performed to examine the pattern of variations in the data sets resulted in 5 components, which explained 87.3% of the total variance (Table 3.5). Of these, the first PC (PC1) accounted for 21.0% of the total variance in soil characteristics among samples, reflecting the influence of the variables such as C: N and nitrogen. PC2 accounted for 20.1%

of the total variance and reflected the influence of the C: P, P and N: P. The influence of EC was reflected by PC3, which accounted for 19.1% of the total variance. PC4 accounting for 14.6% of the variance indicated the influence of soil sulphur and carbon to elemental ratio (C: S), while PC5 accounting for 12.5% of the variance indicated the influence of soil carbon. From these results it was deduced that the most important factors governing variation in soil composition are C: N/Soil N, C: P/Soil P/N: P, EC, Soil S/C: S and Soil C, respectively.

Table 3.3. Physico-chemical properties (means, n=3) of the soil in three bauxite rich locations in the Eastern Ghats

Parameters	Attributes	1	2	3	4	5	6	7	8	9
pH	Month	5.8 ^a	5.5 ^b	5.5 ^b	5.2 ^c	5.3 ^d	5.4 ^b	5.6 ^b	5.5 ^b	
	Location	5.4 ^a	5.4 ^a	5.7 ^b						
	Site	5.4 ^a	5.5 ^a	5.3 ^a	5.3 ^a	5.4 ^a	5.5 ^a	6.1 ^b	5.5 ^a	5.5 ^a
	Layer	5.6 ^a	5.5 ^b	5.5 ^b	5.4 ^c					
EC (mS/cm)	Month	38 ^a	38 ^a	29 ^a	20 ^a	19	42 ^b	27 ^a	29 ^a	
	Location	29 ^a	29 ^a	32 ^b						
	Layer	38 ^a	29 ^b	25 ^c	28 ^b					
TOC (%)	Month	3.0 ^a	3.0 ^a	2.6 ^a	2.5 ^a	2.6 ^a	2.6 ^a	2.4 ^a	2.3 ^b	
	Location	2.6 ^a	3.1 ^b	2.2 ^c						
	Site	2.8 ^a	2.3 ^b	2.7 ^c	3.1 ^c	3.0 ^c	3.1 ^c	1.6 ^d	2.6 ^c	2.4 ^e
	Layer	2.6 ^a	2.5 ^a	2.5 ^a	2.9 ^b					
TN (%)	Month	0.6 ^a	1.1 ^b	1.1 ^b	0.3 ^b	0.2 ^b	0.2 ^b	0.2 ^b	0.1 ^c	
	Location	0.5 ^a	0.5 ^a	0.4 ^b						
	Site	0.6 ^a	0.5 ^b	0.5 ^b	0.5 ^b	0.5 ^b	0.5 ^b	0.4 ^b	0.4 ^b	0.5 ^b
TAP (%)	Month	0.00019 ^a	0.00017 ^b	0.00015 ^b	0.00014 ^b	0.00014 ^b	0.00008 ^c	0.00005 ^d	0.00012 ^e	
	Location	0.00013 ^a	0.00011 ^b	0.00015 ^a						
	Layer	0.00021 ^a	0.00012 ^b	0.00010 ^c	0.00009 ^c					
TAS (%)	Location	0.0021 ^a	0.0022 ^a	0.0018 ^b						
C: N	Month	17.9 ^a	6.8 ^a	2.6 ^a	11.2 ^a	16.4 ^a	22.3 ^a	18.8 ^a	40.7 ^b	
	Location	14.4 ^a	15.9 ^a	21.0 ^b						
	Layer	14.9 ^a	14.1 ^a	15.1 ^a	24.3 ^b					
C: P	Month	24650 ^a	27992 ^a	25574 ^a	34797 ^a	37686 ^a	129475 ^a	666535 ^b	104888 ^a	
C: S	Month	2660 ^a	8508 ^b	3405 ^a	4208 ^a	1380 ^a	1645 ^a	4910 ^a	2128 ^a	
N: P	Month	4640 ^a	10165 ^a	10207 ^a	3956 ^a	3135 ^a	8311 ^a	39487 ^b	6833 ^a	
	Layer	3029 ^a	10464 ^b	16662 ^b	13212 ^b					

Source of variation: months (1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008); location (1, Raktakonda; 2, Galikonda; 3, Chittamgondi); Site (1, R1; 2, R2; 3, R3; 4, G1; 5, G2; 6, G3; 7, C1; 8, C2; 9, C3); and layer (1, 0-5 cm; 2, 5-10 cm; 3, 10-15 cm; 4, 15-20 cm). Within rows, means followed by the same letter are not significantly different at $P < 0.05$



EC: Electrical Conductivity, TOC: Total Organic Carbon, TN: Total Nitrogen, TAS: Total Available Phosphorous, TAS: Total Available Sulphur, C: N: Carbon: Nitrogen, C: P: Carbon: Phosphorous, C: S: Carbon: Sulphur, N: P: Nitrogen: Phosphorous

Table 3.4. Correlation matrix of select parameters in the soil system of Eastern Ghats

Variables	pH	EC	TOC	TN	TAP	TAS	C:N	C:P	C:S	N:P
pH	1									
EC	0.256	1								
TOC	-0.226	0.129	1							
TN	NS	0.153	0.245	1						
TAP	0.258	0.278	NS	0.166	1					
TAS	NS	NS	0.119	NS	0.085	1				
C: N	NS	NS	NS	-0.317	NS	NS	1			
C: P	NS	-0.071	NS	-0.077	-0.158	NS	NS	1		
C: S	NS	NS	NS	NS	NS	-0.175	NS	NS	1	
N: P	NS	NS	NS	NS	-0.191	NS	NS	0.890	NS	1

864 Sample size, $\pm .067$ critical value for R at $P < 0.05$ (two-tail), NS: Not Significant at $P < 0.05$

EC: Electrical Conductivity, TOC: Total Organic Carbon, TN: Total Nitrogen, TAS: Total Available Phosphorous, TAS: Total Available Sulphur, C: N: Carbon: Nitrogen, C: P: Carbon: Phosphorous, C: S: Carbon: Sulphur, N: P: Nitrogen: Phosphorous

Table 3.5. PCA of soil variables from all the three locations – Factor loadings

Parameters	Principal Components				
	PC1 (C: N, Soil N)	PC2 (C: P, Soil P, N: P)	PC3 (EC)	PC4 (Soil S, C: S)	PC5 (Soil C)
pH	0.080	-0.133	0.424	0.021	-0.638
EC	0.068	-0.101	0.958	0.014	0.059
TOC	0.123	0.113	0.167	0.062	0.874
TN	0.939	-0.109	0.124	0.043	0.133
TAP	0.143	-0.854	0.210	-0.036	-0.005
TAS	0.035	-0.045	0.044	-0.908	0.188
C: N	-0.972	0.076	-0.027	0.007	0.080
C: P	-0.107	0.928	-0.080	0.082	0.212
C: S	0.090	0.085	0.031	0.872	0.279
N: P	0.644	0.727	-0.044	0.068	0.111
Total loading*	2.313	2.211	2.098	1.606	1.374

% Variance explained	21.027	20.102	19.076	14.598	12.491
Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser normalization (Rotation converged in 5 iterations), *Sums of squared loadings					
EC: Electrical Conductivity, TOC: Total Organic Carbon, TN: Total Nitrogen, TAS: Total Available Phosphorous, TAS: Total Available Sulphur, C: N: Carbon: Nitrogen, C: P: Carbon: Phosphorous, C: S: Carbon: Sulphur, N: P: Nitrogen: Phosphorous					

3.4 Discussion

3.4.1 General Soil characteristics and Nutrients

Study of spatial structuring of soil properties in natural and man-made ecosystems is important in developing appropriate ecologically sustainable management plans (Maestre and Cortina 2002, Ettema and Yeates 2003, Yankelevich *et al.* 2006). Variation in the diversity of plants, which happens through succession, to an extent, causes the heterogeneity of belowground soil nutrient environment. Fitcher *et al.* (1998) studied the chemistry and the quantitative mineralogy of clay, silt and sand fraction of two acid forest soils from the Strengbach catchment (Vosges Mountain, France). The land use pattern and/or type has significant influence on the distribution of different particle size fractions in the soil; as the slopes become gentler, higher quantities of finer particles get deposited at the bottom; a universal situation and Araku soils are not exceptions. In the case of Araku, soil's red and brown colours are attributable to the Fe compounds resulting from the formation of secondary Fe oxides. Hausenbuiller (1978) mentioned that pronounced red and yellow colours are due to mineral substances that have undergone extensive weathering. In the case of Raktakonda and Galikonda the samples were collected from lands with low or negligible human interference. On the other hand samples from C1 site were collected from areas partially disturbed due to human interferences. Hence, the soil at C1 site was relatively reddish in colour. The organic matter accumulating under grassland vegetation is darkest. The C1 site at Chittamgondi did not harbour much vegetation and the absence of vegetation could be attributed to such colour differences among the sites.

Soil properties are the primary factors determining the carbon content of forest soils within climatic realms. The study of soil pH is important since it controls the base status and microbial activities (Miller and Donahue 1997). The acidic nature of soil as observed

presently could also be a property inherited directly from the parent material. At low pH, acidity can directly inhibit plant growth and make most of the elements including toxic metals in soil bioavailable and induce production of toxic soluble-aluminium in the soil-water solution. All forms of acidity fall after fire, widely seen in the area, due to the practice of slash and burn cultivation. The acidity again starts increasing because of the regeneration of organic matter in the soil and increase in exchangeable Al^{3+} level. Exchangeable bases in soil decrease during cultivation because of removal of weeds/plants, leaching and erosion losses from the soil. As organic matter is the major contributor of pH dependent acidity in the soils, it may decrease after fire due to the burning of organic matter in the soil (Kumar *et al.* 1995). The pH values in the soils of tropical savannah of Araku were slightly higher than reported elsewhere (Saha 2003, Table 3.6).

A good population of indigenous people depends on the tropical savannah of Araku especially on the forest products for their daily needs and it is their traditional right that they have enjoyed for generations, perhaps with no modern-day documents proving their ownership. They cut trees regularly and burn the vegetation as part of their regular cultivation practices. The lower TOC values in certain months might be associated with the regular felling and burning of forest in the area. Rainfall seasonality strongly influences carbon and nutrient fluxes from vegetation to soil, concentrating these fluxes at the onset of the dry season. Such change would affect the nutrient cycling pattern and in turn change the equilibrium between production of biomass, accumulation of organic matter and decomposition, and absorption of minerals (Barbosa and Fearnside 1996). Organic matter is a primary source of organic carbon in the soil and gets accumulated in the topsoil (Brady 1996). Total organic carbon content is supposed to be higher in slopes with lower steepness. Higher accumulation of organic matter in flatter areas is attributable to the almost negligible loss of nutrients at these areas due to a lower slope. Lower steepness in slopes result in reduced loss in nutrient and TOC due to leaching during rainfall. Gradual slopes result in lesser loss in nutrient and TOC during rainfall. High TOC was observed in the top layer of the hillocks which might be attributed to low angle of slope of the hillocks. The higher concentrations of TOC in the upper layers of the soil are due to the continuous growth and decay of grasses, which are great accumulators of TOC. On the basis of the

amount of organic matter, Richardson *et al.* (1978) classified soils into two types: mineral soil having < 20% organic matter and organic soil having > 20% organic matter. Total organic carbon concentrations were significantly distinct among all locations. In the case of sites, TOC values at R1, R2, C1 and C3 were distinct from each other (LSD, $P < 0.05$, Table 3.3) which could be attributed to the varying degrees of slopes at sites. Total organic carbon content in Araku soils were higher than the values reported by Horkar and Totey (2002) in Navegaon National Park, India.

The nutrients are largely interlinked and influenced by other physico-chemical characters of the soil depending on seasonal changes (Hagedorn *et al.* 2001). Yankelevich *et al.* (2006) predicted that if each tree species generates a particular soil environment under its canopy, then under a diverse tree community, soil chemical properties will be spatially very heterogeneous. This should be true for the top soil in particular, because in terms of nutrient availability and cycling, surface soil seems to be where most plant-soil biochemical interaction occurs in forests (Hendrick and Pregitzer 1996, Prusty 2008). Soil nitrogen is an important environmental factor that affects the rate of nutrient uptake by plants. In the present case, the higher concentration of nitrogen in the upper layer of soils may be due to the presence of immobilized nitrogen in the detritus on the soil surface (Barbosa and Fearnside 1996, Kao *et al.* 2003), which is prone to microbial decomposition in soil in the subsequent layers (Maharudrappa *et al.* 2000, Prusty 2007, Prusty *et al.* 2009a). Total nitrogen levels in soil depend on the organic matter build up in different systems, supported by the significant positive correlation between TN and TOC in Araku soils. Although volatilization due to forest fire is likely to remove nutrients from a system, it can also convert them to a more available form. For example, nitrogen is often converted to the more available form ammonium, during the volatilization process. Thus, even though the total amount of nitrogen at a site decreases, the amount of nitrogen available to plants need not follow the same trend; it may actually increase or decrease, depending on the site. Volatilization, a temperature dependant process, most commonly affects nitrogen and to a lesser extent sulphur, phosphorous and carbon, which in the present case seems to be chiefly due to frequent fires. TN values in the present study were higher than that reported by Ajwa *et al.* (1998) from tall grass prairie.

Table 3.6. General concentration range of nutrients in soil in comparison with the concentrations recorded in the present study in the Araku soil system

Parameters	Present observation	Locations	Concentration range	Authors reported
pH	4.2 - 6.4	Singalila Range, Darjeeling	4.9 - 5.9	Saha (2003)
EC (mmho/cm)	10.4 - 75 μ S/cm	Singalila Range, Darjeeling	0.065 - 0.63	Saha (2003)
TOC (%)	0.66 - 4.19%	Navegaon National Park, Maharashtra, India	0.412 - 1.658	Horkar and Totey (2002)
TN (%)	0.01 - 3.3%	Tallgrass Prairie soil profile	0.0392 - 0.2219	Ajwa et al. (1998)
TAP (%)	0.000004 - 0.0007	Okeluse forest reserve, Ondo State Nigeria	0.00045 - 0.0008	Olufemi and Ikulamberu (2004)
TAS (%)	0.00007 - 0.017	Mediterranean forests in Southern Tuscany	0.1070 - 0.2650	Wesemael (1993)
C: N	0.86 – 71.9	Singalila Range, Darjeeling	15 - 50.2	Saha (2003)
C: P	2908 – 649691	NA	NA	NA
C: S	197 – 35487	NA	NA	NA
N: P	86 - 53626	NA	NA	NA
NA: Not Available				
EC: Electrical Conductivity, TOC: Total Organic Carbon, TN: Total Nitrogen, TAS: Total Available Phosphorous, TAS: Total Available Sulphur, C: N: Carbon: Nitrogen, C: P: Carbon: Phosphorous, C: S: Carbon: Sulphur, N: P: Nitrogen: Phosphorous				

Total available phosphorous, irrespective of the sites, showed a general decreasing trend across the soil layers. It is important to note that soils high in organic matter generally exhibit relatively low levels of phosphorus. Phosphates do not normally stay for very long in soils and are readily absorbed by plants (Brady 1996). Distribution and forms of phosphorous in soils help in evaluating the phosphorous status and degree of chemical weathering of the soils (Chang and Jackson 1958, Majumdar *et al.* 2007). Phosphorous availability and soil acidity are closely related and different phosphorous fractions in soil depend upon the magnitude and proportion of different forms of soil acidity. The increase

in TAP (in various forms) after burning might be due to fast mineralization of organic phosphorous present in plant biomass and quick release to inorganic forms and its higher solubility. These observations are in concordance with the findings of Ramakrishnan and Toky (1981). Forest soils normally contain organic and inorganic forms of phosphorous, most of which are unavailable to the plants. Venkatachalam *et al.* (2007) reported that the dominance of unavailable form of iron and aluminium phosphates is characteristic feature of acidic soil having low pH. This could be the reason for lower available phosphorous content when compared to other nutrients observed in the study area. Phosphorous concentration was below the levels reported elsewhere (Table 3.6). This is further affirmed by the relatively high concentration of organic carbon in the soils of Araku. The positive correlation of TAP with pH is in concordance with the findings of Majumdar *et al.* (2007).

Total available sulphur concentrations in the soils of Araku varied significantly among locations. The significant difference in TAS concentrations at Chittamgondi could be due to its location specific conditions. The higher values of TAS along with soil organic matter (SOM) in the upper soil layer and its subsequent decline in the next layer in Chittamgondi indicates that N and S are largely associated with the soil organic matter (SOM), which disappears relatively fast through rapid decomposition (Aluko 1993) mediated by microbes (Arunachalam and Arunachalam 2005, Hossain and Othman 2005) as well as abiotic processes (Vairavamurthy and Wang 2002). Levels of TAP and TAS in soils of Araku were lesser than the reported levels in the soils of Okeluse forest reserve, Nigeria (Olufemi and Ikulamberu 2004) and Mediterranean forests, Southern Tuscany (Wesemael 1993, Table 3.6).

3.4.2 Elemental ratios

Different nutrient ratios showed high variability among the months, locations and layers (GLM-ANOVA, $P < 0.05$). Most of the ratios followed the same pattern as that of nutrients. The nutrient ratios C: P and C: S exhibited a gradual decline with depth. Srivastava and Singh (2002) also reported similar decline in the ratio along the depth. Vejre *et al.* (2003) reported such narrowing of the nutrient ratios downward in the soil layers as a result of the decomposition stage and age of the horizons. C: N ratio during August 2008 was distinct from others due to enhanced growth of vegetation after rain during the month of August. An average C: N ratio >20 , as observed in certain months, indicates slow decomposition with lower mobilization of N (Prusty *et al.* 2009a).

Forest-fires increase TAP levels in soils as discussed above. In Araku the fire is lit during February and March for agriculture. The significant differences in C: P ratio during May 2008 from all other months could be due to such human interventions. The statistical correlations among the nutrient elements and their respective ratios indicate TOC and TN to be important for the biogeochemical processes in soil. The positive correlations of TOC, TN, and TAS indicate the availability of recently shed plant litter, with high elemental ratios. Total organic carbon plays important role in biochemical processes determining nutrient levels (Prusty *et al.* 2010). The five PCs identified in the dataset correspond to i) C: N and Soil N, ii) C: P, Soil P and N: P, iii) EC, iv) Soil S and C: S, and v) Soil C, respectively. In general, variations of the nutrients and their respective ratios were significantly different among months, considering the entire period of study. The nutrient ratios were not significantly distinct among sites. This is attributed to the presence of some common plant species seen at all sites and also the similarity of the chief sources of these nutrient elements.

3.5 Conclusions

The results of nutrient variability in relation to the spatial differences have revealed that land use pattern, topography and the vegetation composition in the area play an important role in nutrient cycling and turn over. All the major parameters i.e., TOC, TN, TAP and TAS were higher in concentrations in the top soil layer. Increase in TOC results in high TN concentrations. The lower values for TAP reveal that soils of Araku have relatively high TOC concentrations. Thus, TOC in soils of Araku control TN, TAP and TAS concentrations. Nutrient accumulation is suggestive of live biomass of various plant species in the stand with their respective composition of nutrients. Loss of aboveground biomass through harvesting or forest fire results in direct nutrient losses. It is well known that the distribution of the plant roots along the soil depth influences nutrient input, its cycling and its mobilization in the soils. Thus, the quality and quantity of plant residues integrated in the soil determine the decomposition rate and plant uptake of nutrient. Clear felling of the vegetation and seasonal man made fire in Araku is likely to lead to losses of nutrients and subsequent changes in nutrient concentrations.

4 ALKALI AND ALKALINE EARTH METALS IN SOIL

4.1 Introduction

Tropical forests are known for their high biodiversity (Myers *et al.* 2000, Schrumpf *et al.* 2006) and for their importance as water catchment areas (Bruijnzeel 2001, 2004). These habitats are rich with effective mycorrhizal system that helps in capturing and recycling nutrients (Kellman 2002). Tropical forests are prone and frequently subjected to forest fire, either natural or man-made through slash and burn agriculture. Such fires help in instantaneous mobilization of nutrients accumulated in the above-ground biomass, and the soil, being one of the most critical support system in the biosphere, is prone to drastic changes from such activities. Mining of minerals is also one such activity that causes serious changes, that too with long-term implications, in soil quality. Once the natural soil properties are lost, though not impossible it's difficult to re-establish the entire area with its natural properties/characteristics. Re-vegetation of such ecologically degraded areas generally need to deal with soil compaction, nutrient deficiency, low organic matter, poor soil texture, low pH, low Cation Exchange Capacity (CEC), potential toxicity of Al, Fe and other elements, and low microbial activity. Watmough and Dillon (2004) worked on major element fluxes in a coniferous catchment in central Ontario. The study documented the magnitude of some alkali metals like Ca, K and Na input through deposition and weathering and its losses from soil due to acid deposition and harvesting. Haddadin *et al.* (2002) report wide spatial variability in Li level, from the mean concentration of 13.1 mg/kg, in Jordanian soils. Kellman (2002) studied the ability of Fe and Al coatings on soil particles to reduce leaching of large nutrient loads. Aracil *et al.* (2003) worked on the geochemical composition and geophysical characterization of a mining silt pond and reported that the pH values of the surface samples were lower than those from the deeper ones. A review by Sharma and Sharma (2004) revealed that the exchangeable Ca^{2+} in the soils increased as a result of incorporation of litter from growing trees making it the dominant one among all the cations. Bhuyan and Sharma (2007) worked on the soil acidity and its effect on exchangeable Al, Ca, Mg, Mn and lime requirement of tea garden soils of Lakhimpur district, Assam, India and found it to be acidic, requiring lime for rectification of Ca deficiency and Al toxicity

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problems. Gupta *et al.* (2005) investigating the effect of leaf litter on plant growth reported that it improved the physico-chemical parameters such as pH, EC, organic carbon and other major available nutrients (N, P, and K) of the amended mine spoil significantly. Certain aspects such as soil structure, soil density, pH, organic matter, P, K, Ca, Mg, Al and CEC in tin mines of the Amazon forest were examined by Longo *et al.* (2005).

As noted above, one of the inevitable consequences of surface mining is the disruption of the soil system. Numerous investigators and observers commented that destruction of soil properties may result in permanent reduction in soil productivity and may significantly alter the hydrologic system. The forest wealth of India is facing multifarious problems, due to escalating demands for meeting food, fodder, industries, etc. Bringing the forest cover up to 33% of the total land area is a declared aim by the Government of India. In view of these specifics, an understanding of the soil nutrients including alkali and alkaline earth metals is important for re-establishment of vegetation similar to the original one in the area after the mining activities are ceased. Nevertheless not many studies talk about exchangeable metal (alkali and alkaline earth metals) concentrations or metal ratios. Keeping this in view, the present investigation, on soil alkali and alkaline earth metals, their distribution along the depth profile and their ratios on spatio-temporal scale in the three potential bauxite sites in Eastern Ghats was conducted.

4.2 Materials and methods

The sampling strategy and preliminary sample processing are discussed earlier in the Section 2.3. As mentioned earlier 864 soil samples were collected for analysis. A portion of the sample was analysed for the alkali (Na, K and Li) and alkaline earth metals (Ca and Mg). As our aim was to estimate exchangeable fractions (bioavailable portion) of the metals, the samples were extracted with 1M neutral ammonium acetate solution (Moorhead *et al.* 2000; Wang and Scott 2001). Extractions were done by shaking 5 g samples of air-dry soil in 25 ml of the extractant for 30 minutes (SubbaRao and SammiReddy 2005), followed by filtration and subsequent storage till further analyses. All extractions were made at room

temperature. Sodium, K and Li were analysed using a Flame Photometer (Systronics 126), and Ca and Mg were determined following EDTA titrimetric method. The metal ratios, Na: K and Mg: Ca, were estimated empirically following Rivera-Monroy *et al.* (2004). Sodium Absorption Ratio (SAR) for each sample was computed as $SAR = Na/\sqrt{(Ca+Mg)/2}$. The percentage ratio of Na to the total of all the cations (Na, K, Ca, Li and Mg) was calculated as $pNa = [Na / (Na+K+Ca+Li+Mg)] * 100$ (Prusty and Azeez 2007). Likewise percentage ratio of other cations was also calculated. The ratio of Ca to the total of all other major cations was calculated as $rCa = Ca / (Na+K+Li+Mg)$. Similar ratios of other cations were also calculated. All cationic ratios were calculated after converting the elemental concentrations into milli equivalents (meq/kg).

4.3 Results

Sodium concentrations in the soils of Araku ranged from 4 to 82 mg/kg (Figure 4.1A, B, C, D, E, F, G, H and I). The GLM-ANOVA ($P < 0.05$) showed that Na varied only among months and locations. The post-hoc analysis (LSD, $P < 0.05$, Table 4.1) specified that February 2007, May 2007, February 2008 were significantly different from all other months. Potassium concentration varied from 15 to 746 mg/kg (Figure 4.2A, B, C, D, E, F, G, H and I). The concentrations varied among locations, sites and layers (GLM-ANOVA, $P < 0.05$). 0-5cm and 5-10cm layers were significantly distinct from other layers (LSD, $P < 0.05$, Table 4.1). Lithium values ranged from 1.2 to 14 mg/kg (Figure 4.3A, B, C, D, E, F, G, H and I). Lithium concentrations were distinct among all the locations (GLM-ANOVA, LSD, $P < 0.05$). Calcium was in the range of 119 to 2875 mg/kg (Figure 4.4A, B, C, D, E, F, G, H and I) and was varied among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Among the months November 2006, February 2007 and May 2007 were distinct from others (LSD, $P < 0.05$, Table 4.1). Among the sites, C1, at Chittamgondi, was found distinct from others. All layers were distinct and varied from each other for Ca and Li (LSD, $P < 0.05$, Table 4.1).

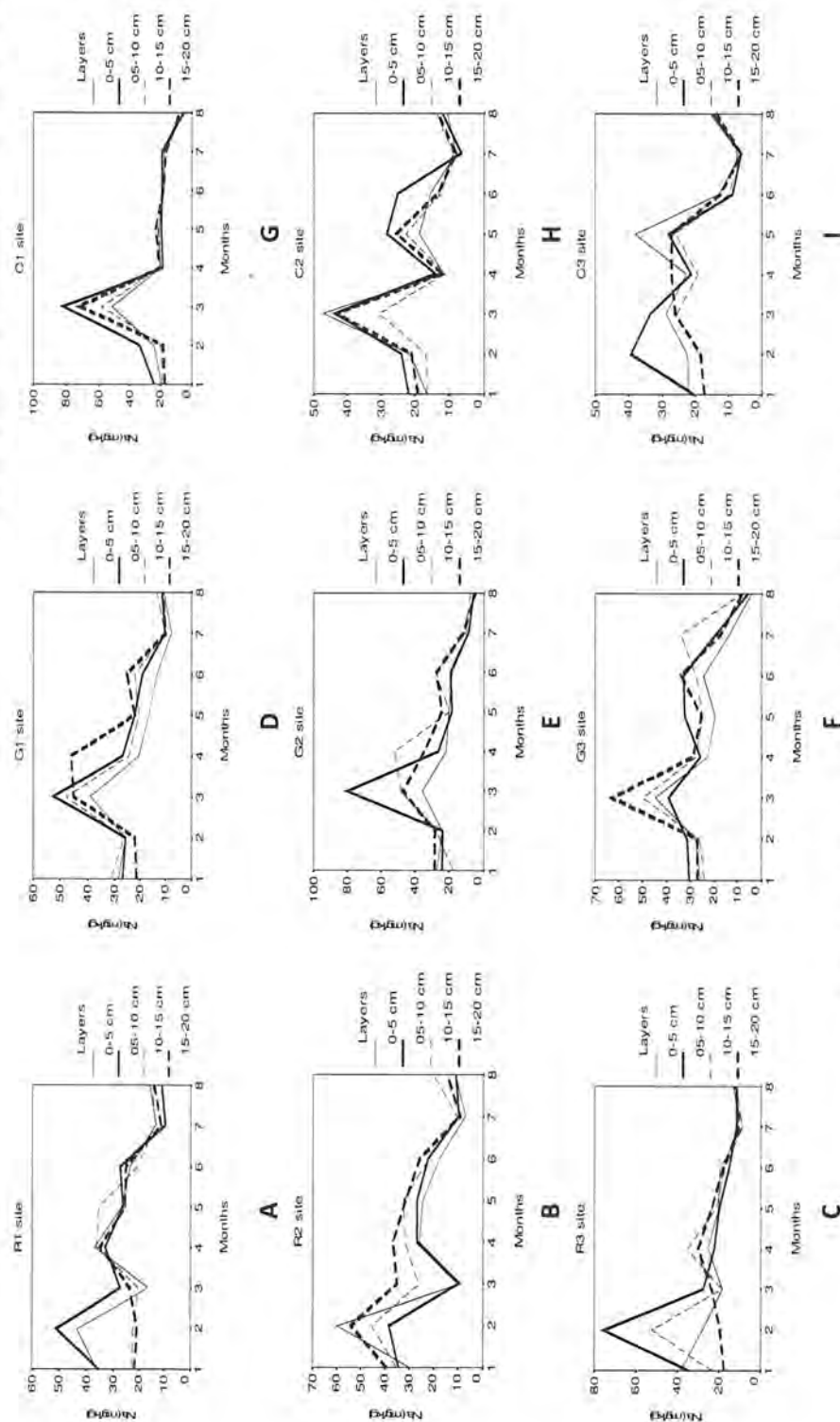


Figure 4.1. Concentrations of Na in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

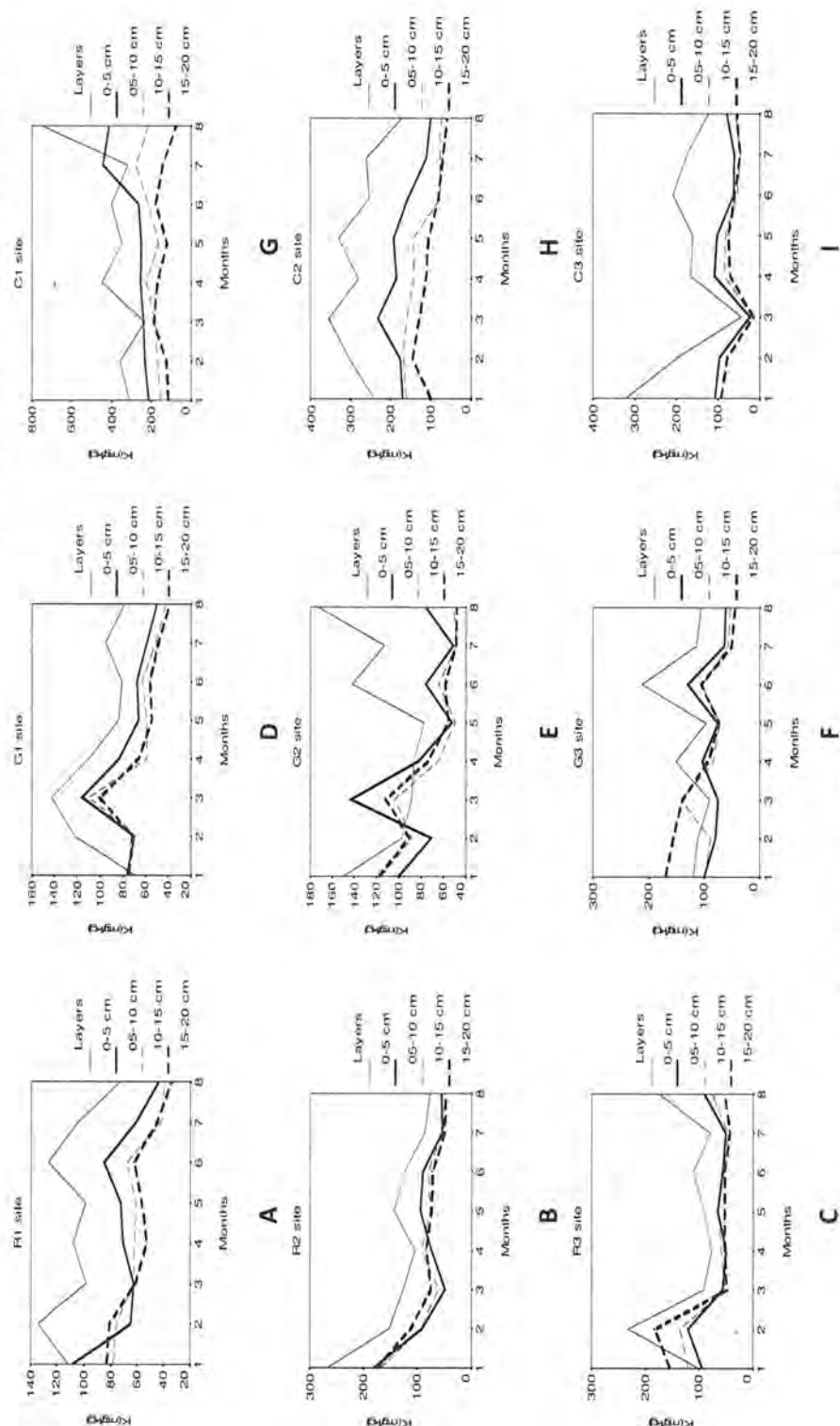


Figure 4.2. Concentrations of K in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

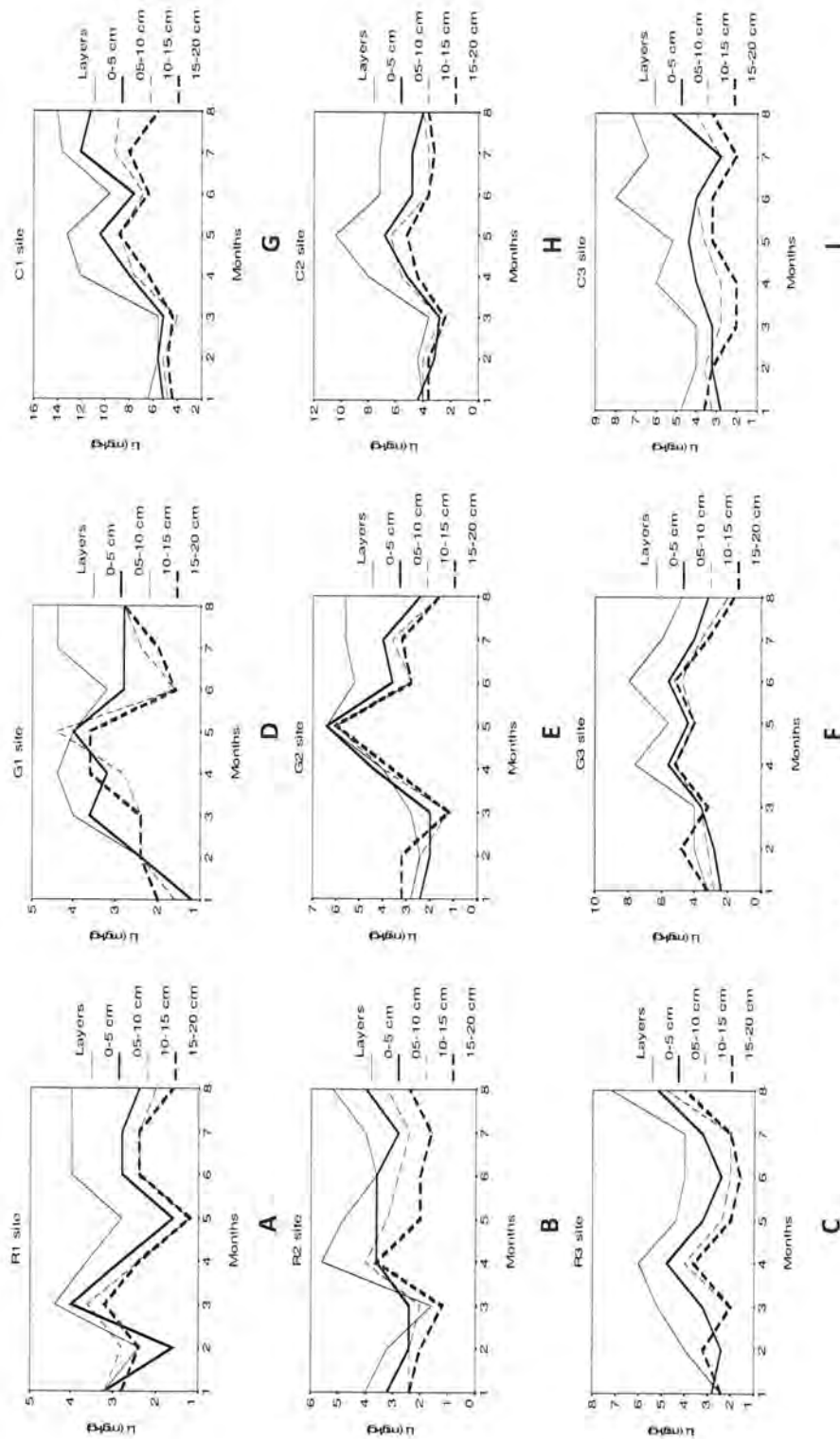


Figure 4.3. Concentrations of Li in soils of Araku

Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

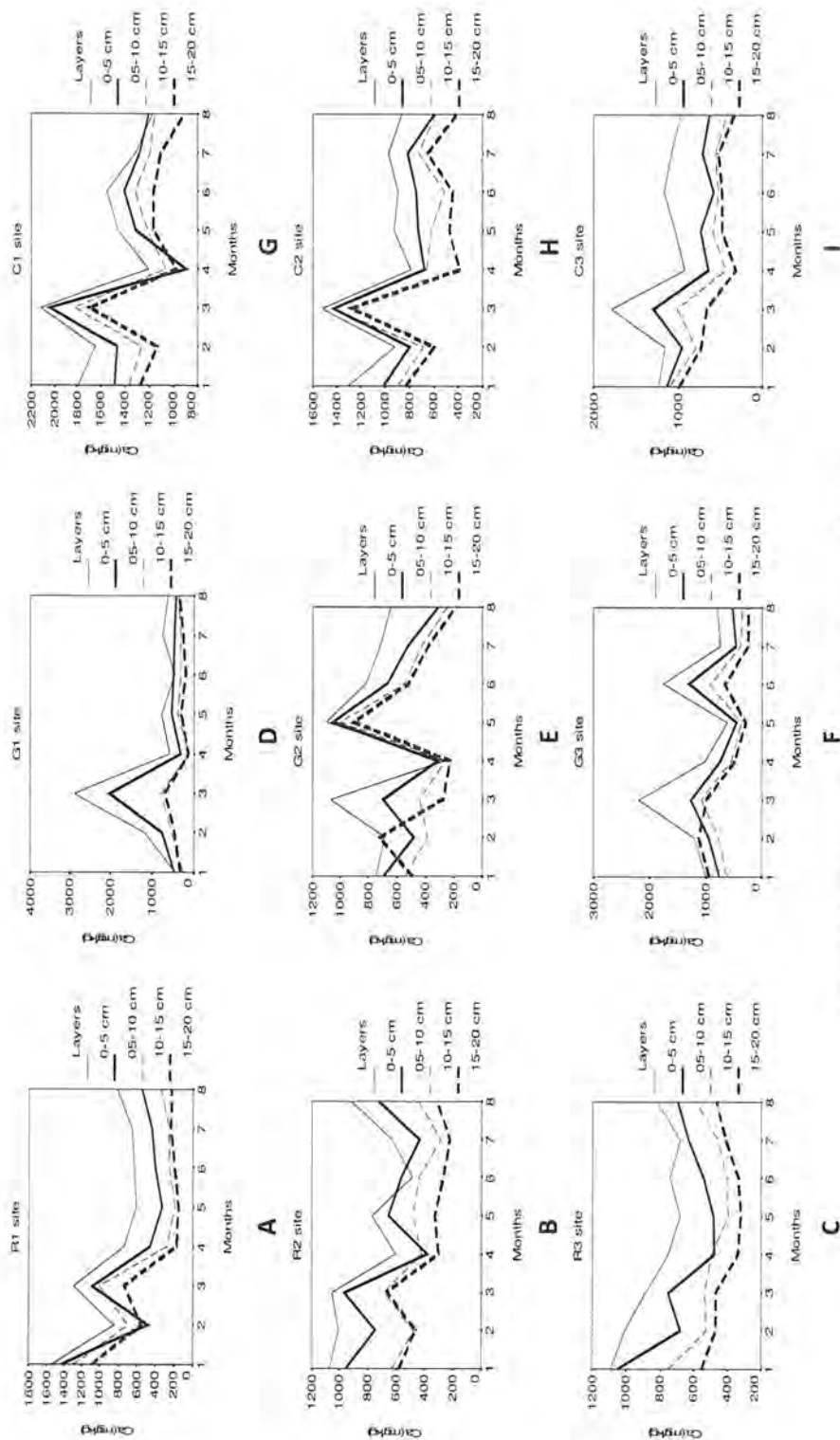


Figure 4.4. Concentrations of Ca in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

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Magnesium concentrations ranged from 350 to 2392 mg/kg (Figure 4.5A, B, C, D, E, F, G, H and I). Magnesium levels differed significantly among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). November 2006 and February 2007 were different from each other and from the rest of the months (LSD, $P < 0.05$, Table 4.1). All three hillocks/locations were distinct from each other with respect to Mg levels. With reference to Mg concentrations C1 site was distinct from rest of the sites. The upper two layers were also distinct from the rest with respect to Mg. Based on the highest concentration, the base cations follow the sequence $\text{Ca} > \text{Mg} > \text{K} > \text{Na} > \text{Li}$. Cation exchange capacity values ranging from 41 to 233 meq/kg were found significantly distinct among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$, Table 4.1). November 2006 was significant from rest of the months (LSD, $P < 0.05$) with respect to CEC levels. Cation exchange capacity values at C1 varied significantly from the rest. Layers, 0-5 cm and 5-10 cm were distinct from others with respect to CEC. Sodium absorption ratio ranged from 0.023 to 0.53 and varied among months, locations and layers (GLM-ANOVA, $P < 0.05$). Among months May 2007 was significantly distinct from others (LSD, $P < 0.05$, Table 4.1) for SAR levels in Araku soils. Sodium absorption ratio in the top layer was different from the rest of the layers.

The ratio of Na: K varied from 0.0085 to 1.7372. The ratio of Na: K value during May 2007 was distinct from other months, and top layer varied significantly from others (GLM-ANOVA, LSD, $P < 0.05$). The ratio of C: Ca ranged between 5.7 and 280.1 and varied significantly among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Sites G1 and C1 were distinct from others. The ratio of C: Ca was distinct for all the layers. Values for pNa ranged between 0.14 and 3.63, and varied significantly among months, locations and soil layers (GLM-ANOVA, $P < 0.05$). November 2006 was significantly different from rest of the months (LSD, $P < 0.05$, Table 4.1) and all layers were significantly distinct from each other (LSD, $P < 0.05$) with respect to pNa. Values for pK ranged from 0.37 to 12.28 and significantly varied among locations, sites and layers (GLM-ANOVA, $P < 0.05$). Among the sites, the levels of pK at C1 and C2 sites were distinct from each other and from the rest of the sites, and among the soil layers, top layer was distinct from the rest. Range of pCa was

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from 9.2 to 67.5, and varied among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Among months, May 2007, August 2007 and November 2007 were distinct from other. Site C1 was distinct from other sites. All the four layers of soil varied significantly from each other (LSD, $P < 0.05$, Table 4.1). Range for pLi was from 0.089 to 1.312, and varied significantly among, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Months August 2007 and May 2008 were distinct from each other and from others. R1 and C1 sites were distinct from each and from the other sites. 0-5cm and 5-10cm layers were distinct from each other and from the other layers (LSD, $P < 0.05$, Table 4.1). Values of pMg varied from 29.6 to 87.5 and varied significantly among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Among months May 2007 was distinct from all the others. Site C1 was distinct from the rest. 0-5 cm and 15-20 cm layers were distinct from other layers (LSD, $P < 0.05$).

The values for rNa ranged between 0.0014 and 0.038 whereas, rK varied from 0.0037 to 0.145. The trend by rNa and rK was similar to that of pNa and pK, respectively. Values for rCa ranged from 0.102 to 2.350 and varied significantly among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Among months, November 2006 and May 2007 varied from all the others, and among sites, C1 was distinct from the rest. 0-5 cm and 15-20 cm layers were also distinct from rest other layers (LSD, $P < 0.05$) in rCa. 0-5 cm and 15-20 cm layers were also distinct from rest other layers (LSD, $P < 0.05$) in rCa. Values for rLi ranged from 0.0009 to 0.013 and varied among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). August 2007 and February 2008 varied from other months (LSD, $P < 0.05$). Sites R1 and C1 were distinct from each other and also from other sites. 0-5 cm and 5-10 cm layer were distinct from all other layers. Values for rMg ranged from 0.44 to 7.84 and varied among months, locations, sites and layers (GLM-ANOVA, $P < 0.05$). Among months, rMg during May 2007 was distinct. Sites G1 and R1 were distinct from each other and from rest of the sites. Among soil layers top (0-5 cm) and bottom (15-20 cm) layers were distinct from all other layers (LSD, $P < 0.05$).

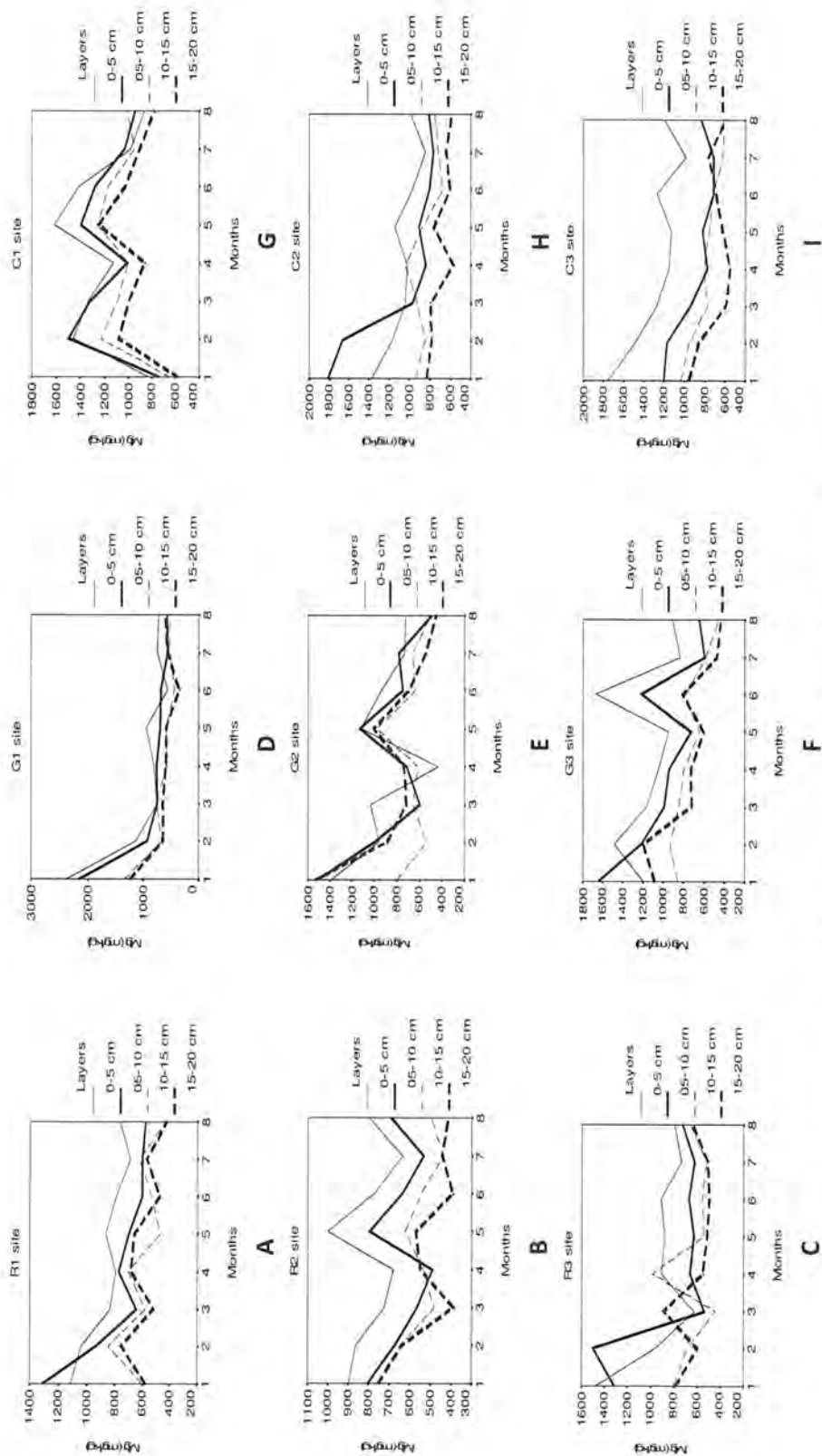


Figure 4.5. Concentrations of Mg in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

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The ratio of Mg: Ca ranged between 0.279 and 8.619, and differed significantly among months, locations, sites and layers. Among months, May 2007 was distinct from the rest all months and among sites C1 was distinct from rest all with respect to Mg: Ca ratio. Layer 15-20 cm at all locations was significantly distinct from the rest (LSD, $P < 0.05$, Table 4.1) for Mg: Ca ratio. Chittamgondi was distinct from other locations in the case of Na, K, Ca, Na: K, SAR, pNa, pK, rNa and rK. All the three locations were distinct from each other in the case of C: Ca, CEC, pCa, pLi, pMg, rCa, rLi, rMg and Mg: Ca (LSD, $P < 0.05$, Table 4.1). All ratios and soil parameters analysed were correlated with K and Li (Table 4.2). Cation exchange capacity was negatively correlated to other variables, except pCa and rCa. Principal Component Analysis performed for the soil parameters resulted in 5 PCs, which explained 95.6% of the total variance (Table 4.3). Among the 5 PCs, PC1 explained for 29.2% of the total variance in soil characteristics among samples, reflecting the influence of the variables such as pCa, rMg, Mg: Ca, rCa and pMg. PC2 accounted for 20.6% of the total variance and reflected the influence of SAR, pNa, rNa and Na. The influence of Mg and CEC was reflected by PC3, which accounted for 19.2% of the total variance. PC4 accounted for 14.2% of the variance indicating the influence of soil pK, rK and K. PC5 accounting for 12.5% of the variance indicated influence of pLi, rLi and Li. Thus, the 5 Principal components could be stated as linked to i) pCa, rMg, Mg: Ca, rCa and pMg, ii) SAR, pNa, rNa and Na, iii) Mg and CEC, iv) pK, rK and K, and v) pLi, rLi and Li.

Table 4.1.1. Soil alkali and alkaline earth metals (means, n=3) in three bauxite proposed locations in Eastern Ghats

Parameters	Attributes	1	2	3	4	5	6	7	8	9
Na	Month	25 ^a	31 ^b	39 ^c	26 ^a	24 ^a	20 ^d	11 ^a	11 ^a	
	Location	25 ^a	25 ^a	21 ^b						
	Location	87 ^a	87 ^a	172 ^b						
K	Site	75 ^a	98 ^a	87 ^a	75 ^a	86 ^a	101 ^a	256 ^b	166 ^c	95 ^a
	Layer	172 ^a	112 ^b	93 ^c	85 ^c					
Ca	Month	938 ^a	816 ^b	1183 ^c	540 ^d	665 ^d	686 ^d	610 ^d	589 ^d	
	Location	608 ^a	658 ^a	993 ^b						
	Site	622 ^a	594 ^a	610 ^a	590 ^a	573 ^a	811 ^a	1347 ^b	819 ^a	814 ^a
	Layer	1016 ^a	794 ^b	643 ^c	560 ^d					
Li	Location	3.15 ^a	3.51 ^b	5.47 ^c						
	Site	2.8 ^a	3.0 ^a	3.1 ^a	2.9 ^a	3.5 ^a	4.2 ^a	7.8 ^b	4.7 ^c	3.9 ^a
	Layer	5.3 ^a	4.0 ^b	3.5 ^c	3.2 ^d					
Mg	Month	1140 ^a	998 ^b	804 ^c	774 ^c	855 ^c	784 ^c	679 ^c	679 ^c	
	Location	697 ^a	847 ^b	975 ^c						
	Site	703 ^a	633 ^a	754 ^a	807 ^a	820 ^a	914 ^a	1086 ^b	922 ^a	916 ^a
	Layer	1023 ^a	903 ^b	732 ^c	699 ^c					
Na: K	Month	0.3 ^a	0.3 ^a	0.5 ^b	0.3 ^a	0.3 ^a	0.2 ^a	0.2 ^a	0.2 ^a	
	Location	0.3 ^a	0.3 ^a	0.2 ^b						
	Layer	0.2 ^a	0.3 ^b	0.3 ^b	0.3 ^b					
C: Ca	Month	53.6 ^a	50.3 ^a	34.0 ^b	76.5 ^a	66.2 ^a	68.8 ^a	60.2 ^a	63.3 ^a	
	Location	66.0 ^a	80.6 ^b	30.7 ^c						
	Site	74.8 ^a	56.3 ^a	67.0 ^a	107.4 ^b	79.3 ^a	55.1 ^a	12.7 ^c	38.5 ^a	40.8 ^a
	Layer	34.6 ^a	44.2 ^b	66.0 ^c	91.6 ^d					
CEC	Month	146 ^a	128 ^b	130 ^b	95 ^b	108 ^b	103 ^b	90 ^b	89 ^b	

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	Location	91 ^a	106 ^b	136 ^c		100 ^a	120 ^a	165 ^b	123 ^a		
	Site	92 ^a	86 ^a	96 ^a	99 ^a	100 ^a	120 ^a	165 ^b	123 ^a		120 ^a
	Layer	141.00 ^a	118.46 ^b	96.19 ^c	89.17 ^c						
	Month	0.14 ^a	0.18 ^a	0.22 ^b	0.18 ^a	0.16 ^a	0.14 ^a	0.08 ^a	0.08 ^a		
SAR	Location	0.2 ^a	0.2 ^a	0.1 ^b							
	Layer	0.12 ^a	0.15 ^b	0.16 ^b	0.17 ^b						
	Month	0.8 ^a	1.2 ^b	1.4 ^b	1.5 ^b	1.3 ^b	1.2 ^b	0.6 ^b	0.6 ^b		
pNa	Location	1.3 ^a	1.2 ^a	0.7 ^b							
	Layer	0.7 ^a	1.0 ^b	1.2 ^c	1.4 ^d						
	Location	2.6 ^a	2.4 ^a	3.2 ^b							
pK	Site	2.2 ^a	2.9 ^a	2.6 ^a	2.3 ^a	2.6 ^a	2.3 ^a	4.1 ^b	3.5 ^c	2.1 ^a	
	Layer	3.2 ^a	2.5 ^b	2.6 ^b	2.6 ^b						
	Month	33 ^a	31 ^a	44 ^b	27 ^c	28 ^d	31 ^a	32 ^a	31 ^a		
pCa	Location	32 ^a	29 ^b	36 ^c							
	Site	31 ^a	33 ^a	31 ^a	27 ^a	27 ^a	32 ^a	41 ^b	33 ^a	33 ^a	
	Layer	35 ^a	33 ^b	32 ^c	29 ^d						
	Month	0.34 ^a	0.39 ^a	0.35 ^a	0.75 ^b	0.66 ^a	0.59 ^a	0.65 ^c	0.68 ^a		
pLi	Location	0.51 ^a	0.54 ^b	0.60 ^c							
	Site	0.45 ^a	0.53 ^b	0.54 ^b	0.51 ^b	0.55 ^b	0.57 ^b	0.71 ^c	0.60 ^b	0.50 ^b	
	Layer	0.6 ^a	0.5 ^b	0.6 ^a	0.6 ^a						
	Month	63 ^a	64 ^a	52 ^b	68 ^a	67 ^a	64 ^a	64 ^a	65 ^a		
pMg	Location	64 ^a	67 ^b	60 ^c							
	Site	65 ^a	62 ^a	65 ^a	69 ^a	68 ^a	64 ^a	54 ^b	62 ^a	64 ^a	
	Layer	60 ^a	63 ^b	64 ^b	66 ^c						
rNa	Month	0.0085 ^a	0.0122 ^b	0.0147 ^b	0.0148 ^b	0.0128 ^b	0.0117 ^b	0.0065 ^b	0.0064 ^b		
	Location	0.0132 ^a	0.0125 ^a	0.0072 ^b							

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	Layer	0.0072 ^a	0.0102 ^b	0.0124 ^c	0.0139 ^d							
	Location	0.0264 ^a	0.0248 ^a	0.0335 ^b								
rK	Site	0.0226 ^a	0.0297 ^a	0.0269 ^a	0.0241 ^a	0.0264 ^a	0.0241 ^a	0.0435 ^b	0.0360 ^c	0.0211 ^a		
	Layer	0.0331 ^a	0.0256 ^b	0.0270 ^b	0.0274 ^b							
	Month	0.6 ^a	0.5 ^b	0.8 ^c	0.4 ^b	0.4 ^b	0.5 ^b	0.5 ^b	0.5 ^b			
rCa	Location	0.50 ^a	0.45 ^b	0.60 ^c								
	Site	0.5 ^a	0.5 ^a	0.5 ^a	0.5 ^a	0.4 ^a	0.5 ^a	0.8 ^b	0.5 ^a	0.5 ^a		
	Layer	0.59 ^a	0.53 ^b	0.50 ^b	0.45 ^c							
	Month	0.00345 ^a	0.00389 ^a	0.00351 ^a	0.00753 ^b	0.00664 ^a	0.00594 ^c	0.00654 ^a	0.00683 ^a			
rLi	Location	0.00511 ^a	0.00547 ^b	0.00605 ^c								
	Site	0.00454 ^a	0.00538 ^b	0.00541 ^b	0.00511 ^b	0.00556 ^b	0.00572 ^b	0.00713 ^c	0.00600 ^b	0.00503 ^b		
	Layer	0.00577 ^a	0.00524 ^b	0.00560 ^a	0.00556 ^a							
	Month	2.5 ^a	1.9 ^a	1.3 ^b	2.5 ^a	2.2 ^a	2.0 ^a	2.0 ^a	2.0 ^a			
rMg	Location	2.1 ^a	2.5 ^b	1.6 ^c								
	Site	2.3 ^a	1.8 ^a	2.2 ^a	2.9 ^b	2.6 ^a	1.9 ^a	1.2 ^c	1.7 ^a	1.9 ^a		
	Layer	1.7 ^a	2.0 ^b	2.1 ^b	2.4 ^c							
	Month	1.9 ^a	1.3 ^a	0.9 ^b	1.9 ^a	1.6 ^a	1.5 ^a	1.4 ^a	1.4 ^a			
Mg: Ca	Location	1.5 ^a	1.8 ^b	1.1 ^c								
	Site	1.7 ^a	1.4 ^a	1.6 ^a	2.2 ^a	2.0 ^a	1.3 ^a	0.8 ^b	1.2 ^a	1.3 ^a		
	Layer	1.2 ^a	1.4 ^a	1.5 ^a	1.9 ^b							

Source of variation: months (1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008); location (1, Raktakonda; 2, Galikonda; 3, Chittamgondli); Site (1, R1; 2, R2; 3, R3; 4, G1; 5, G2; 6, G3; 7, C1; 8, C2; 9, C3); and layer (1, 0-5 cm; 2, 5-10 cm; 3, 10-15 cm; 4, 15-20 cm). Within rows, means followed by the same letter are not significantly different at $P < 0.05$

Na: Sodium, K: Potassium, Ca: Calcium, Li: Lithium, Mg: Magnesium, Na: K: Sodium: Potassium, C: Ca: Carbon: Calcium, CEC: Cation Exchange Capacity, SAR: Sodium Absorption Ratio, Mg: Ca: Magnesium: Calcium

Table 4.2. Correlation matrix of select parameters in the soil system of Eastern Ghats

Variables	Na	K	Ca	Li	Mg	Na: K	C:Ca	CEC	SAR	pNa	pK	pCa	pLi	pMg	rNa	rK	rCa	rLi	rMg	Mg: Ca
Na	1																			
K	NS	1																		
Ca	0.198	0.414	1																	
Li	-0.130	0.673	0.507	1																
Mg	0.154	0.323	0.539	0.377	1															
Na: K	0.555	-0.370	-0.123	-0.333	-0.101	1														
C: Ca	NS	-0.335	-0.662	-0.440	-0.371	0.195	1													
CEC	0.205	0.454	0.840	0.516	0.908	-0.135	-0.567	1												
SAR	0.909	-0.093	-0.119	-0.282	-0.156	0.621	0.214	-0.150	1											
pNa	0.689	-0.208	-0.358	-0.380	-0.382	0.592	0.452	-0.415	0.924	1										
pK	NS	0.792	NS	0.397	-0.167	-0.334	NS	-0.084	NS	0.105	1									
pCa	0.077	0.229	0.753	0.304	NS	-0.094	-0.698	0.361	-0.095	-0.242	NS	1								
pLi	-0.281	0.270	-0.178	0.599	-0.309	-0.221	0.090	-0.266	-0.140	NS	0.467	NS	1							
pMg	-0.121	-0.346	-0.713	-0.352	0.079	0.105	0.654	-0.308	NS	0.145	-0.191	-0.980	NS	1						
rNa	0.689	-0.205	-0.355	-0.376	-0.379	0.591	0.450	-0.411	0.924	1.000	0.106	-0.240	NS	0.143	1					
rK	NS	0.801	NS	0.406	-0.157	-0.323	NS	-0.073	NS	0.093	0.998	NS	0.464	-0.193	0.094	1				
rCa	NS	0.165	0.691	0.203	NS	NS	-0.489	0.305	-0.070	-0.182	NS	0.894	-0.074	-0.876	-0.181	NS	1			
rLi	-0.280	0.271	-0.178	0.599	-0.308	-0.221	0.090	-0.266	-0.139	NS	0.468	NS	1.000	NS	NS	0.465	-0.074	1		
rMg	NS	-0.218	-0.468	-0.283	0.225	0.124	0.655	-0.091	NS	0.078	-0.171	-0.747	-0.152	0.771	0.076	-0.168	-0.527	-0.151	1	
Mg: Ca	NS	-0.155	-0.418	-0.230	0.186	0.112	0.673	-0.089	NS	0.113	-0.093	-0.667	-0.099	0.675	0.112	-0.092	-0.455	-0.099	0.964	1
864 Sample size, $\pm .067$ critical value for R at $P < 0.05$ (two-tail), NS: Not Significant at $P < 0.05$																				
Na: Sodium, K: Potassium, Ca: Calcium, Li: Lithium, Mg: Magnesium, Na: K: Sodium: Potassium, C: Ca: Carbon: Calcium, CEC: Cation Exchange Capacity, SAR: Sodium Absorption Ratio, Mg: Ca: Magnesium: Calcium																				

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Table 4.3. PCA of soil variables from all the three locations – Factor loadings

Parameters	Principal Components				
	PC1 (pCa, rMg, Mg: Ca, rCa, pMg)	PC 2 (SAR, pNa, rNa, Na)	PC 3 (Mg, CEC)	PC 4 (pK, rK, K)	PC 5 (pLi, rLi, Li)
Na	-0.044	0.894	0.319	0.017	-0.18
K	-0.222	-0.046	0.557	0.786	0.079
Ca	-0.712	-0.129	0.682	-0.005	-0.071
Li	-0.279	-0.207	0.599	0.182	0.683
Mg	0.081	-0.132	0.971	-0.063	-0.147
Na: K	0.083	0.753	-0.12	-0.521	-0.082
C: Ca	0.703	0.173	-0.622	-0.04	-0.029
CEC	-0.284	-0.122	0.935	-0.009	-0.136
SAR	0.028	0.979	-0.067	0.066	-0.088
pNa	0.15	0.906	-0.374	0.059	-0.025
pK	-0.026	0.06	-0.149	0.954	0.232
pCa	-0.973	-0.087	0.1	0.0007	0.037
pLi	-0.004	-0.104	-0.171	0.222	0.953
pMg	0.934	-0.006	-0.065	-0.129	-0.005
rNa	0.128	0.897	-0.35	0.081	0.01
rK	-0.054	0.026	-0.071	0.913	0.248
rCa	-0.942	-0.058	0.102	-0.028	-0.052
rLi	0.009	-0.09	-0.156	0.242	0.948
rMg	0.97	0.006	-0.047	-0.135	-0.1
Mg: Ca	0.959	0.067	-0.073	-0.049	-0.067
Total loading*	5.834	4.113	3.833	2.831	2.507
% Variance explained	29.170	20.565	19.167	14.157	12.535
Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser normalization (Rotation converged in 6 iterations), *Sums of squared loadings					
Na: Sodium, K: Potassium, Ca: Calcium, Li: Lithium, Mg: Magnesium, Na: K: Sodium: Potassium, C: Ca: Carbon: Calcium, CEC: Cation Exchange Capacity, SAR: Sodium Absorption Ratio, Mg: Ca: Magnesium: Calcium					

4.4 Discussion

Given the influence of climatic conditions, human disturbances, geological set-up and plant species diversity, wide dissimilarity in distribution and mobilization of alkali and alkaline earth metals was expected among the months, locations, sites and soil layers at the potential bauxite hillocks in Araku. Most of the metals differed significantly among locations, sites and layers. The present investigation reported significant variations in nutrient concentrations at Chittamgondi which could be ascribed to the differential vegetation patterns among locations as mentioned in section 2.1.3. Locational differences with little microclimatic variations result in drastic variations in the nutrient patterns. The locations namely Raktakonda and Galikonda are nearly 1.5km apart aerially, while the third location, Chittamgondi is almost 7km away from Raktakonda. Na concentrations at Chittamgondi were lower than rest other locations. The high values of K and Ca at Chittamgondi could be attributed to the differences in species diversity and distance from the rest two.

Repeated burning of vegetation cover may expose the top soil which when trampled over by grazing animals gets pulverized and the dislodged particles are washed away with the first heavy monsoon shower. The significant variations in Na during the months of February 2007, May 2007 and February 2008 are likely to be due to the intermittent human caused forest fires. The lesser concentrations of Na in the subsequent seasons are attributed to the monsoons. Roots during monsoon seasons grow at their fastest rates and the concentrations of the nutrients get absorbed by new roots. Hence the significant differences observed in these months are ascribed to this process. Silicate minerals with low weathering rates constitute the primary mineral pool of the alkali elements (Tyler 2004). Potassium in general was distributed more in the upper layers. Potassium has an additional biogenic source (Chakrapani 2002, Prusty and Azeez 2007). Many dominant plant species in the area were seen to have high K concentrations in their various compartments (root, stem, leaf). Thus, significant variations of K in upper soil layers (0-5 cm and 5-10 cm) are attributable to the decomposition of plant species. Our findings agree with the findings of Olufemi and Ikulamberu (2004) who reported similar observations on K in soils.

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Variations in the Ca levels during November 2006, February 2007 and May 2007 may be due to the variations in rainfall pattern which results in the leaching of Ca after the first fall. The significant variations in Ca concentrations at Chittamgondi location from rest other sites is attributable to the higher density of herbs and grasses with no trees at this location which serve as soil binders. These characters contribute to nutrient availability in soils depending on the amount of Ca present in their leaves and litter decomposition. Site C1 is more disturbed due to higher human interferences. Calcium in soil originates from rocks and minerals. The concentration of calcium is very low in sandy soil of humid regions and highly weathered soils of humid tropics, whereas, it is generally high in arid region soils regardless of texture, as a result of low rainfall and little leaching (Balakrishnan 1995). Calcium, similar to K, was high in surface layers of soil. Calcium being less mobile, conservative in movement, and one of the constituents of cell wall and/or chlorophyll (Garg and Singh 2005) can add to the total concentration in the upper layer considerably through plant litter. The present study is in concordance with the findings of Kelly and Mays (1999) and Sahu *et al.* (2001). The values for exchangeable Na, K and Ca in soils of Araku were higher than the values reported elsewhere (Table 4.4). Lithium, one among the most mobile elements (Rudnick *et al.* 2004), is present in soils mainly as a component of silicates. Sandstone soils are especially rich in Li. The soils of tropical forests are low in Li concentrations, largely based on the parent rock. The presently reported concentration of Li (1.2 to 14.0 mg/kg) in soils of tropical savannah is considerably lesser than the concentration from Jordanian soils (Haddadin *et al.* 2002). According to Balakrishnan (1995) and Haddadin *et al.* (2002), soils with high levels of organic matters tend to be low (3-4 mg/kg) in Li. The lower levels of Li in soils of Araku are attributable to the presence of relatively high organic matter in soil. As Li is a mobile element, it is expected to leach during weathering, just like Na, K and Ca (Rudnick *et al.* 2004). Under rainy climates, deep soil horizons get gradually less impoverished in alkali and alkaline earth cations than the upper horizons. The role of Li contribution to the nutrient requirements of trees is unknown (Richter 1994, Berger *et al.* 2006).

Table 4.4. General levels of select alkali-alkaline earth elements in soil

Parameters	Present observation	Locations	Concentration range	Authors reported
Exc. Na (mg/kg)	4 - 82	Singalila Range, Darjeeling	37 - 43	Saha (2003)
Exc. K (mg/kg)	15.2 - 746	Singalila Range, Darjeeling	58 - 191	Saha (2003)
Exc. Ca (mg/kg)	119.6 - 2875.2	Singalila Range, Darjeeling	91 - 434	Saha (2003)
Exc. Li (mg/kg)	1.2 - 14	Jordanian soils	10.2 - 44.9	Haddadin <i>et al.</i> (2002)
Exc. Mg (mg/kg)	349.8 - 2391.9	Singalila Range, Darjeeling	177 - 281	Saha (2003)
Na: K	0.0085 - 1.7372	NA	NA	NA
C: Ca	5.7 - 280.1	NA	NA	NA
CEC	41.2 - 232.7	Acid brown soil, Vosges Mountains	97 - 154	Fitcher <i>et al.</i> (1998)
Ca: Mg	0.174 - 4.235	NA	NA	NA
NA: Not available				
Exc. Na: Exchangeable Sodium, Exc. K: Exchangeable Potassium, Exc. Ca: Exchangeable Calcium, Exc. Li: Exchangeable Lithium, Exc. Mg: Exchangeable Magnesium, Na: K: Sodium: Potassium, C: Ca: Carbon: Calcium, CEC: Cation Exchange Ca: Mg: Calcium: Magnesium				

Chapter 4: Alkali and alkaline earth metals in soil

Magnesium showed a downward trend along the soil layers. Magnesium values in Araku soils were higher (Table 4.4) than that of soils of Singalila Range, Darjeeling, India as reported by Saha (2003). Calcium and Mg in the proper proportions maintain soil in good condition of tilth and structure (Warhate *et al.* 2006). The low levels of the base cations, K, Ca and Mg, may be due to the low weathering potential of parent material and marked leaching from soils (Aluko 1993). Exchangeable cations including P, Mg, K, Ca and Mg typically tend to increase following a fire, resulting in an abrupt release of elements, which in the absence of fire would have been only gradually available through the slow decay of plant litter. Most important soil chemical functions of alkali and alkaline earth metals are connected with their role in cation exchange reactions and in controlling the composition of soil solution (Orlov 1992). Cation exchange capacity may be much influenced by the elevation of the base cations. Such influences may be ascribed to two factors viz. increased clay content, and increased organic matter content. Higher rainfall intensifies the weathering processes leading to increase in the finer fractions/clay in soil. In general, pH and rainfall are negatively correlated. Thus, Ca and Mg contents are also found to decrease with increasing rainfall.

The amount of Na, K, Ca and Mg (base cations) stored in the mineral soil fraction predetermines the status of soils and, in the long term, its evolution in response to anthropogenic activities (Fitcher *et al.* 1998) as well. In most of the soils K, Ca and Mg stand out from other base cations in that they occur in important quantities in exchangeable forms. Although exchangeable K is normally present in much lower concentrations than either Ca or Mg, plants utilize it in appreciably greater amounts than the later two (Prusty *et al.* 2007). Not only the quantum but also the ratio of cations in the soil solution is of importance in determining their behaviour in different soils. In the present case Na: K and Mg: Ca ratios were examined as i) Ca and Na are the major competing cations in normal and alkali soils (Mehta *et al.* 1983, Prusty and Azeez 2007), and ii) among the alkaline earth metals, Ca is relatively less mobile (Garg and Singh 2005) while the others are highly mobile. At Chittamgondi Na: K showed an increasing trend along the depth profile. As the K levels were high in the upper soil layers, it was obvious for Na: K for such increasing patterns. The negative correlation of Na: K with K, pK and rK could be also attributed to such variations.

Chapter 4: Alkali and alkaline earth metals in soil

Relatively coarse textured (sand with higher clay content) reddish-brown coloured soils of Araku are an indication of the presence of iron oxides in soil. Iron and aluminium oxides are ubiquitous in tropical soils and act as coatings on the surface of many soil particles. Kellman (2002) showed that the rapid nutrient adsorption on soil particle surfaces coated with iron and aluminium oxides in tropical soils contributed to the major retention of nutrients, especially when the system was exposed to large nutrient loads. The mineral content of bauxite bears close relationship with the residual ferruginous rock commonly found in tropical regions. Calcium and Mg are antagonistic to soil permeability with Na. Low Mg: Ca ratio in the upper layer is indicative of the role of vegetation on pedogenesis. As higher levels of Calcium were recorded in plant samples and also Ca being relatively less mobile, it remains in the upper soil layer after plant decomposition. This might have resulted in low Mg: Ca ratio. The low value of Na: K ratio indicates the dominating presence of K salts. Calcium is a less mobile base cation which helps in determining the type of enrichment in saline and alkaline soil. The cationic ratio above 1.0 denotes to Ca type enrichment and a ratio below 0.5 shows Na type enrichment (Prusty and Azeez 2007). In the present case, the lowest value of rCa , i.e. 0.102 was observed in 10-15 cm and the highest (i.e. 2.350) in 0-5 cm. This indicates Na type enrichment in the 10-15cm layer and Ca type enrichment in 0-5cm layer. This is supported by the higher values of pNa , rNa and SAR in the area. In the present case, the highest value of pNa was 3.63. However, a pNa value of upto 4 would not likely have an adverse effect on plant growth (Hausenbuiller 1978), while the pNa value of 14 may. The present pNa values are well within the range for supporting plant growth. Samecka-Cymerman *et al.* (2002) reported a high Mg: Ca ratio up to a range of 1.3 to 11 in some serpentine soils in Lower Silesia, Poland. Contrary to the findings of Amiel *et al.* (1986), the present findings reported an increasing trend in Mg: Ca ratio along the deeper layers, the molar ratio ranging from 0.279 to 8.619. Potassium being one of the exchangeable cations, its availability is governed by the complementary ions on the exchange complex, and therefore, ultimately by soil properties such as pH, contents of $CaCO_3$ and organic matter (Verma and Verma 1968).

4.5 Conclusion

Potassium, Ca and Mg in general were distributed more in the upper layers. Lithium levels were lower in soils of Araku. Among the base cations Ca and Mg were seen in relatively high levels. Our data suggests that differences exist among the locations for Na, K, Li, Ca and Mg as well as with respect to the type of cationic enrichment. While doing PCA analysis the highest factor loading was seen for pCa. It appears that pCa, rMg, Mg: Ca, rCa and pMg followed by SAR, pNa, rNa and Na can be used to measure indicative variables to predict cation enrichment in the soil systems. The study reveals that though the physiography along the gradient is similar, the chemical characteristics among the locations are different. While soil influences the vegetation, the vegetation in turn has bearings on soil characteristics. Differences in the variations and retentiveness among the base cations in soils presumably reflect the nutrient requirements of the plant species occurring in the Araku hillocks. The parent material also may have distinctive influence on variation and availability of these base cations.

5 HEAVY METALS IN SOILS OF ARAKU

5.1 Introduction

Movement of heavy metals in soil layers is a major environmental concern as its transport in the soil eventually leads to deterioration of other components of environment such as water. The concentrations of heavy metals in soil are associated with biological and geochemical cycles and are influenced by anthropogenic activities (Prusty and Azeez 2007; Prusty 2008). Due to human activity and its subsequent impacts on the environment, issues related to metal contamination have become common (Fernandes and Henriques 1991). Most metal contamination occurs through anthropogenic disturbance, such as mining, where unnaturally high amounts of metals are released during various processes (Helmisaari *et al.* 1995). It is well known that metals are present in soil in different chemical forms, which influence their reactivity and hence their mobility and bioavailability, and subsequent toxicity. Some metals are micronutrients and can be toxic at higher concentrations (Kabata-Pendias and Pendias 1992). Natural mineral deposits containing particularly large quantities of heavy metals are present in many locations across the globe. Such areas often support characteristic plant species that could thrive well in these metal-enriched environments. By and large, metal toxicity does not arise in natural soils with their native vegetation. Even if the soil is naturally high in a particular metal, over a period of time, the native plants often would have become adapted to the elevated levels (Brooks *et al.* 1992, Ouzounidou 1994). However, in case of new growth regimes, such as agriculture, issues of toxicity may arise (Fergus 1954).

Heavy metal content of soil are influenced by several factors including mineralogical and geochemical composition of parent rock, organic matter content, particle size distribution, soil horizonation, age, drainage, vegetation, anthropogenic and even aerosol input (Kabata-Pendias 1993, Prusty and Azeez 2007, Prusty *et al.* 2008). The information on soil properties and related metal concentrations can be used while reclaiming the area with the dominant plant species. The majority of studies on soil referring to metals have been undertaken in highly contaminated and industrial areas. Studies focusing on metal distribution in naturally

occurring forest ecosystems are relatively less. The present study aims at examining the soil characteristics and assessing levels of select heavy metals (Cu, Ni and Zn) in natural habitats that are likely to be utilized in future for mining of bauxite. Examination of the distribution and availability of these metals (Cu, Ni and Zn) were attempted owing to the geological formation of the area; the area is covered by patchy charnockites. The results are discussed in relation to the pH, ORP, organic matter, P and K to assess the extent of metal variability in the investigated area. The aim of the present work was to 1) assess the variation of Cu, Ni and Zn distribution on a temporal scale, i.e. amongst different seasons, 2) assess the variation of the metal distribution amongst locations and sites, and 3) assess the variation of metal distribution on a spatial scale, i.e. among layers.

5.2 Materials and methods

The details of soil sampling and processing are given in Section 2.3 and Table 2.2. According to Tokalioğlu *et al.* (2003), vital information on distribution of trace metals may be lost when soil samples are dried. However, drying is the best compromise to achieve stability of samples since moist soils are difficult to homogenize, and microbial and chemical reactions may lead to transformations of the fractionation pattern, when immediate extraction is not possible (Rauret *et al.* 2000, Prusty *et al.* 2009a). Soil pH, ORP, TOC, CEC, P and K values were measured following standard methods (Allen 1989, Tandon 2005, Table 2.2).

5.3 Results

As mentioned in Chapter 3 invariably, the soil was acidic, the pH ranging from 4.2-6.4, characteristic of lateritic soil. The redox potentials in the soil solution of the studied samples were between +25 and +209 mV. Cu at Raktakonda was in the range of 16.8 to 25.8 mg/kg (Figure 5.1A, B and C), at Galikonda between 15.0 and 24.9 mg/kg (Figure 5.1D, E and F) and at Chittamgondi between 13.0 and 31.8 mg/kg (Figure 5.1G, H and I). GLM-ANOVA ($P < 0.05$) and post-hoc test (LSD, $P < 0.05$, Table 5.1) revealed that all the months and locations differed significantly with respect to soil Cu. Among the 09 sampling sites R1, G1, G2, G3, C2

and C3 differed significantly with each other and from the rest in terms of the Cu level in soil.

At Raktakonda Ni was seen between 38.1 and 79.9 mg/kg (Figure 5.2A, B and C), at Galikonda between 28.9 and 66.9 mg/kg (Figure 5.2D, E and F) and at Chittamgondi between 23.5 and 101.9 mg/kg (Figure 5.2G, H and I). Nickel levels in soil varied among the months, locations, sites and layers (ANOVA, $P < 0.05$). All months, except May 2007 and November 2007, were distinct with respect to Ni in soil. Site R1, R3, G2, C2 and C3 were distinct from each other and rest other sites with respect to Ni levels. Nickel distribution in upper two layers was significantly distinct from others (LSD, $P < 0.05$). Zinc at Raktakonda ranged between 10.4 and 48.5 mg/kg (Figure 5.3A, B and C), at Galikonda between 13.4 and 46 mg/kg (Figure 5.3D, E and F) and at Chittamgondi between 11.0 to 52.1 mg/kg (Figure 5.3G, H and I). Zinc levels in soil varied significantly in all the months (GLM-ANOVA and LSD, $P < 0.05$, Table 5.1). Sites R2, G1, G2 and C2 were found significant and distinct from each other. Among the different soil layers 0-5 cm was distinct from the rest with respect to Zn level. Both Ni and Zn were distinct among locations. Copper was positively correlated with Ni, CEC and K (2-tail test, $P < 0.05$). Nickel showed a negative correlation with Zn, TOC, CEC and P. Zinc was positively correlated with pH, TOC, CEC, P and K and negatively with ORP. Ni showed a negative correlation with TOC (Table 5.2). The PCA resulting in 4 PCs (Table 5.3) explained 77.8% of the total variance. PC1 accounted for 31.4% of the total variance among soil metals, reflecting the influence of the variables ORP, pH and CEC. PC2 accounted for 16.2% of the total variance and reflected the influence of Cu and Ni. The influence of P was reflected by PC3, which accounted for 16.1% of the total variance. Likewise the influence of TOC and Zn was reflected by PC4, which accounted for 14.1% of the total variance. Thus, the 4 PCs could be indicating the axes formed of i) ORP, pH and CEC, ii) Cu and Ni, iii) P, and iv) TOC and Zn, respectively.

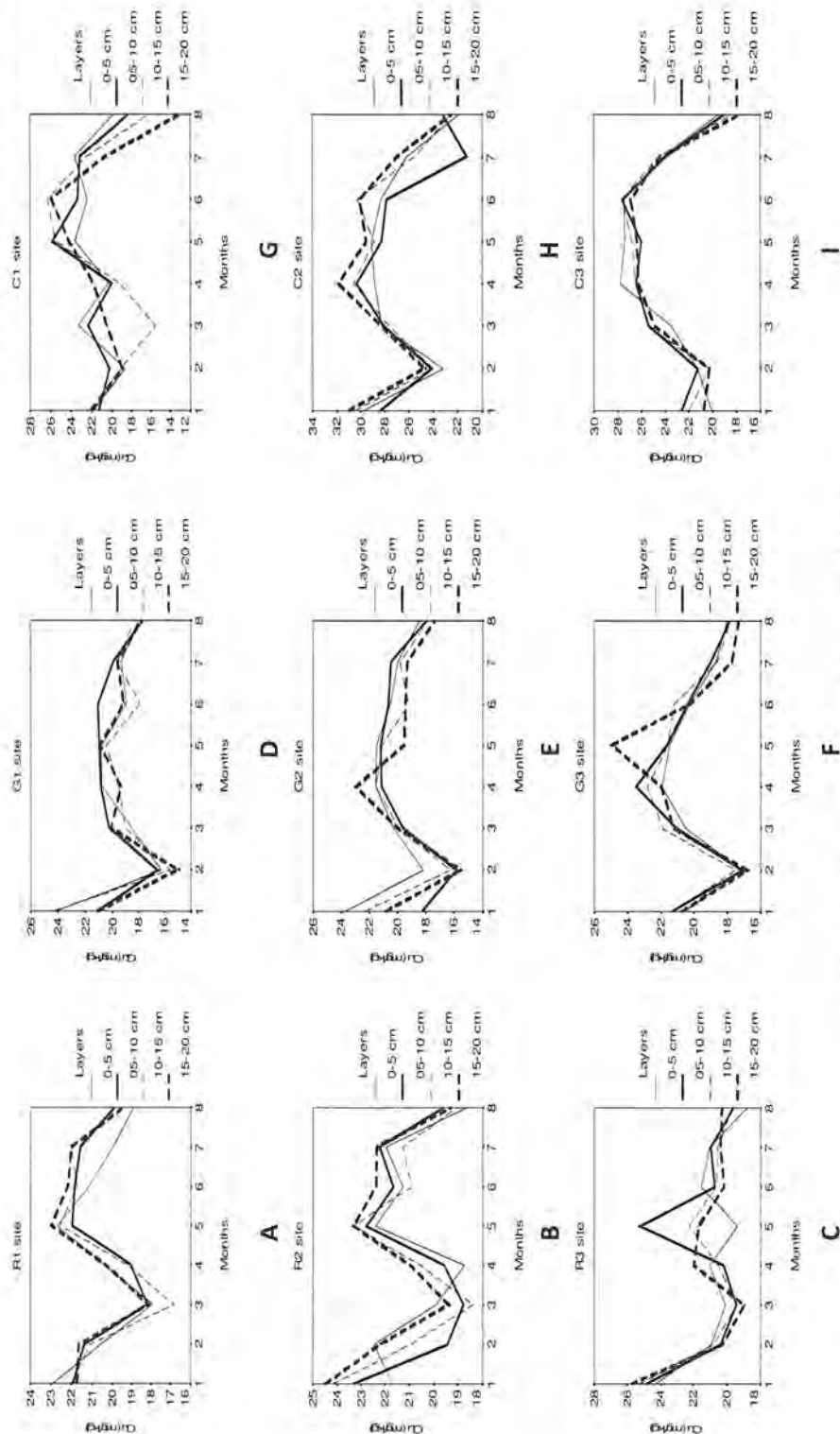


Figure 5.1. Concentrations of Cu in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

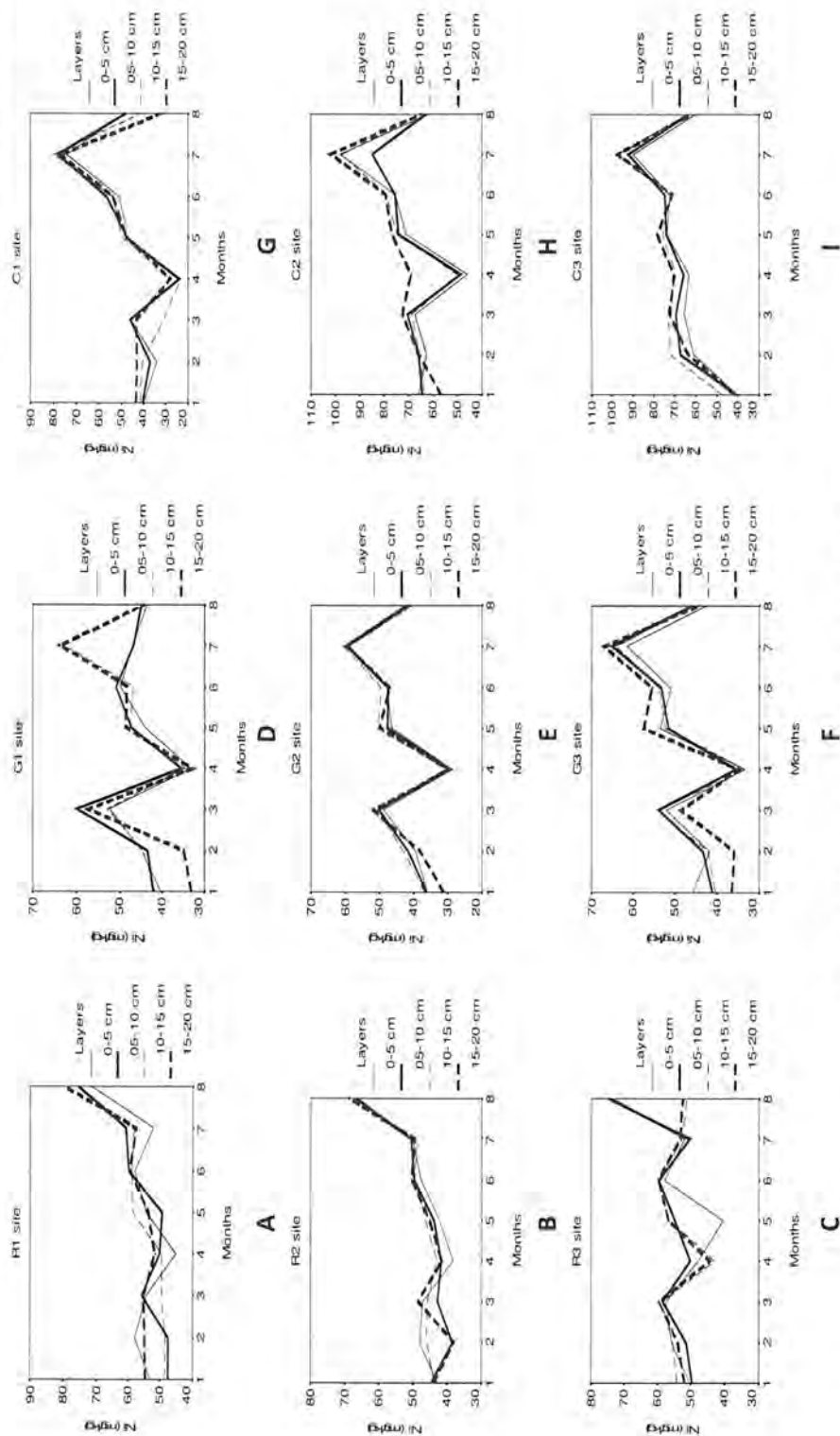


Figure 5.2. Concentrations of Ni in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

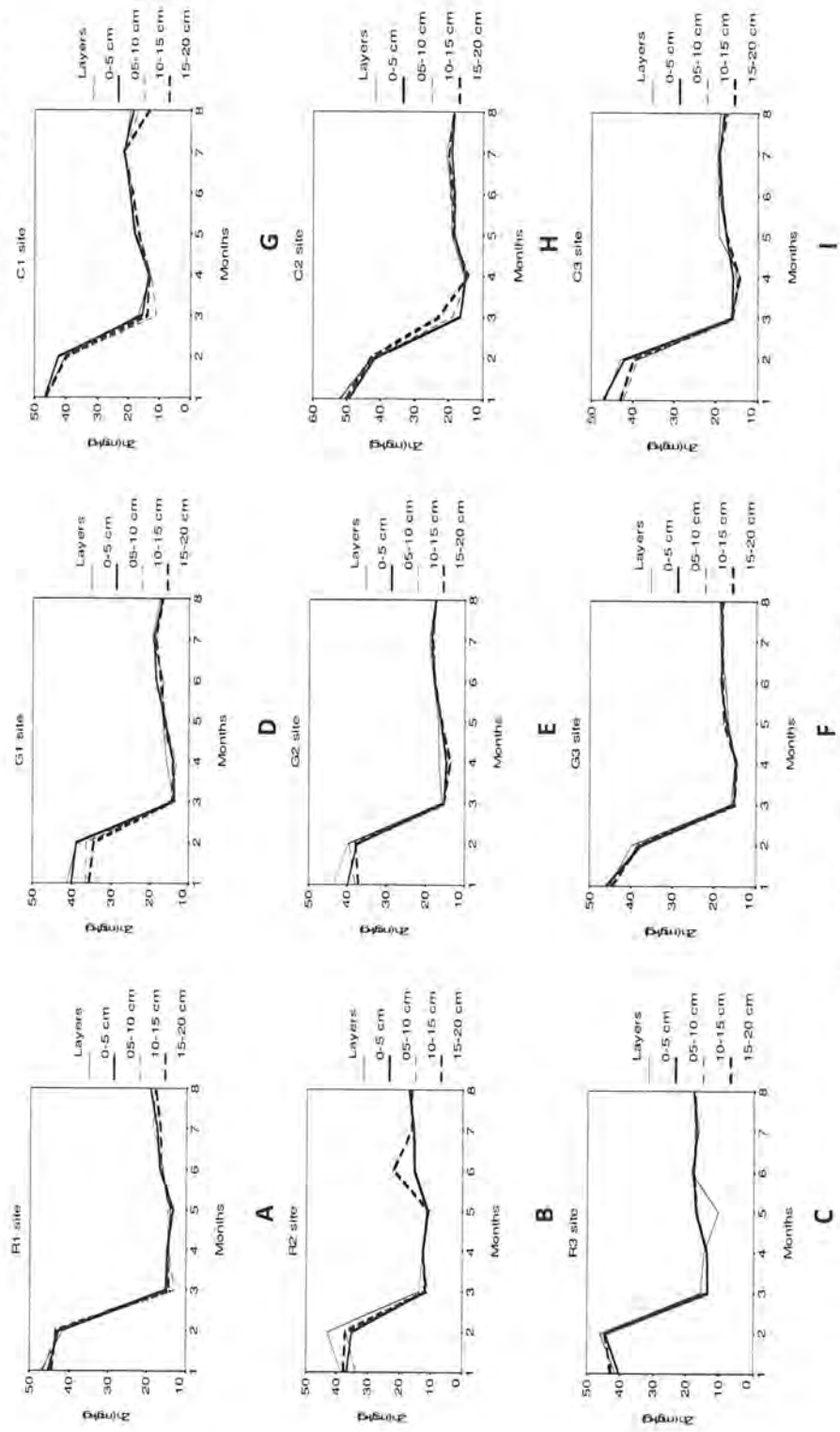


Figure 5.3. Concentrations of Zn in soils of Araku
Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

Table 5.1. Soil metals (means, n=3) in three bauxite proposed locations in Eastern Ghats

Parameters	Attributes	1	2	3	4	5	6	7	8	9
Cu	Month	23.2 ^a	19.6 ^b	21.1 ^c	22.5 ^d	23.6 ^e	22.8 ^f	21.6 ^g	18.9 ^h	
	Location	21 ^a	20 ^b	24 ^c						
	Site	20.8 ^a	21.2 ^b	21.2 ^b	19.5 ^c	19.8 ^d	20.1 ^e	21.3 ^b	27.3 ^f	23.8 ^g
Ni	Month	45 ^a	49 ^b	55 ^c	42 ^d	55 ^c	58 ^e	67 ^f	56 ^g	
	Location	53 ^a	46 ^b	62 ^c						
	Site	57 ^a	48 ^b	55 ^c	46 ^b	44 ^d	48 ^b	46 ^b	70 ^e	69 ^f
	Layer	52.6 ^a	53.6 ^b	54.1 ^c	54.0 ^c					
Zn	Month	43 ^a	40 ^b	15 ^c	14 ^d	16 ^e	18 ^f	19 ^g	18 ^f	
	Location	22.0 ^a	22.3 ^b	24.3 ^c						
	Site	23.0 ^a	20.1 ^b	22.9 ^a	21.6 ^c	22.3 ^d	23.0 ^a	23.7 ^a	25.3 ^e	23.8 ^a
	Layer	23.4 ^a	22.9 ^b	22.5 ^b	22.6 ^b					

Source of variation: months (1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008); location (1, Raktakonda; 2, Galikonda; 3, Chittamgondi); Site (1, R1; 2, R2; 3, R3; 4, G1; 5, G2; 6, G3; 7, C1; 8, C2; 9, C3); and layer (1, 0-5 cm; 2, 5-10 cm; 3, 10-15 cm; 4, 15-20 cm). Within rows, means followed by the same letter are not significantly different at $P < 0.05$

Cu: Copper, Ni: Nickel, Zn: Zinc

Table 5.2. Correlation matrix of metals and physico-chemical parameters in the Araku soil

Variables	Cu	Ni	Zn	pH	ORP	TOC	CEC	P	K
Cu	1								
Ni	0.456	1							
Zn	NS	-0.131	1						
pH	NS	NS	0.293	1					
ORP	NS	NS	-0.299	-0.955	1				
TOC	NS	-0.118	0.273	-0.226	0.226	1			
CEC	0.13	-0.081	0.297	0.627	-0.638	-0.084	1		
P	NS	-0.217	0.187	0.133	-0.13	-0.101	0.195	1	
K	0.179	NS	0.148	0.403	-0.398	-0.263	0.454	0.169	1

864 Sample size, $\pm .067$ critical value for R at $P < 0.05$ (two-tail), NS: Not Significant at $P < 0.05$

Cu: Copper, Ni: Nickel, Zn: Zinc, ORP: Oxidation Reduction Potential, TOC: Total Organic Carbon, CEC: Cation Exchange Capacity, P: Phosphorous, K: Potassium

Table 5.3. PCA of soil metals and other variables from all the three locations – Factor loadings

Parameters	Principal Components			
	PC1 (ORP, pH, CEC)	PC2 (Cu, Ni)	PC3 (P)	PC4 (TOC, Zn)
Cu	-0.002	0.894	0.198	0.027
Ni	0.021	0.758	-0.453	-0.060
Zn	0.373	0.022	0.184	0.749
pH	0.943	-0.038	0.014	-0.025
ORP	-0.949	0.072	-0.044	0.041
TOC	-0.305	-0.037	-0.121	0.830
CEC	0.738	0.137	0.346	0.098
P	0.070	-0.102	0.841	0.042
K	0.504	0.217	0.571	-0.065
Total loading*	2.826	1.459	1.449	1.272
% Variance explained	31.400	16.206	16.104	14.129
Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser normalization (Rotation converged in 6 iterations), *Sums of squared loadings				
Cu: Copper, Ni: Nickel, Zn: Zinc, ORP: Oxidation Reduction Potential, TOC: Total Organic Carbon, CEC: Cation Exchange Capacity, P: Phosphorous, K: Potassium				

5.4 Discussions

Heavy metal movement with water in soil requires the metal to be in soluble phase or associated with mobile particulates (Waller and Pickering 1992). McBride *et al.* (1997) reported the strong influence of pH on metal solubility. Anthropogenic processes which result in the lowering of substrate pH can cause metal toxicities, even if no extra metal has been added to the system (Fergus 1954, Kelly *et al.* 1990, Robinson *et al.* 1995). Gnanidi and Tobschall (2002) reported that redox potential and pH in soil solution are the main agents for metal mobility in the soil layers. Thus, in the acidic soil with soil redox potential between +25 and +209 mV, the higher rainfall and temperatures at the Araku hillocks, may lead to release of trace metals. Tack *et al.* (1996) reported that Zn becomes mobile at a pH <6 and Cu is more mobile at pH <2. McLaren and Crawford (1973) also reported higher Cu adsorption with increased pH. Mertens *et al.* (2004) reported that nitrogen fixing plant species cause an accelerated decline in soil pH resulting in higher availability of metals. The soils of Araku support good plant diversity. Plants such as *Crotalaria* sp., *Indigofera* sp.,

Tephrosia sp., members of the family Fabaceae and nitrogen-fixing species/mimosoids were commonly seen during certain months in Araku. Therefore, perhaps the seasonal variations (among months) in the concentrations of Cu, Ni and Zn in soils of Araku are attributable to the plant species growing in the area in various months. Human disturbances such as forest fire might also causes variations in the metal concentrations in the soil samples. Biddappa and Rao (1973) reported that rainfall and pH have a negative correlation due to intensive washout of the bases from the soil. Perhaps, the higher CEC and lower pH of soils in Araku would stimulate release of more trace elements, as suggested by Zhang and Shan (2000).

Total concentrations of Cu, Ni and Zn in soils are dependent on a number of factors. Background concentrations of the metals chiefly are determined by local bedrock geochemistry, and may be supplemented to differing degrees by anthropogenic inputs (Prusty *et al.* 2009b). Regional differences in geology and anthropogenic sources give rise to spatial variations in total metal concentrations. Location specific significant variations for metals in soils of Araku may be attributed to the geology of the area, since no major anthropogenic source is known in the area except the slash and burn practice of agriculture. Nickel occurs in the soil in more readily extractable forms as compared to Cu and it may be assumed to be more mobile showing high affinity (Alloway 1990). Thus, higher mobility of Ni might have resulted into its higher levels compared to Cu in the studied soil. In general, greater mobility of Ni is strongly associated with organic carbon/matter. Ni was negatively related with organic carbon in soils in Araku. Nickel and Zn varied significantly among the soil layers. Total metal concentrations in soils are influenced by geochemical and biogeochemical processes such as podsolization, whereby metals may be redistributed to different parts of the soil profile. Further, Kabata-Pendias and Pendias (1992) reported total Cu content of uncontaminated surface soils worldwide as varying from 13 to 24 mg/kg. Copper levels in Araku soil are marginally higher and in all likelihood its source is geologic substratum.

Generally, the smaller the ionic radius of any metal, the greater is its tendency to hydrolyze leading to reduced sorption (Horsfall and Spiess 2005). Evans (1989) and Alloway (1990), in reviewing the subject, state that the adsorbing solid will usually prefer one cation over another, the preference being proportional to the valency (charge) and inversely proportional to the hydrated radii (larger in cations with smaller ionic radii due to their increased polarizing power). Positive correlation between Cu and Ni, and negative relationship between Ni and Zn may be attributable to the isomorphic replacement between the two metal ions and relatively higher affinity of metals like Cu for the binding sites. Moreover, PCA also reveals interlinking of Cu and Ni. Organic matter can interact with metals in two important ways. First the metals can be mineralized from the soluble organic matter and changed into bio-available forms. Secondly, metal can become bound into organic matter constituents that are immobile in the soil and constitute a fixation mechanism by which metal is not released easily. Negative correlation between Ni and organic carbon is indicative of presence of organic complexing agents in these higher organic-carbon soils, thus affecting metal availability. Organic matter usually fixes Cu and hence prevents leaching of the metal, thus, available form of Cu deficiency frequently occurs in soils with high OM. Rajagopal *et al.* (1974) have reported negative relationship between Cu and organic carbon.

In general Zn concentration in soils can be classified as deficient if less than 10 mg/kg, normal if between 25 and 150 mg/kg, excessive or toxic if more than 400 mg/kg (Kiekens 1990). Kabata-Pendias and Pendias (1992) reported a worldwide Zn range of 17-125 mg/kg. Zinc in soils of Araku ranged between 10.4 to 52.1 mg/kg which are fairly normal for available Zn levels in soils. pH, ORP and rainfall pattern (resulting in leaching) might be the influencing factors for the reported seasonal variations in Zn levels in soils. The differences in Zn concentrations among soil layers are attributable to pH variations. Lal and Biswas (1973) reported that calcareousness and high pH prevent the leaching loss of Zn. Thus, leaching results in lowering the content of Zn. Zinc in the top layer was maximum and distinct from the rest of the layers. Almost similar variations were observed in the case of

pH (0-5 cm and 15-20 cm layers). Zinc is more mobile under acidic conditions (McGrath *et al.* 2004) than other heavy metals and thus, a greater proportion of this metal would be getting leached over time from the acidic soils of the area. Since, Zn is known to form phosphate salts (soluble) with the available phosphorous, lower pH values induce dissolution of phosphates and release of Zn into the soil.

The present investigation recorded positive correlation of Zn with TOC, CEC and P. The lower levels of Zn could be attributed to the lower levels of P in soil layers. This is an indication of fixation of Zn (as zinc phosphate) in solid phase of soil which might have also reduced the availability of P in the soil. Gnandi and Tobschall (2002) reported no relation of organic carbon with Zn. The mechanisms involved in the retention of metals by organic carbon/matter appear to include both complexation and adsorption, i.e. inner sphere reactions as well as ion exchange (Evans 1989, Rieuwerts *et al.* 2002). While many studies suggest a link between soil organic carbon content and fixation of metals in the soil solid phase, some authors (Sanchez-Camazano *et al.* 1994, Brallier *et al.* 1996) have found no such association. This apparent difference may be due to the tendency of metals to bind with organic components in both the solid and solution phase in soil. In the present study, ORP and pH were negatively correlated. The factor loading on the first PC (PC1) also suggests a negative relationship between ORP and pH. On the lower slopes of the Araku, mountain soils are high in organic matter and acidic in nature, which might have accounted for the strong negative correlation between ORP and pH. The negative correlation of ORP with Zn was recorded by Chuan *et al.* (1996), who reported that the solubility of Zn and other metals (Pb and Cd) in soils increased with decreased redox potential. Such mechanism is likely to be due to the dissolution of Fe-Mn oxyhydroxides under reducing conditions resulting in the release of adsorbed metals. PC2 suggests positive relationship between Cu and Ni reflecting their lithogenic origin, i.e. they may be inherited directly from common parent materials.

5.5 Conclusion

Redox potential and pH value in soil solution are the main agents for metal mobility in the soil layers in Araku. Organic carbon seemed to influence Zn fixation in the soils. Marginally higher values of Cu were obtained from the soil system of Araku. Concentrations of other metals examined were well within the safe limits. Seasonal variations in metal concentrations in soil were attributable to the nitrogen-fixing species which are commonly seen in the study area. Elements are present in soil in various chemical forms which strongly affect the behaviour of the element in terms of its bioavailability, potential toxicity, chemical interactions and mobility across the layers. Therefore, to gain a more precise understanding of the potential and actual impact of elevated levels of metals in soil, it is necessary to identify and quantify the forms in which the metal is present in the soil.

6 METALS IN PLANTS OF ARAKU

6.1 Introduction

The fate of various metals, such as Cd, Cr, Cu, Mn, Ni, Pb and Zn, in the natural environment is of great concern (Adriano 1992), in urban areas and industrial centers generally in and around former mine sites, dumps, tailing piles, and impoundments in particular. Soil, sediment, water, and organic materials in such areas may contain higher than average abundances of these metals, due to previous mining and (or) industrial works or due to nature of the parent materials. Therefore, accumulation of metals by plant species has been widely investigated to generate information required for remediation of such areas. Some plants phytostabilize (immobilize) heavy metals in the rhizosphere region making use of root exudates' immobilization (Blaylock and Huang 2000), while some other species incorporate them into root tissues (Khan 2001). Certain plant species also transfer metals to their aboveground tissues, potentially allowing the soil to be decontaminated by harvesting the aboveground parts of the plants. Such information may be effective for selecting potential plants to be used in remediation of contaminated mined out areas and to know the metal dispersion, with reference to their mobility to biomass (Dinelli and Lombini 1996, Freitas *et al.* 2004).

The ability of living tissues to accumulate, magnify and transform pollutants in the environment has made them of great significance in environmental studies. As mentioned earlier, mining of minerals leads to changes in landscape, soil properties, vegetation, etc. In view of the potential changes leading to habitat degradation likely to happen with opening up mining activities in Araku, it was felt useful to investigate dominant plant species with respect to their accumulation capacity for select elements including heavy metals. Such information would facilitate developing an appropriate plan of action for remediation/restoration in due course. Thus, an attempt was made to assess the metal concentrations in dominant plant species in the area that are non-edible in nature. Alkali and alkaline earth metals in plant organs were analysed to relate them with the soil properties discussed in Chapter 4. Heavy metals in plant organs were analysed to relate

them with soil properties as discussed in Chapter 5. Heavy metals being potent enough to create pollution in soils due to mining activities, the concentrations and levels of distribution of heavy metals are emphasized in the present chapter.

6.2 Materials and Methods

The procedure for the sampling of plants and their preliminary processing are presented in the Section 2.4. Seven plant species (*A. adenophora*, *C. odorata*, *E. wightii*, *L. camara*, *P. acaulis*, *T. roxburghiana* and *T. procumbens*) were collected from three different localities where they were predominantly distributed. *A. adenophora* was not recorded from Raktakonda. At Galikonda it was recorded during February 2007, August 2007 and November 2007. At Chittamgondi the species was recorded in every sampling month with an exception during May 2008. *C. odorata* was recorded round the year from Raktakonda and Galikonda locations. At Chittamgondi the species was recorded during February 2007, May 2007, May 2008 and August 2008. *E. wightii* was recorded only from Galikonda (during February 2007, May 2007, November 2007, May 2008 and August 2008). *L. camara* was recorded only from Chittamgondi during August 2007 and May 2008. *P. acaulis* was recorded round the year from all the three locations. *T. roxburghiana* was recorded during May 2007, August 2007 and August 2008 only from Raktakonda. *T. procumbens* was recorded during November 2007 and August 2008 from Chittamgondi only. In total 357 plant samples were collected and analysed. The homogenized plant samples were subjected to mixed acid digestion (Allen 1989). Concentrations of Na, K, Ca and Li were analysed using a Flame Photometer (Systronics 126). Concentrations of Cu (mg/kg), Ni (mg/kg) and Zn (mg/kg) in different organs (root, stem, and leaf) were estimated using Atomic Absorption Spectrometer (AAS Perkin Elmer). The precision and bias in the case of this analysis was generally <10%. Standard addition technique was followed to reduce the matrix effects in the analyses. The average estimated detection limit for the metals analysed in the sample was 0.1 µg/g and re-analysis of pre-analysed soil samples showed an average recovery rate of 96.9%. Multiple regression analysis was performed for heavy metals accumulation in various organs of plant species to identify the influencing factors. The Transportation index

(*Ti*) for different metals for the plant was determined as ([metal concentration in shoot] / [metal concentration in root]). The *Ti* helps to evaluate the extent of metal transportation from roots to shoots (Stolz and Greger 2002, Deng *et al.* 2004).

6.3 Results

6.3.1 Alkali and alkaline earth metals

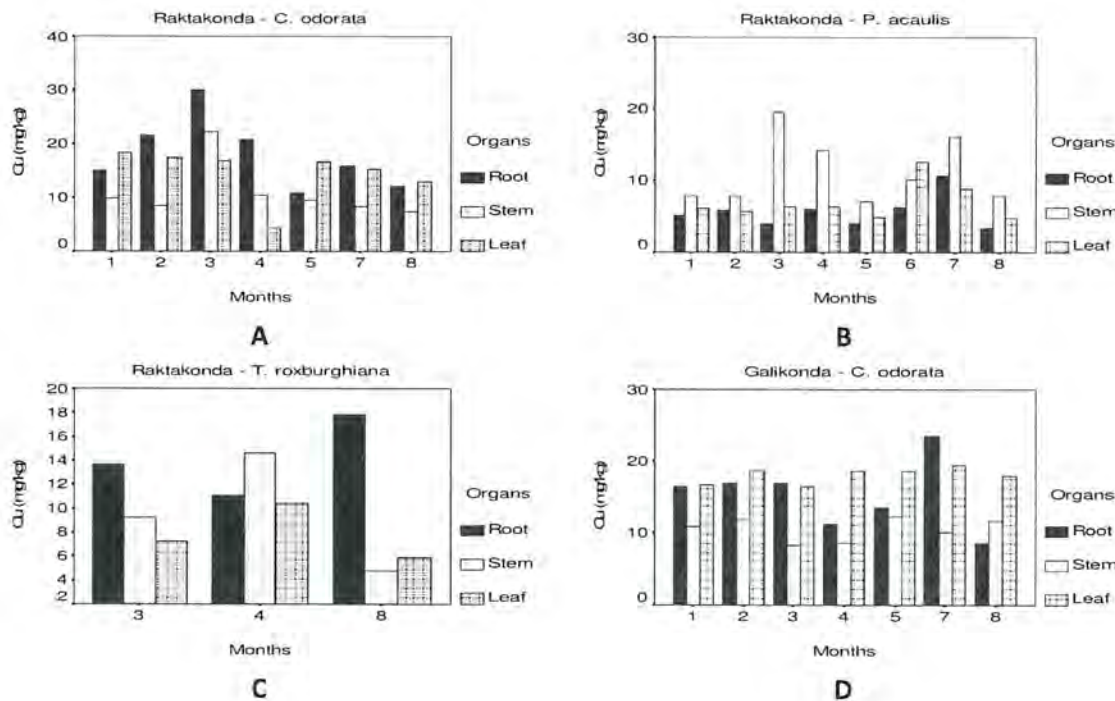
The concentration of Na in plants varied from 50 to 1112 mg/kg in Araku hillocks. Na in plants from Raktakonda was found between 75 and 1112 mg/kg, in Galikonda plants between 55 and 880 mg/kg, and in plants from Chittamgondi between 50 and 737 mg/kg. Significant variation of Na was observed among the species and organs (GLM-ANOVA, $P < 0.05$). The K level in plants ranged between 360 and 19422 mg/kg among the months. K at Raktakonda was found between 380 and 13945 mg/kg, at Galikonda between 360 and 11009 mg/kg, and at Chittamgondi between 560 and 19422 mg/kg. The K levels during November 2006 and August 2008 varied from rest other months. Chittamgondi was distinct from other locations in K level in plants. *P. acaulis* varied significantly and was distinct from the other species with respect to Na and K concentrations (LSD, $P < 0.05$, Table 6.1). Calcium ranged between 355 and 6696 mg/kg in the analysed plant species. In the plants of Raktakonda Ca varied between 355 and 6185 mg/kg, at Galikonda between 355 and 6324 mg/kg, and at Chittamgondi between 613 and 6696 mg/kg. Calcium varied significantly during May 2007, November 2007 and August 2008. All locations were distinct from each other with regard to plant concentrations of Ca. Most of the species were distinct and varied significantly with few exceptions (Table 6.1). Lithium in plant from Raktakonda varied between 5.0 and 134.6 mg/kg, those from Galikonda between 5.0 and 120 mg/kg, and those from Chittamgondi between 10 and 189 mg/kg. Lithium in plants in August 2008 was distinct from those from other months. Chittamgondi was distinct from other locations with respect to Li levels. *C. odorata*, *P. acaulis* and *T. procumbens* were distinct from each other and other species with regards to Li concentrations. Sodium, K, Ca and Li varied significantly among the organs; roots, stems and leaves. Transportation index for Na differed significantly only among locations. In the case of K and Ca, *Ti* varied only among months

(GLM-ANOVA, $P < 0.05$). The post-hoc test (LSD, $P < 0.05$) revealed that plants from Chittamgondi were distinct regarding their Na concentration. Potassium was distinct during May 2008 and Ca during February 2008. Lithium did not vary for any of the fixed variables in the present investigation, i.e., among the months, locations, species and organs. *C. odorata* and *A. adenophora* had Ti values >1 for Na thus indicating or suggesting the species to be a potential hyperaccumulator for Na. All the seven species studied accumulated higher amounts of K, Ca and Li in leaves compared to root, Ti values being >1 . Sodium was negatively correlated with K, Ca and Li, while K and Ca were positively correlated with other metals.

6.3.2 Heavy Metals

Concentration of Cu, Ni and Zn in plants varied from 3.4 to 76.7 mg/kg (Figure 6.1A to L), 1.9 to 41.4 mg/kg (Figure 6.2A to L) and 1.5 to 52.2 mg/kg (Figure 6.3A to L), respectively. Copper in the plants from Raktakonda ranged from 3.4 to 30.0 mg/kg, at Galikonda the concentration range was 4.0 to 34.0 mg/kg and at Chittamgondi 3.4 to 76.7 mg/kg. Nickel in species from Raktakonda varied from 4.7 to 32.9 mg/kg, in those from Galikonda 3.0 to 39.6 mg/kg and in Chittamgondi from 1.9 to 41.4 mg/kg. Plant concentrations of Zn at Raktakonda ranged between 1.8 and 52.2 mg/kg, at Galikonda 2.1 and 38.5 mg/kg, and at Chittamgondi 1.5 and 50.8 mg/kg. The highest concentration of Cu was recorded in root of *L. camara* (in May 2008, Chittamgondi) and lowest in root of *P. acaulis* (in August 2008, Raktakonda). The highest concentrations of Ni were recorded from root of *P. acaulis* (in February 2007, Chittamgondi) and lowest from stem of *T. procumbens* (in August 2008, Chittamgondi). The highest concentration of Zn was recorded from root of *C. odorata* (in May 2007, Raktakonda) and lowest from root of *P. acaulis* (in November 2007, Chittamgondi). The variables (species and organs) for metal concentrations studied showed significant spatial heterogeneity (GLM- ANOVA, $P < 0.05$) for Zn concentrations. Copper concentrations varied significantly among species and among organs (LSD, $P < 0.05$, Table 6.1). Copper levels in *L. camara* were distinct from the rest. Copper level varied significantly in roots. Nickel concentrations varied significantly among the months with few exceptions

(August 2007 and May 2008). Nickel concentrations at Chittamgondi were distinct from rest of the locations. Plant species *A. adenophora* showed significant variations from the other species for Ni. Nickel in leaf was distinct from rest other organs. Zinc levels in plants were significantly distinct only during February 2007, November 2007 and August 2008. *E. wightii* showed significant and distinct variations for Zn. Zinc concentrations in root were distinct from other organs. Multiple regression analysis performed for heavy metals accumulation in various organs of plant species is presented in Appendix 2. A test of correlation (2-tail test, $P < 0.05$), performed on the metals, showed that Cu and Zn, and Ni and Zn were positively correlated with each other. The average concentration of Cu in *C. odorata* was in the order of leaf > root > stem, and in the case of *P. acaulis* it was stem > leaf > root. The average highest concentration of Zn in *C. odorata* followed the same order as above.



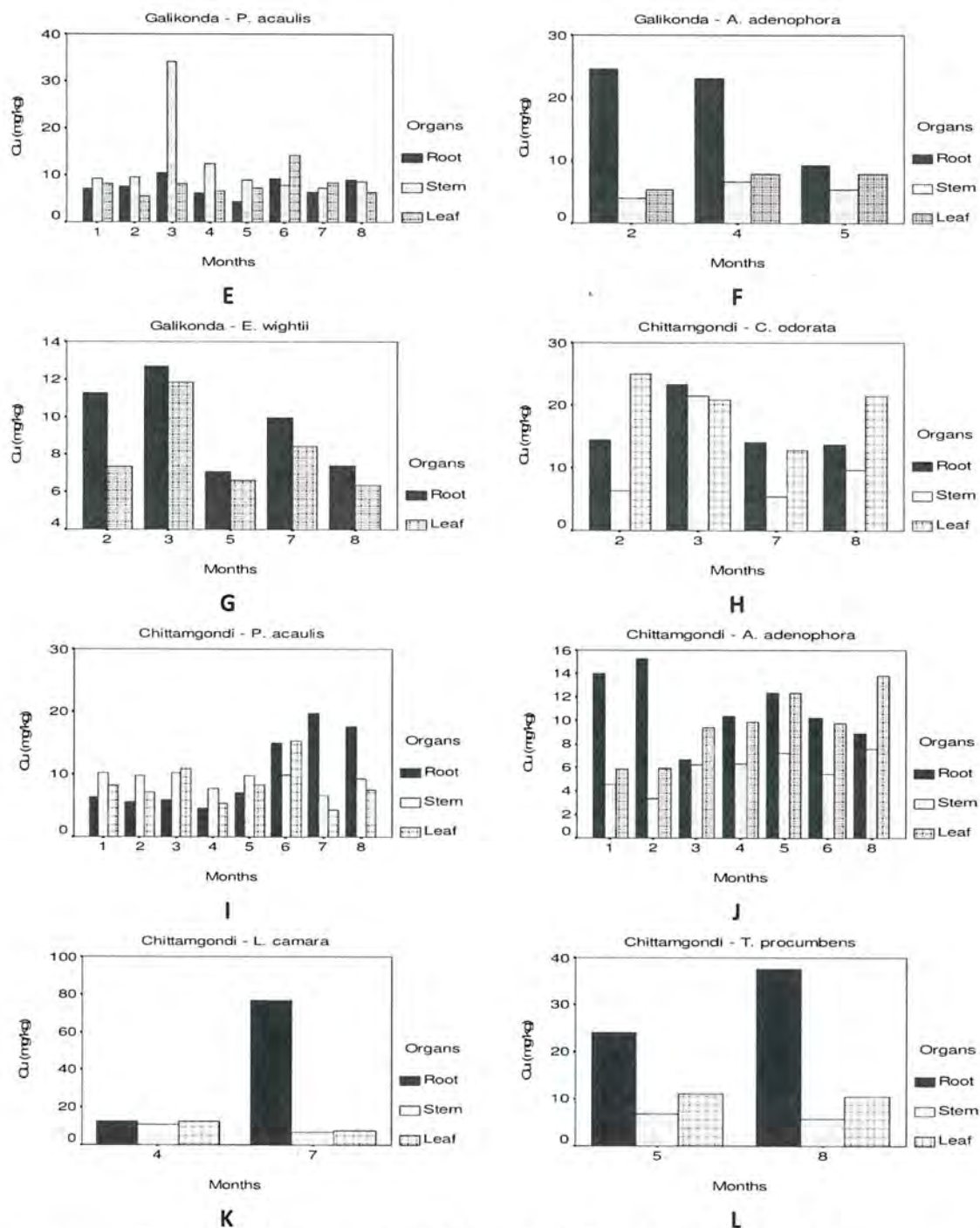
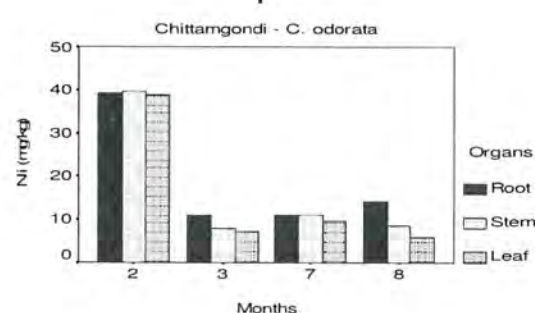
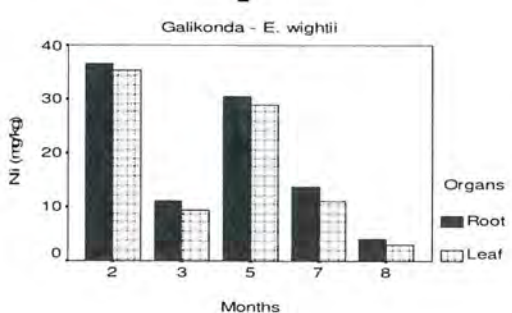
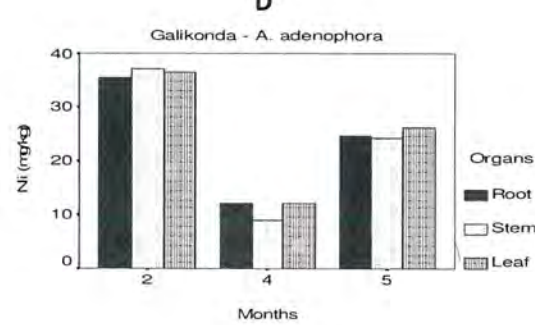
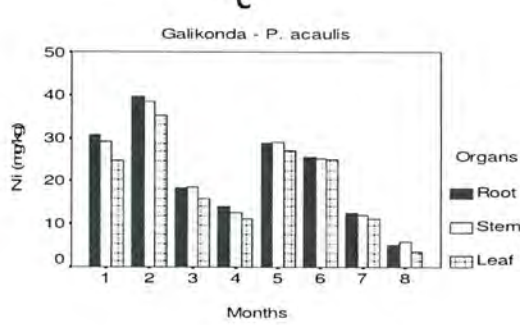
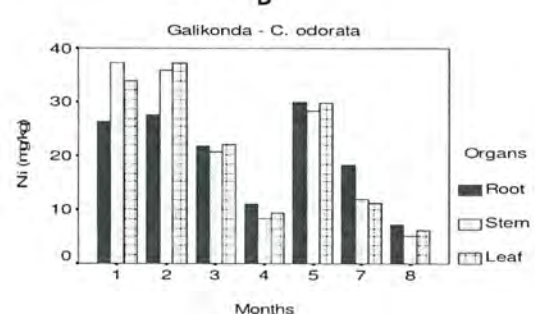
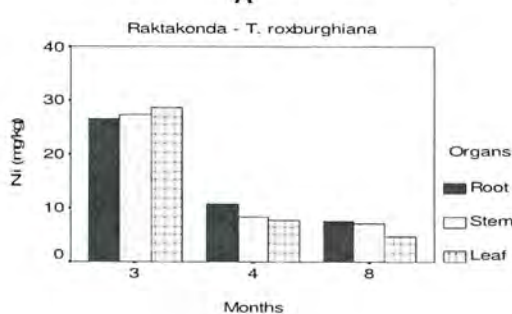
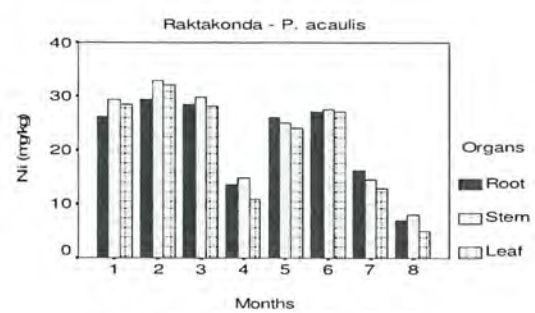
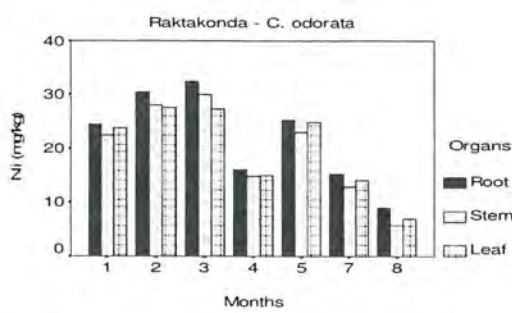


Figure 6.1. Concentrations of Copper in different organs of plants

Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

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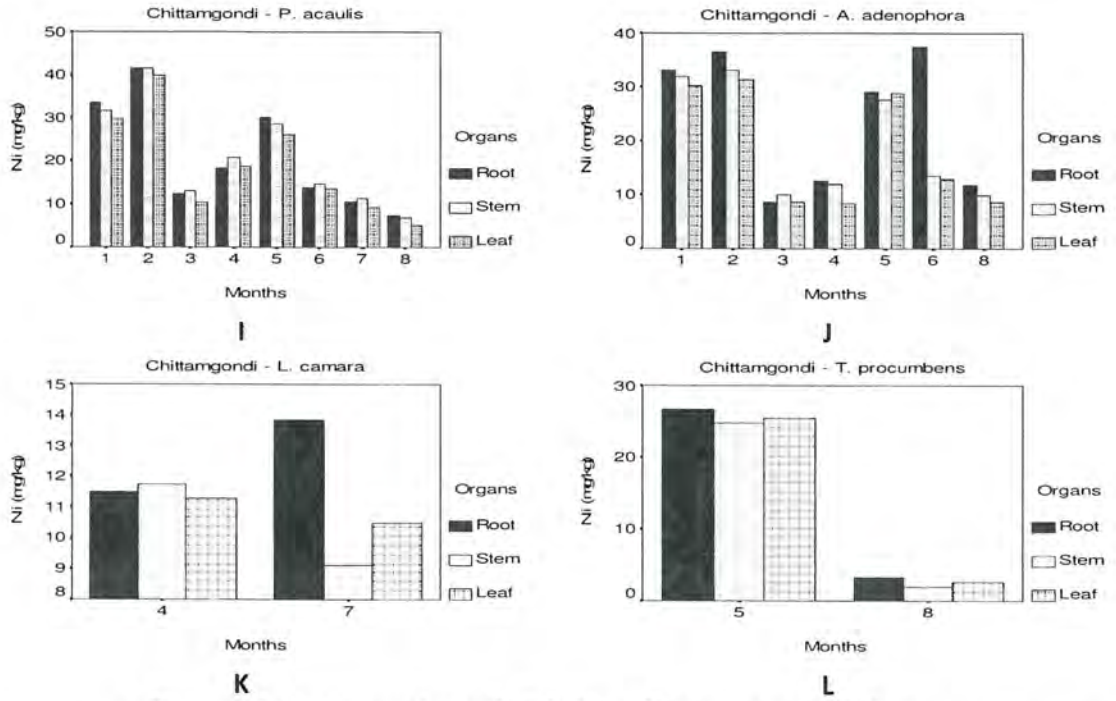
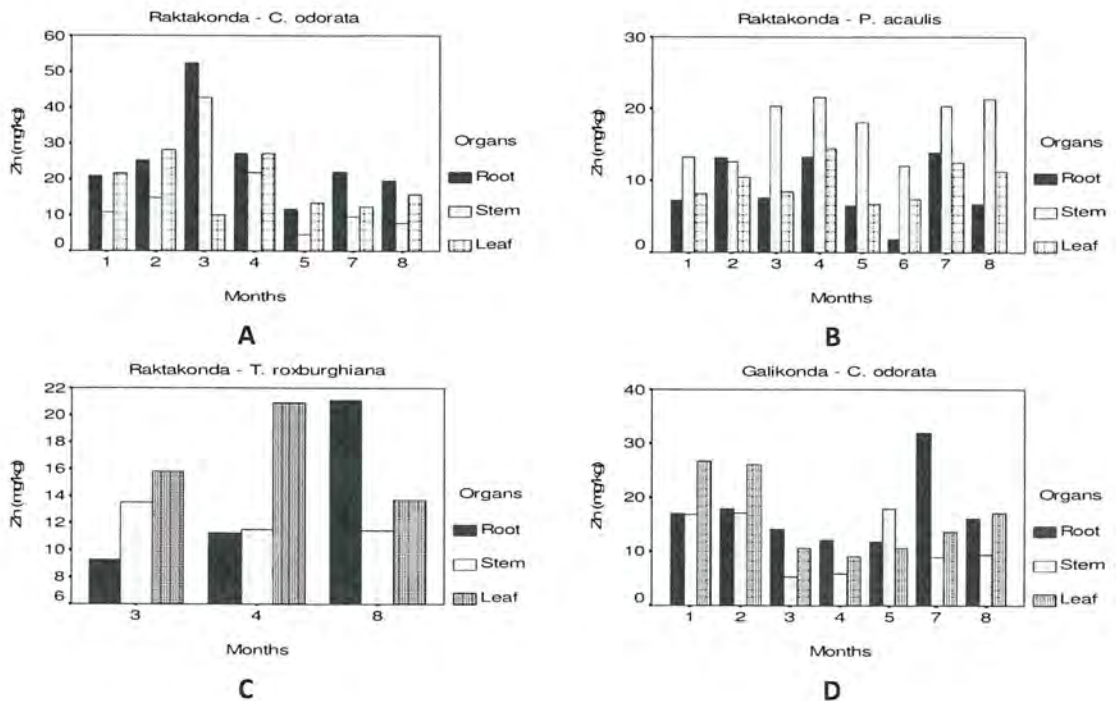


Figure 6.2. Concentrations of Nickel in different organs of plants

Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008



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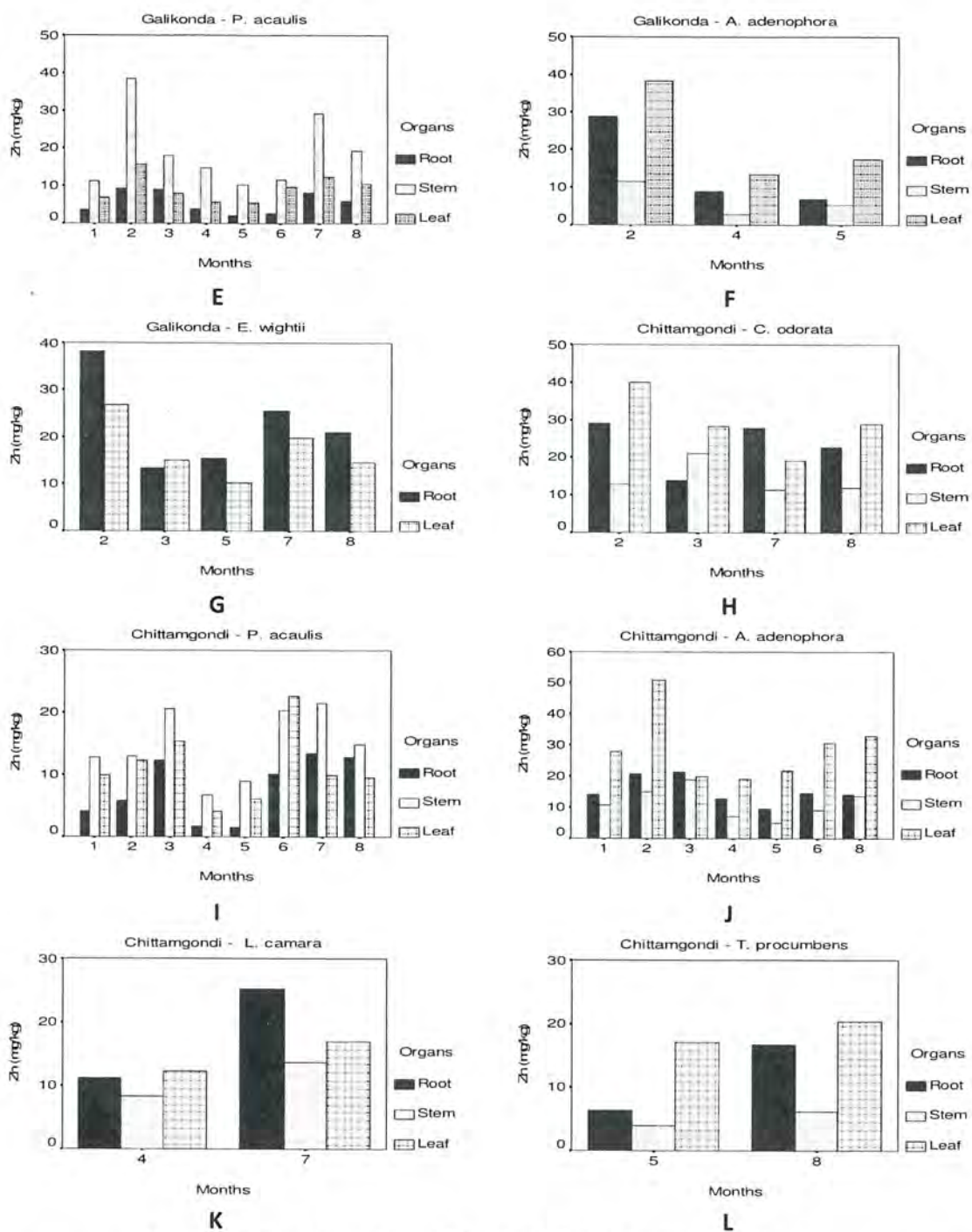


Figure 6.3. Concentrations of Zinc in different organs of plants

Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

6.3.2.1 Heavy Metal Transportation Index (Ti)

In most of the cases, *C. odorata* and *P. acaulis* had $Ti > 1$ for Cu, and *A. adenophora*, *P. acaulis*, *T. roxburghiana*, *L. camara* and *T. procumbens* for Zn. Though Ni concentrations were relatively high in soil it was least transported in plant body. Transportation index for Cu varied significantly among months and species (GLM-ANOVA, $P < 0.05$). Transportation index of Cu during February 2008 were distinct from the rest of the months. *C. odorata* and *P. acaulis* varied significantly between each other and from the rest of the species (LSD, $P < 0.05$) with respect to Cu concentrations. In the case of Ni the Ti varied significantly among months and locations. Transportation index for Ni varied significantly during August 2008. Among the three hillocks, Ti for Ni was distinct at Chittamgondi. Transportation index for Cu in the case of *C. odorata* was highest during August 2008 at Galikonda (Figure 6.4A). In the case of *P. acaulis* it was highest during August 2007 at Galikonda (Figure 6.4B), and in the case of *A. adenophora* it was highest at Chittamgondi during August 2008 (Figure 6.4C). In *E. wightii* Ti for Cu was highest at Galikonda during May 2007 (Figure 6.4D), in *T. roxburghiana* it was highest at Raktakonda during August 2007 (Figure 6.4E). In *L. camara* and *T. procumbens* it was highest at Chittamgondi during August 2007 (Figure 6.4F) and at Raktakonda during August 2008 (Figure 6.4G), respectively. Transportation index for Ni in the case of *C. odorata* was highest during February 2007 at Galikonda (Figure 6.5A), in *P. acaulis* it was highest at Raktakonda during November 2006 (Figure 6.5B), and in *A. adenophora* it was highest at Chittamgondi during May 2007 (Figure 6.5C). In the case of *E. wightii* Ti for Ni was highest at Galikonda during August 2008 (Figure 6.5D), in *T. roxburghiana* it was highest at Raktakonda during August 2007 (Figure 6.5E), in *L. camara* it was highest at Chittamgondi during August 2007 (Figure 6.5F) and in *T. procumbens* it was highest at Chittamgondi during August 2008 (Figure 6.5G). Transportation index for Zn in the case of *C. odorata* was highest during May 2007 at Chittamgondi (Figure 6.6A), in *P. acaulis* it was highest at Chittamgondi during November 2007 (Figure 6.6B), in *A. adenophora* it was highest at Galikonda during November 2007 (Figure 6.6C), in *E. wightii* it was highest at Galikonda during May 2007 (Figure 6.6D), in *T. roxburghiana* it was highest at Raktakonda during August 2007 (Figure 6.6E), in *L. camara* it was highest at Raktakonda during May 2007 (Figure 6.6F), and *T. procumbens* it was highest at Chittamgondi during November 2007 (Figure 6.6G).

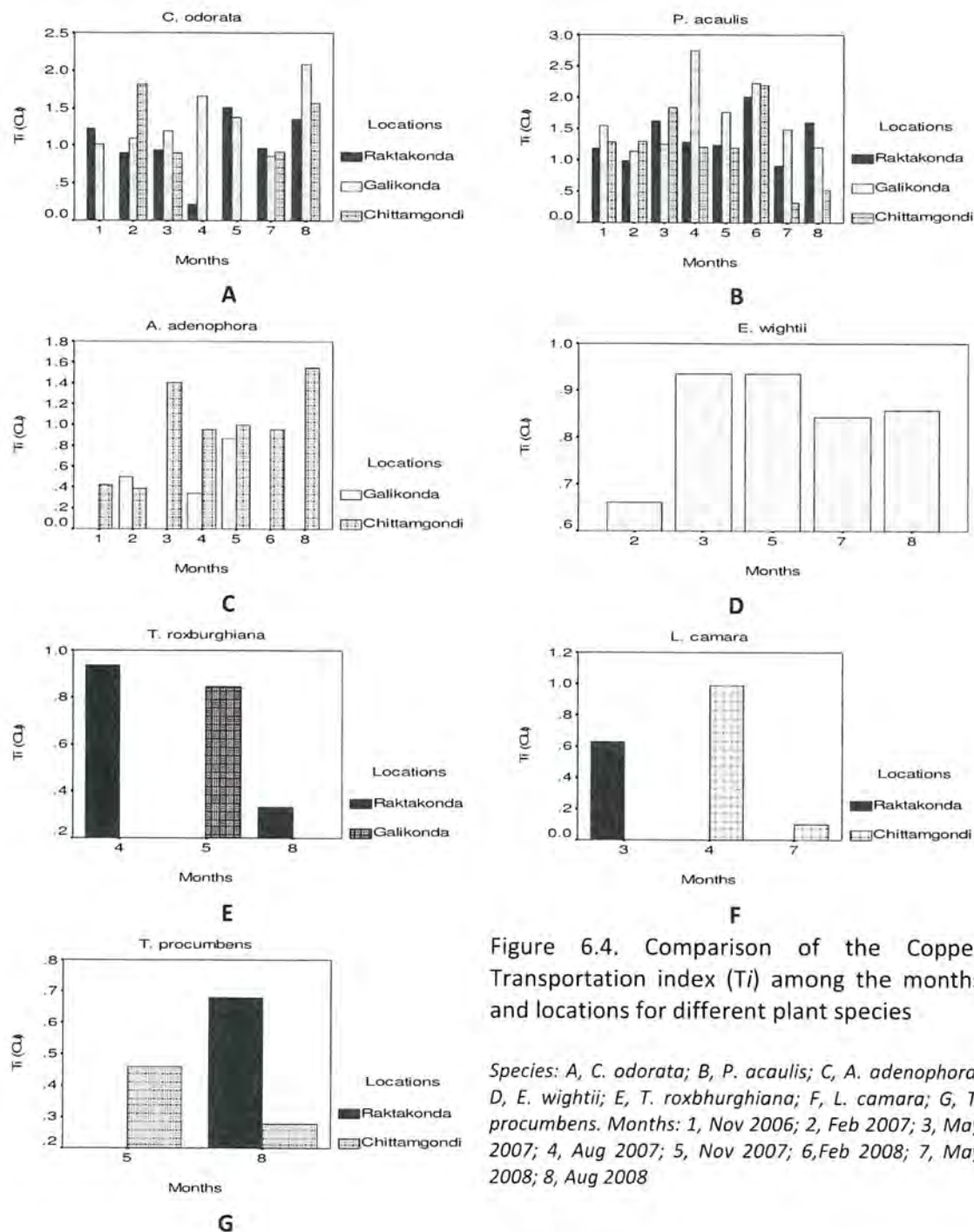


Figure 6.4. Comparison of the Copper Transportation index (T_i) among the months and locations for different plant species

Species: A, *C. odorata*; B, *P. acaulis*; C, *A. adenophora*; D, *E. wightii*; E, *T. roxburghiana*; F, *L. camara*; G, *T. procumbens*. Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

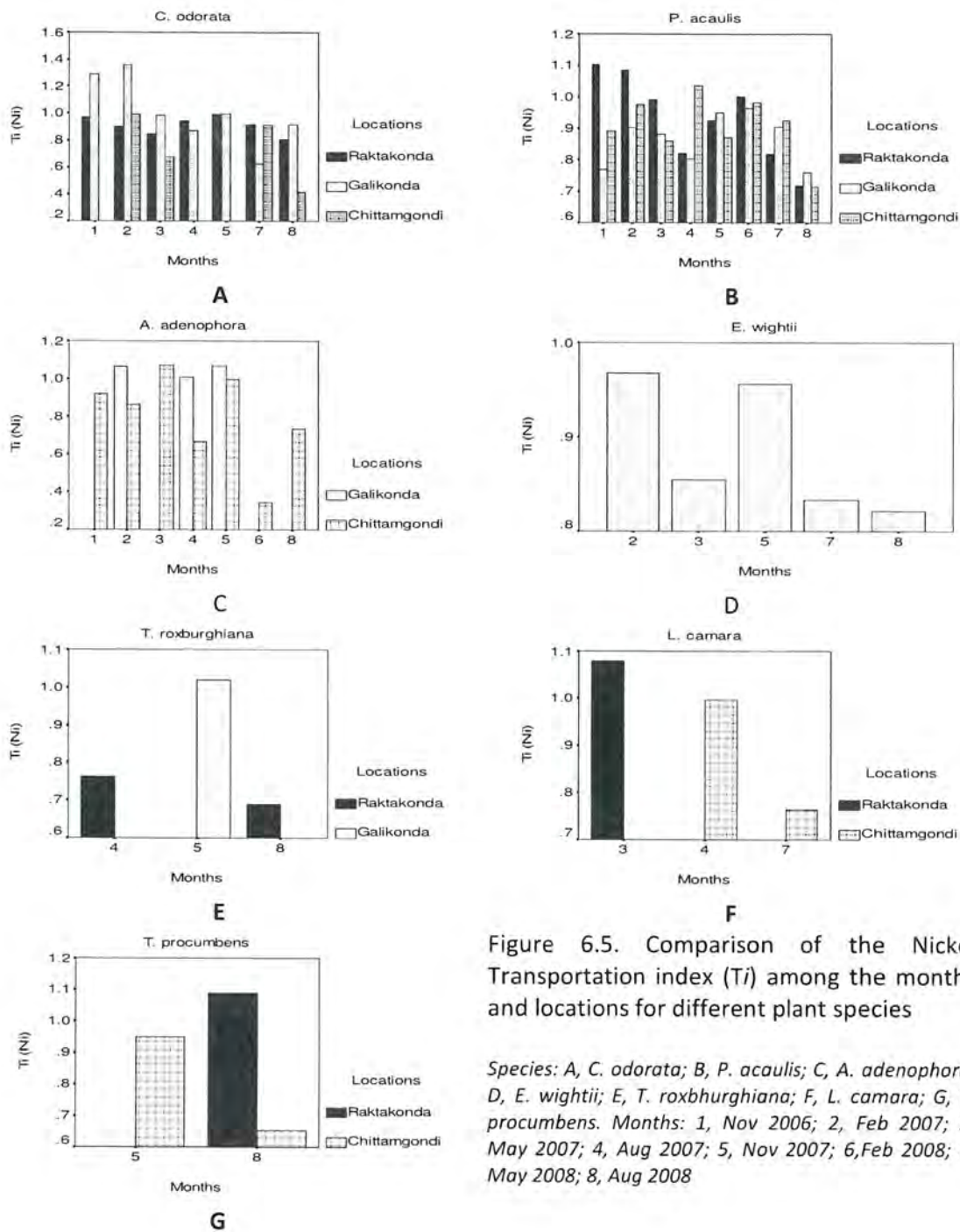


Figure 6.5. Comparison of the Nickel Transportation index (T_i) among the months and locations for different plant species

Species: A, *C. odorata*; B, *P. acaulis*; C, *A. adenophora*; D, *E. wightii*; E, *T. roxburghiana*; F, *L. camara*; G, *T. procumbens*. Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

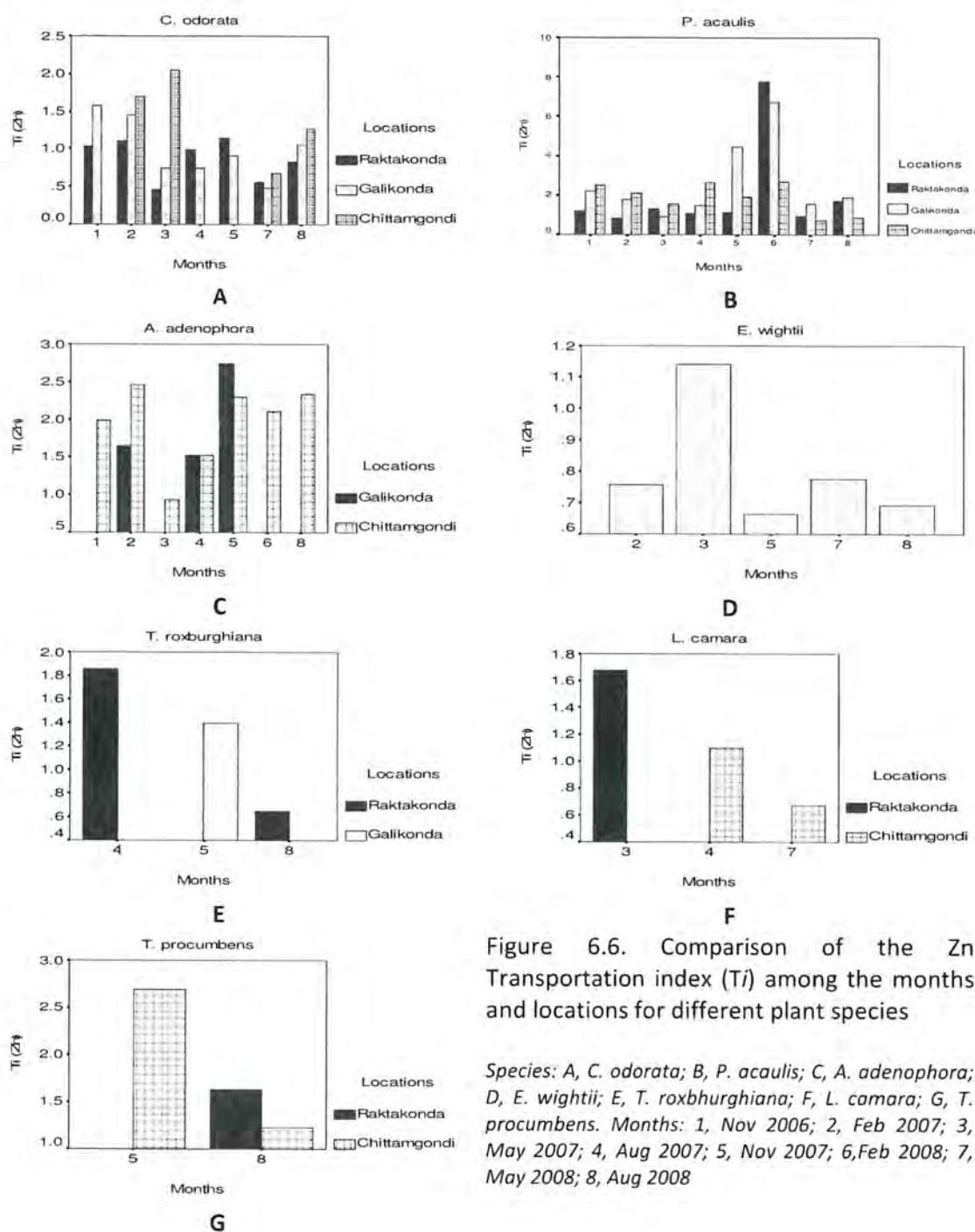


Figure 6.6. Comparison of the Zn Transportation index (T_i) among the months and locations for different plant species

Species: A, *C. odorata*; B, *P. acaulis*; C, *A. adenophora*; D, *E. wightii*; E, *T. roxburghiana*; F, *L. camara*; G, *T. procumbens*. Months: 1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008

Table 6.1. Alkali and alkaline earth metals, and heavy metal concentrations in plants in bauxite rich locations in the Eastern Ghats

Parameters	Attributes	1	2	3	4	5	6	7	8
Na	Species	239 ^a	212 ^b	350 ^a	295 ^a	333 ^a	279 ^a	270 ^a	
	Organs	286 ^a	274 ^b	261 ^c					
K	Month	2792 ^a	3676 ^b	4541 ^b	3599 ^b	4254 ^b	4105 ^b	3394 ^b	5271 ^c
	Location	3501 ^a	3559 ^a	5372 ^b					
	Species	5647 ^a	2317 ^b	8350 ^a	3821 ^a	3822 ^a	6182 ^a	8574 ^a	
	Organs	2393 ^a	3636 ^b	6214 ^b					
Ca	Month	1497 ^a	1837 ^a	2770 ^b	1991 ^a	2535 ^c	1582 ^a	1979 ^a	2308 ^d
	Location	1937 ^a	2068 ^b	2444 ^c					
	Species	2980 ^a	1361 ^b	3426 ^c	2238 ^d	3225 ^c	2606 ^e	3401 ^c	
	Organs	1348 ^a	1910 ^b	3196 ^c					
Li	Month	41 ^a	48 ^a	53 ^a	43 ^a	53 ^a	46 ^a	43 ^a	65 ^b
	Location	45 ^a	45 ^a	65 ^b					
	Species	67 ^a	32 ^b	92 ^c	49 ^c	49 ^c	85 ^c	101 ^d	
	Organs	35 ^a	47 ^b	70 ^c					
Cu	Species	15 ^a	9 ^a	10 ^a	9 ^a	10 ^a	21 ^b	16 ^a	
	Organs	12 ^a	10 ^b	10 ^b					
Ni	Month	29 ^a	35 ^b	20 ^c	13 ^d	27 ^e	23 ^f	13 ^d	6 ^g
	Location	21 ^a	21 ^a	20 ^b					
	Species	20 ^a	21 ^a	24 ^b	21 ^a	19 ^a	11 ^a	12 ^a	
	Organs	22 ^a	21 ^a	20 ^b					
Zn	Month	11 ^a	22 ^b	16 ^a	12 ^a	9 ^c	11 ^a	17 ^a	15 ^d
	Species	19 ^a	12 ^a	19 ^a	23 ^b	13 ^a	15 ^a	14 ^a	
	Organs	13 ^a	15 ^b	15 ^b					

Source of variation: Month (1, Nov 2006; 2, Feb 2007; 3, May 2007; 4, Aug 2007; 5, Nov 2007; 6, Feb 2008; 7, May 2008; 8, Aug 2008); location (1, Raktakonda; 2, Galikonda; 3, Chittamgondi); Species (1, *C. odorata*; 2, *P. acaulis*; 3, *A. adenophora*; 4, *E. wightii*; 5, *T. roxburghiana*; 6, *L. camara*; 7, *T. procumbens*) and Organs (1, Root; 2, Stem; 3, Leaf). Within rows, means followed by the same letter are not significantly different at $P < 0.05$

Na: Sodium, K: Potassium, Ca: Calcium, Li: Lithium, Cu: Copper, Ni: Nickel, Zn: Zinc

6.4 Discussion

6.4.1 Alkali and alkaline earth metals

The distribution of nutrients in plant bodies are a result of long-term evolution. Various base cations including alkali and alkaline earth metals perform different functions in plant organs or body (Nie 1991, Xibiao *et al.* 2006), probably resulting in the differences in distribution of these cations among organs. Monsoonal rain induces rapid litter decomposition followed by mineralization resulting in more nutrient release into soil. This consequentially increases in uptake of nutrients by plants and hence the higher availability in different plant organs, as is observed during certain months in the present case. However, it holds good only in the flatter or moderate slope areas as discussed in section 3.4.1 (as steep slopes are more likely to lead to soil erosion). The present investigation reports significant variations in the cation levels (Na, K, Li and Ca) among species and organs. The observed variations in the cation concentrations among seasons as well as locations are attributable to their mobilization. The growth stage of the species also results in variations in cation levels among months and organs. Osgood and Zieman (1993) suggested that the greatest accumulation of nutrients is found in the leaves as a result of the photosynthetic metabolic demands. Nutrient uptake from soil by roots depends on the chemical concentration in soil solution, soil - microbial relationship and mechanism, the intensity factor, and the ability of the soil to supply nutrients to the soil solution (Al-Khafaf *et al.* 1989). Root morphology plays an important role in attainment of cations/metals from the soil. Root growth in turn is affected by several other factors (physical, chemical and biological properties of the soil). Generally fine root biomass is much greater in areas with lower soil Ca as found by Gower (1987) and such variations and differences could be explained as an inverse relation of root growth with Ca availability in soil. Vogt *et al.* (1985) suggested similar inverse relationship between fine root biomass and nitrogen. Thus, species specific variations for the cation/metal analysed may be attributed to the morphology, physiological/structural functions, life cycle and root growth of the plant in the Araku.

6.4.2 Heavy Metals

The analyses of the three metals (Cu, Ni and Zn) in plant species in the three hillocks of Araku showed two main features; differences in the metal levels among species, and differences among plant organs (roots, stems and leaves). The concentration of an element in plant tissues is the result of mainly the following processes: a) uptake, which increases the concentrations, b) production of living tissue, which dilutes the concentration, c) soil microbial fauna which help maintain the pH at desired levels, and c) any active method of prevention of accumulation by the plants. Transportation within the plant, especially to and from storage organs, further complicates the situation and its interpretations. Significant variations were found between the metal concentrations in plant species among the months. *C. odorata* (erstwhile *Eupatorium odoratum*) is an annual and flowering happens in the species during July through February and it completes its life cycle. Similar was the case with *A. adenophora* (erstwhile *Eupatorium glandulosa*) as the two species belong to the closely allied genus. *P. acaulis* is a perennial plant and growth happens during August and November. In the case of *L. camara* (a perennial plant), flowering happens throughout the year. *T. roxburghiana* is an annual and it flowers during August through October. *T. procumbens*, an annual species, flowers during July through December. *E. wightii*, an annual, flowers during August through December. As observed in the present investigation (Figure 6.4A-G, Figure 6.5 A-G, Figure 6.6 A-G), the differential accumulation of metals in plant organs in different months is an indication of effective utilization of specific metals for certain/specific metabolic activities. Plants in general exhibit season specific metabolic activities. However, no such attempt was made in the present investigation to ascertain this fact, and hence, it needs further investigation. Tyler (1972) suggests that the concentration increase in Cu during the growth season may be due to an increased uptake as the permeability of the ageing roots increases, and gets more concentrated with loss of living organic matter by respiration and decay. The heavy metal concentrations in the present investigation in various organs of species showed identical seasonal/month-wise variations with few exceptions which are probably associated with the growth dynamics of the species. The accumulated elements differed much among various plant organs and this was

primarily attributed to differences in the physiological activities and biomass among various components in the plant body (Xibiao *et al.* 2006).

The leaf: root concentration ratio of metals gives the composition of the plant with respect to the percentage metal uptake from the soil. The concentration ratio is element specific and also exhibits certain dependency on the plant species as revealed in the present investigation. The concentration ratio shows much variation, both among metals, as well as among different samples from the same location/site. According to Ololade *et al.* (2007), both such variations were explained as a complex nature of the plant-soil-relationship coupled with the physico-chemical nature of the environment, and the plant diversity. Considering the physiological state of the plant species in the present study at the time of sampling, they can be said to have displayed high level of tolerance to the metals in their root, stem and leaf cells as there were no noticeable deformities or malfunction in these organs. According to few studies (Lange and Wagner 1990, Ortiz *et al.* 1995) hyper tolerance is believed to result from vacuolar compartmentalization and chelation. It was noticed that a few plant species at times of human made fire in the forest in the study area were resistant to it and could withstand for a longer time when compared to other softer plant species.

A hyperaccumulator plant should possess tolerance to high levels of a particular micro-element in root and shoot cells by means of vacuolar compartmentalization and chelation, and ability to translocate an element from roots to shoots at high rates. In addition such plants should produce high biomass. Normally, Zn, Ni, etc. concentrations in root are 10 or more times higher than shoot concentrations, but in hyperaccumulators, shoot metal concentrations in most cases exceed root levels. The highest concentration of Cu found in the leaves of *C. odorata* and *P. acaulis* is an indication of preferential accumulation of the metals in the leaves, and the lowest concentration was found in the roots, indicating to the active transportation from the functionally, basically the, absorbing organ to metabolizing organ. The higher levels of Cu in the leaves and hence high $Ti \geq 1$ of Cu suggest that *C.*

odorata and *P. acaulis* have an efficient transportation mechanism for the metal, which is a recognized characteristic of accumulator plants. Enhanced root metal uptake and enhanced root to shoot metal transportation, with a shoot to root metal concentration ratio exceeding unity, are the major characteristics of a hyperaccumulator (McGrath *et al.* 1993, Pollard *et al.* 2002). Thus, these two species can be called as potential hyperaccumulators for Cu.

The present investigation reported significant variations in metal concentrations among the locations only in the case of Ni. As discussed in Chapter 3 Raktakonda and Galikonda are proximate locations, while the third location, Chittamgondi is more distal. The site specific differences with micro level variations result sometimes in notable variations in the mobility of metals in the plant parts. Further, Chittamgondi has no mature trees on the hill top. Contrary to this, Raktakonda and Galikonda have several trees, the species diversity (H') there being 1.2 and 1.1, respectively (Azeez *et al.* 2008). In the present case, the distance between the locations and the difference in the characteristics and the microenvironment (such as climate, soil type, rock type) of each area must be responsible for the variations in the metal concentrations among the locations. The variations of metals among species might also be an effect of the age-dependent distribution of the respective metals. Several factors, such as biological and physico-chemical conditions, may influence the bioavailability of heavy metals (Lyngby and Brix 1982, Prusty and Azeez 2007). Variations of these factors, together with variation in heavy metals load, may influence the seasonal variation patterns in plant organs. Location-dependent seasonal variations have been reported in certain species (Bryan and Hummerstone 1973, Pulich 1980). According to Xibiao *et al.* (2006) the variations in accumulated element contents may differ greatly among hillocks because of different age of vegetation and due to different species distribution on the ground.

Higher concentration of metal in stems and leaves are because of the efficiency of transportation, a recognized character of accumulator plants (Mogopodi *et al.* 2008). Rodriguez *et al.* (1983) reported that in the leaves, Zn is mostly sequestered in the base of

the trichomes (epidermal hairs) and in mesophyll cells. Trichomes, present at the surface of plant leaves have diverse function ranging from exudation of various compounds, protection against the wind and sunlight (Rodriguez *et al.* 1983), and the storage of metals (Chandra and Azeez 2009). The present data shows that Zn is preferentially accumulated in shoots than in the roots. The higher levels of Zn may be attributed to its accumulation in the trichomes of the leaves. The leaves of *T. roxburghiana* are hairy thus providing sufficient surface area for metal accumulation in the organs. The ability of *A. adenophora*, *P. acaulis*, *T. roxburghiana*, *L. camara* and *T. procumbens* to accumulate higher concentrations of Zn in leaves coupled with its high *Ti* makes them possible accumulators. At times small amount of root biomass, having a greater surface area (depending on the type of root system) will be in contact with a greater volume of soil, thus being able to accumulate higher level of heavy metals. In the present case roots and stems were lower in metal content than leaves. This is in line with the results of Baker and Brooks (1989) and Chaney *et al.* (1997), who state that high accumulator plants should exhibit such responses. Plants with numerous thin roots accumulate more metals than one with few thick roots (Das *et al.* 1997). Thus, the greater surface area of thin and long roots compared to thick and short roots contributes to more absorption of metals in plant roots. Hemphill (1972) stresses the importance of the root morphology of different plant species in relation to their uptake of mineral elements. A smaller root surface area would mean a reduced area for metal uptake (Matthews *et al.* 2005). Additionally, other factors such as the microbes in rhizosphere region and root exudates (e.g. organic acids) may influence soil structure and metal availability. As may be expected, metals are deposited within the plant tissue in pattern that is unique for each metal, organ and species. However, this pattern may change in response to the level of environmental contamination. The higher values in some species for Cu and Zn in leaves over other organs may be because of the selective transport of ions within the plants (Kabata-Pendias and Pendias 1992). Poor phloem loading of root-adsorbed copper coupled with limited phloem mobility may also account for these observations (Salisbury and Ross 1992). Zinc accumulated more in roots and aerial parts, especially leaves. A possible explanation may be that Zn, due to its essential function in the formation of the plant

hormone indole acetic acid (IAA), is accumulated where this growth hormone primarily is required. Various authors have suggested that the greatest accumulation of metals (mainly Zn and Cu) is found in the leaves as a result of the metabolic demands of photosynthesis (Osgood and Zieman 1993, Otero *et al.* 2000).

Lower concentration of Ni was found in the roots, stems and leaves for all the species, indicating reduced transportation of this metal from the roots to other plant compartments. This can be well explained by the findings of Tanton and Crowdy (1971) which suggests that the root endodermis plays an important role as a barrier to this transportation. The study by Kabata-Pendias and Pendias (1992) shows that the mobility of Cu is very less within plants and hence, once they are taken up from the soil the accumulation tends to take place in roots rather than stems and leaves. Generally the soil with low organic matter content is accessible to Pb and Zn absorption. Study by ChandraSekhar *et al.* (2005) revealed that the uptake of Pb in presence of co-metal ions such as Ni, decreased Pb uptake by about 50%. Further, light metal ions/macronutrients such as Na^+ , Ca^{+2} and Mg^{+2} have considerable effect on the sorption of Cu(II) by the substrate. Gharde *et al.* (2006) reported that the sorption of the metal ion gradually decreases in the presence of increasing concentrations of light metal ions.

Several plant species are reported to be capable of accumulating higher concentrations of heavy metals in organs. Metal accumulations by plant organs are likely to be a function of the concentrations of various forms of heavy metals in soil. As discussed earlier in Chapter 2, soil pH is known as one of the important chemical factors controlling the solubility and plant availability of metal ions in the soil. The mobile fraction of metals increases as soil acidity increases. Metal mobility depends not only on the chemical properties of the metals but mostly on the physical and chemical properties of the soil, such as soil organic matter content, clay content (Prusty and Azeez 2007), mineral composition, pH and redox state (Prusty *et al.* 2009a). In addition to this soil micro fauna remains actively involved in metal mobility by maintaining optimum pH levels around the rhizosphere region. In the present

investigation on select dominant plants, the pH seemed to have the greatest effect on the solubility or retention of metals in soils, thus enhancing metal accumulation. The degree of availability of heavy metals to plants depends on the chemical form in which these elements are present in the growth medium. Following Tessier *et al.* (1979) sequential extraction scheme, generally it has been found that low pH, high Eh, and low CEC values favour the presence of easily available heavy-metal forms. In general sorption to soil particles reduces the activity of metals in the system. Thus, higher the soil CEC, greater is the sorption and immobilization of the metals. In acidic soils, as in the case of Araku, metal desorption from soil binding sites into solution is stimulated due to H^+ competing for the binding sites. Soil pH affects not only metal bioavailability, but also the very process of metal uptake into roots. This effect appears to be metal specific. The transport within plants is also species dependent as well as metal-specific.

In tropical climatic conditions, accumulation of oxide minerals of iron, manganese, and aluminum in soil profiles may limit the mobility and bioavailability of both metals and metalloids. Abundant bioavailable amounts of essential nutrients, including phosphorous and Ca, can decrease plant uptake of non-essential but chemically/functionally similar elements. Bioavailability of metals released from mineral deposits is very complex and dependent on many interrelated chemical, biological, and environmental processes. The plant species which can accumulate only one or few metals in their body parts are preferred for reclamation purposes to species which are capable of accumulating many metals. Hence, the metal specific/specialist species are preferred to the generalist from remediation point of view. The need to further study the seasonal variations on the ability of plant species is envisaged.

6.5 Conclusion

The results highlight possible use of the plant species in the initial stages of soil stabilization and bioremediation of metal pollution in soil. The present investigation was carried out as a primary step to evaluate the accumulation capacity of select plant species to various alkali

and alkaline earth metals and also, various toxic heavy metals. Based on *Ti* species *C. odorata* and *P. acaulis*, could be potential accumulators for Cu. Nickel was less transported in all the species from roots to shoot and thus, none of the species could accumulate higher Ni levels in leaves. Transportation index >1 revealed that *A. adenophora*, *P. acaulis*, *T. roxburghiana*, *L. camara* and *T. procumbens* can be potential hyperaccumulators for Zn. Of the seven species examined, *E. wightii* did not have *Ti* >1 for any heavy metals. Some species reported here may be considered as hyperaccumulators because of their tolerance to concentrations of soil metal and their relatively high levels in leaves than in roots. Practically these species are easier to grow and do not require care/attention, they being unwanted/weeds. The mechanism(s) of metal uptake and translocation as well as the genetic basis of accumulation in plant species require further investigation.

7 SUMMARY AND CONCLUSIONS

Industrialization and urbanization in past few decades have caused tremendous ecological repercussions, which could be best seen in mining/extractive industry. India is endowed with a wide range of mineral wealth, and large scale mining activities are happening in various places in the country. Some important effects due to mining activities are the change in land use pattern and the associated changes in distribution of plants, animals, water bodies and soil system. Reclamation and reforestation of mined out areas have become necessary due to stern environmental laws in effect in the country, although exceptions are widely seen. The vegetation grown in mine sites is anticipated to accumulate or selectively exclude/tolerate high levels of toxic metals. Several of the soil characteristics can be playing important role in mobility of nutrients and metals in soil system. Thus, knowledge about these soil properties becomes obligatory as assessment of their distribution on a spatio-temporal scale would help better understand their likely mobility and bioavailability.

The present investigation undertaken in three proposed mining locations at Araku, Andhra Pradesh, India during 2006 through 2008 is an attempt to examine the nutrients, alkali and alkaline earth metals, select heavy metals across the soil layers, and also alkali and alkaline earth metals, and select heavy metals in organs of select predominant plant species in the area. These species were primarily screened out on the basis of their *Ti* ability so that they can be used during the initial stages of mine restoration programme, after the mining activities are ceased. As hyperaccumulators take up particularly high amounts of metals in their shoots, an attempt was made to assess the trace and heavy metal from view point of Transportation index ($Ti = [\text{metal concentration in leaf}] / [\text{metal concentration in root}]$) in various organs/compartments of the select plant species naturally occurring in the area.

The soil samples were collected from three sites in each location (Raktakonda, Galikonda and Chittamgondi). At each site, samples were collected in triplicates from four successive layers, i.e., 0-5cm, 5-10cm, 10-15cm and 15-20cm depth, using a plastic scoop. The samples after processing were examined for select physico-chemical parameters following standard methods. The dominant plant species, *Ageratina adenophora*, *Eulalia wightii*, *Chromolaena*

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odorata, *Lantana camara*, *Phoenix acaulis*, *Tephrosia roxburghiana* and *Tridax procumbens*, were collected from the sampling locations. The individuals were separated into roots, stems and leaves using plant cutter. Totally, 864 soil and 357 plant samples were collected. The salient findings are briefed as below:

- The soil was moderately textured in hill top and fine textured in valleys. Due to secondary Fe oxides formation the soil was red and brown in colour. Invariably, the soil was acidic with pH ranging from 4.2 to 6.4, a characteristic of lateritic soil. pH values increased along the soil layers. The EC showed a decline trend across the soil layers. Diminishing chlorides, sulphates, nitrates, carbonates and phosphates with depth reduced EC levels in soil. Total organic carbon decreased across the soil layers. Regular felling and fire in the area significantly reduced TOC levels in the soil in certain months. However, persistent growth and subsequent decline and decay of grasses contributed to the increased TOC levels in top soil layers.
- Elevated phosphorous concentrations in certain months were associated with burning which caused fast mineralization of organic phosphorous and its quick release and mobilisation of inorganic forms due to increased pH and certain microbial activities. Increase in N and S resulted in increased TOC. Almost all of the nutrients showed wide spatial variability due to land use type, topography and the vegetation composition in the area. Species specific growth period contributed for reported variability of C: S ratio among months.
- Sodium concentrations were affected by man made fire in certain months. However, monsoonal rains diluted its concentration in soil. Highest root growth during monsoon was associated with absorption of nutrient at much elevated rates.
- High K in soils is a result of decomposition of plant species, rich in K. The low levels of the base cations, K, Ca and Mg is associated with the low weathering potential of parent material and marked leaching of soils. The study reveals that though certain physical characteristics i.e., colour and texture of the soils along the gradient are similar, the chemical characteristics did differ.
- Seasonal variations in heavy metal (Cu, Ni and Zn) in soils were observed. The metal mobility depended on pH, which in turn was probably governed by the occurrence of certain nitrogen fixing plant species that have the ability to lower the pH. Type and

vegetation composition played significant role in metal variability. Additionally, presence of some organic complexants, present in greater amounts in these organic soils, appeared to have affected the metal availability.

- Zinc concentrations in soils were positively related to TOC, pH and CEC, and negatively to ORP. The rainfall in association with certain other factors might have affected the Zn levels seasonally and other metal mobility in the soil layers in Araku.
- Sodium, K, Li and Ca varied significantly among organs, and this was governed by physiological activities and biomass of each plant organ. Metal variation in species occurred due to the age-dependent distribution of the metals. Further, the pH seemed to have effect on the solubility or retention of metals in soils thus, enhancing metal accumulation. Ion selective transport resulted in high values in few plant species for Cu and Zn.
- The information may be used while reclaiming the area with the dominant plant species. Based on *Ti*, *C. odorata* and *P. acaulis* may be used for Cu remediation in soils. Five species viz. *A. adenophora*, *P. acaulis*, *T. roxburghiana*, *L. camara* and *T. procumbens* may be used for remediating soils with elevated levels of Zn. Enduring plants growing in the sites exhibited high metal adaptability. Certain species may also be useful for furniture purposes.
- These plant species can be used and planted once the mining activities are ceased. However, they should be planted during the initial stages only as later more indigenous species may be planted for long term ecological value addition of the area. As many of these species do not find any use by the local human community, they will not face any local human pressure and would thrive well. The plant biomass could be a good source of biofuel (biogas/ bio-oil/ bio-alcohol, etc.) ensuring that during the processing there is no release of volatile and noxious gases. The heavy metals that will be absorbed will largely be settling in the ash which can be disposed of safely. In case the concentration is acceptable, the spent biomass (residue) could also be used as a crop-nutrition supplement.

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Appendix 1. Checklist of plant species in and around Araku

S.No.	Species	Family	Habit
1	<i>Adhatoda zeylanica</i> Medicus	Acanthaceae	Shrub
2	<i>Andrographis ovata</i> (Beddome) C.B. Clarke	Acanthaceae	Herb
3	<i>Andrographis paniculata</i> (Burm.f.) Wallich ex Nees	Acanthaceae	Herb
4	<i>Asystasia gangetica</i> (L.) T. Anderson	Acanthaceae	Shrub
5	<i>Barleria acuminata</i> Nees	Acanthaceae	Shrub
6	<i>Barleria cristata</i> L.	Acanthaceae	Shrub
7	<i>Barleria strigosa</i> Willd.	Acanthaceae	Herb
8	<i>Dicliptera cuneata</i> Nees	Acanthaceae	Herb
9	<i>Dicliptera foetida</i> (Forssk.) Blatter.	Acanthaceae	Herb
10	<i>Eranthemum nervosum</i> R. Br. ex Roem. et Scult.	Acanthaceae	Herb
11	<i>Hemigraphis latebrosa</i> (Heyne ex Roth) Nees	Acanthaceae	Herb
12	<i>Justicia betonica</i> L.	Acanthaceae	Shrub
13	<i>Justicia procumbens</i> L.	Acanthaceae	Herb
14	<i>Justicia prostrata</i> (C.B. Clarke) Gamble	Acanthaceae	Herb
15	<i>Justicia simplex</i> D. Don	Acanthaceae	Herb
16	<i>Lepidagathis cristata</i> Willd.	Acanthaceae	Herb
17	<i>Peristrophe bicalyculata</i> (Retz.) Nees.	Acanthaceae	Herb
18	<i>Phaulopsis imbricata</i> (Forsskal) Sw.	Acanthaceae	Herb
19	<i>Rhinacanthus nasutus</i> (L.) Kurz	Acanthaceae	Herb
20	<i>Ruellia patula</i> Jacq.	Acanthaceae	Herb
21	<i>Rungia pectinata</i> (L.) Nees	Acanthaceae	Herb
22	<i>Strobilanthes jeyporensis</i> Bedd.	Acanthaceae	Shrub
23	<i>Thunbergia fragrans</i> Roxb.	Acanthaceae	Straggler
24	<i>Acer laurinum</i> Hassk.	Aceraceae	Tree
25	<i>Agave americana</i> L.	Agavaceae	Shrub
26	<i>Dracaena terniflora</i> Roxb.	Agavaceae	Shrub
27	<i>Alangium salviifolium</i> (L.f.) Wangerin	Alangiaceae	Tree
28	<i>Achyranthes aspera</i> L.	Amaranthaceae	Herb
29	<i>Aerva javanica</i> (Burm.f.) Juss. ex Schultes	Amaranthaceae	Herb
30	<i>Celosia argentea</i> L.	Amaranthaceae	Shrub
31	<i>Pancratium triflorum</i> Roxb.	Amaryllidaceae	Herb
32	<i>Anacardium occidentale</i> L.	Anacardiaceae	Tree
33	<i>Buchanania lanzan</i> Sprengel	Anacardiaceae	Tree
34	<i>Lannea coromandelica</i> (Houtt.) Merr.	Anacardiaceae	Tree
35	<i>Mangifera indica</i> L.	Anacardiaceae	Tree
36	<i>Nothopegia heyneana</i> Gamble	Anacardiaceae	Tree
37	<i>Semecarpus anacardium</i> L.	Anacardiaceae	Tree
38	<i>Annona squamosa</i> L.	Annonaceae	Tree
39	<i>Miliusa velutina</i> (Dunal) Hook. f. et Thorns.	Annonaceae	Tree
40	<i>Polyalthia cerasoides</i> (Roxb.) Beddome	Annonaceae	Tree

41	<i>Polyalthia suberosa</i> (Roxb.) Thwaites	Annonaceae	Tree
42	<i>Saccopetalum tomentosum</i> Hook.f. & Thomson	Annonaceae	Tree
43	<i>Bupleurum andhrlica</i> P.K. Mukherjee	Apiaceae	Herb
44	<i>Bupleurum wightii</i> P.K. Mukherjee	Apiaceae	Herb
45	<i>Centella asiatica</i> (L.) Urban	Apiaceae	Herb
46	<i>Peucedanum graveolens</i> (L.) C.B. Clarke.	Apiaceae	Herb
47	<i>Pimpinella bracteata</i> Haines	Apiaceae	Herb
48	<i>Pimpinella wallichiana</i> (Miq) Gandhi	Apiaceae	Herb
49	<i>Aganosma caryophyllata</i> G. Don.	Apocynaceae	Climber
50	<i>Alstonia venenata</i> R. Br.	Apocynaceae	Shrub
51	<i>Anodendron manubriatum</i> Merr.	Apocynaceae	Liana
52	<i>Catharanthus pusillus</i> (Murray) Don	Apocynaceae	Herb
53	<i>Holarrhena pubescens</i> (Buch.-Ham.) Wallich ex Don	Apocynaceae	Shrub
54	<i>Ichnocarpus frutescens</i> (L.) R.Br.	Apocynaceae	Climber
55	<i>Plumeria rubra</i> L.	Apocynaceae	Tree
56	<i>Rauvolfia serpentina</i> (L.) Benth. ex Kurz	Apocynaceae	Herb
57	<i>Vallis solanacea</i> (Roth) Kuntze	Apocynaceae	Climber
58	<i>Wrightia arborea</i> (Dennst.) Mabb.	Apocynaceae	Tree
59	<i>Alocasia fornicata</i> (Roxb.) Schott	Araceae	Herb
60	<i>Colocasia esculenta</i> (L.) Schott	Araceae	Herb
61	<i>Remusatia vivipara</i> (Roxb.) Schott	Araceae	Herb
62	<i>Schefflera stellata</i> (Gaertner) Harms	Araliaceae	Tree
63	<i>Schefflera venulosa</i> (Wight & Arn.) Harms,	Araliaceae	Tree
64	<i>Caryota urens</i> L.	Arecaceae	Tree
65	<i>Phoenix acaulis</i> Roxb.	Arecaceae	Shrub
66	<i>Phoenix sylvestris</i> (L.) Roxb.	Arecaceae	Tree
67	<i>Aristolochia tagala</i> Cham.	Aristolochiaceae	Climber
68	<i>Calotropis gigantea</i> (L.) R.Br.	Asclepiadaceae	Shrub
69	<i>Ceropegia candelabrum</i> L.	Asclepiadaceae	Climber
70	<i>Cryptolepis buchananii</i> Roemer & Schultes	Asclepiadaceae	Climber
71	<i>Cryptolepis elegans</i> Wall. ex G. Don.	Asclepiadaceae	Climber
72	<i>Cryptostegia grandiflora</i> R.Br.	Asclepiadaceae	Climber
73	<i>Cynanchum callialatum</i> Buchanan-Hamilton ex. Wight	Asclepiadaceae	Climber
74	<i>Gymnema sylvestre</i> (Retz.) R.Br. ex Roemer & Schultes	Asclepiadaceae	Climber
75	<i>Hemidesmus indicus</i> (L.) R.Br.	Asclepiadaceae	Climber
76	<i>Marsdenia tenacissima</i> (Roxb.) Moon	Asclepiadaceae	Climber
77	<i>Secamone emetica</i> (Retz.) R.Br. ex Schultes	Asclepiadaceae	Climber
78	<i>Wattakaka volubilis</i> (L.f.) Stapf	Asclepiadaceae	Climber
79	<i>Acanthospermum hispidum</i> DC.	Asteraceae	Herb
80	<i>Ageratina adenophora</i> (Sprengel) R. King & H. Robinson	Asteraceae	Shrub
81	<i>Ageratum conyzoides</i> L.	Asteraceae	Herb
82	<i>Anaphalis adnata</i> Wall. ex DC.	Asteraceae	Herb

83	<i>Artemisia nilagirica</i> (C.B. Clarke) Pampan.	Asteraceae	Shrub
84	<i>Bidens biternata</i> (Lour.) Merr. & Sherff	Asteraceae	Herb
85	<i>Bidens pilosa</i> L.	Asteraceae	Herb
86	<i>Blainvillea acmella</i> (L.) Philipson	Asteraceae	Straggler
87	<i>Blumea bifoliata</i> (L.) DC.	Asteraceae	Herb
88	<i>Blumea hieracifolia</i> (Spreng.) DC.	Asteraceae	Herb
89	<i>Blumea laciniata</i> (Roxb.) DC.	Asteraceae	Herb
90	<i>Blumea virens</i> Wallich ex DC.	Asteraceae	Herb
91	<i>Centipeda minima</i> (L.) A. Braun & Asch.	Asteraceae	Herb
92	<i>Chromolaena odorata</i> (L.) R. King & H. Robinson	Asteraceae	Shrub
93	<i>Conyza bonariensis</i> (L.) Cronq.	Asteraceae	Herb
94	<i>Conyza leucantha</i> (D. Don) Ludlow & Raven	Asteraceae	Herb
95	<i>Conyza stricta</i> Willd.	Asteraceae	Herb
96	<i>Cosmos caudatus</i> H.B.K. Nov. Gen. et Sp.	Asteraceae	Herb
97	<i>Cyathocline purpurea</i> (Buch.-Ham. ex D. Don) Kuntze	Asteraceae	Herb
98	<i>Dichrocephala integrifolia</i> (L.f.) Kuntze	Asteraceae	Herb
99	<i>Elephantopus scaber</i> L.	Asteraceae	Herb
100	<i>Emilia sonchifolia</i> (L.) DC.	Asteraceae	Herb
101	<i>Erigeron canadensis</i> L.	Asteraceae	Herb
102	<i>Galinsoga parviflora</i> Cav.	Asteraceae	Herb
103	<i>Glossocardia bosvellea</i> (L.f.) DC.	Asteraceae	Herb
104	<i>Glossogyne bidens</i> (Retz.) Alston	Asteraceae	Herb
105	<i>Gnaphalium luteo-album</i> L.	Asteraceae	Herb
106	<i>Grangea maderaspatana</i> (L.) Poiret	Asteraceae	Herb
107	<i>Gynura aurantiaca</i> (Blume) DC.	Asteraceae	Herb
108	<i>Gynura lycopersicifolia</i> DC.	Asteraceae	Herb
109	<i>Lagascea mollis</i> Cav.	Asteraceae	Herb
110	<i>Laggera crispata</i> (Vahl) Hepper & J.R.I. Wood	Asteraceae	Herb
111	<i>Launaea acaulis</i> (Roxb.) Babc. ex Kerr	Asteraceae	Herb
112	<i>Parthenium hysterophorus</i> L.	Asteraceae	Herb
113	<i>Saussurea heteromalla</i> (D. Don) Hand.-Mazz	Asteraceae	Herb
114	<i>Senecio corymbosus</i> Wall. ex DC.	Asteraceae	Herb
115	<i>Senecio nudicaulis</i> Buch.Ham.	Asteraceae	Herb
116	<i>Sigesbeckia orientalis</i> L.	Asteraceae	Herb
117	<i>Sonchus wightianus</i> DC.	Asteraceae	Herb
118	<i>Sphaeranthus indicus</i> L.	Asteraceae	Herb
119	<i>Spilanthes calva</i> DC.	Asteraceae	Herb
120	<i>Spilanthes radicans</i> Jacq.	Asteraceae	Herb
121	<i>Synedrella nudiflora</i> (L.) Gaertner	Asteraceae	Herb
122	<i>Tridax procumbens</i> L.	Asteraceae	Herb
123	<i>Vernonia albicans</i> DC.	Asteraceae	Shrub
124	<i>Vernonia anthelmintica</i> (L.) Willd.	Asteraceae	Herb

125	<i>Vernonia cinerea</i> (L.) Less.	Asteraceae	Herb
126	<i>Vernonia divergens</i> (Roxb.) Edgew.	Asteraceae	Herb
127	<i>Vicoa indica</i> (L.) DC.	Asteraceae	Herb
128	<i>Wedelia urticifolia</i> DC.	Asteraceae	Herb
129	<i>Balanophora dioica</i> R. Br.	Balanophoraceae	Herb
130	<i>Impatiens balsamina</i> L.	Balsaminaceae	Herb
131	<i>Impatiens chinensis</i> L.	Balsaminaceae	Herb
132	<i>Oroxylum indicum</i> Vent.	Bignoniaceae	Tree
133	<i>Stereospermum personatum</i> (Hassk.) Chatterjee	Bignoniaceae	Tree
134	<i>Bischofia javanica</i> Blume.	Bischofiaceae	Tree
135	<i>Bixa orellana</i> L.	Bixaceae	Tree
136	<i>Bombax ceiba</i> L.	Bombacaceae	Tree
137	<i>Cordia dichotoma</i> Forster f.	Boraginaceae	Tree
138	<i>Cynoglossum zeylanicum</i> Brand	Boraginaceae	Herb
139	<i>Trichodesma indica</i> L.	Boraginaceae	Herb
140	<i>Commiphora caudata</i> (Wight & Arn.) Engl.	Burseraceae	Tree
141	<i>Garuga pinnata</i> Roxb.	Burseraceae	Tree
142	<i>Protium serratum</i> (Wallich ex Colebrooke) Engler	Burseraceae	Tree
143	<i>Sarcococca saligna</i> (D. Don) Muell.-Arg.	Buxaceae	Tree
144	<i>Acrocarpus fraxinifolius</i> Wight et Arn.	Caesalpiniaceae	Tree
145	<i>Bauhinia malabarica</i> Roxb.	Caesalpiniaceae	Tree
146	<i>Bauhinia purpurea</i> L.	Caesalpiniaceae	Tree
147	<i>Bauhinia semla</i> Wunderlin	Caesalpiniaceae	Tree
148	<i>Bauhinia vahlii</i> Wight & Arnott	Caesalpiniaceae	Liana
149	<i>Bauhinia variegata</i> L.	Caesalpiniaceae	Tree
150	<i>Caesalpinia bonduc</i> (L.) Roxb.	Caesalpiniaceae	Straggler
151	<i>Caesalpinia coriaria</i> (Jacq.) Willd.	Caesalpiniaceae	Tree
152	<i>Caesalpinia decapetala</i> (Roth) Alston	Caesalpiniaceae	Straggler
153	<i>Cassia auriculata</i> L.	Caesalpiniaceae	Shrub
154	<i>Cassia fistula</i> L.	Caesalpiniaceae	Tree
155	<i>Cassia grandis</i> L.f.	Caesalpiniaceae	Tree
156	<i>Cassia hirsuta</i> L.	Caesalpiniaceae	Herb
157	<i>Cassia leschenaultiana</i> DC.	Caesalpiniaceae	Herb
158	<i>Tamarindus indica</i> L.	Caesalpiniaceae	Tree
159	<i>Lobelia alsinoides</i> Lam.	Campanulaceae	Herb
160	<i>Lobelia heyneana</i> Roemer & Schultes	Campanulaceae	Herb
161	<i>Cannabis sativa</i> L.	Cannabinaceae	Shrub
162	<i>Capparis brevispina</i> DC.	Capparaceae	Straggler
163	<i>Cleome monophylla</i> L.	Capparaceae	Herb
164	<i>Cleome viscosa</i> L.	Capparaceae	Herb
165	<i>Crateva magna</i> (Lour.) DC.	Capparaceae	Tree
166	<i>Maerua oblongifolia</i> (Forsskal) A. Rich.	Capparaceae	Straggler

167	<i>Agrostemma verticillatum</i> Walt.	Caryophyllaceae	Herb
168	<i>Drymaria cordata</i> (L.) Roemer ex Schultes	Caryophyllaceae	Herb
169	<i>Polycarpaea corymbosa</i> (L.) Lam.	Caryophyllaceae	Herb
170	<i>Polycarpon prostratum</i> (Forsk.) Asch. & Schweinf.	Caryophyllaceae	Herb
171	<i>Cassine glauca</i> (Rottb.) Kuntze	Celastraceae	Tree
172	<i>Celastrus paniculatus</i> Willd.	Celastraceae	Straggler
173	<i>Maytenus emarginata</i> (Willd.) Ding Hou	Celastraceae	Straggler
174	<i>Maytenus hookeri</i> Loes.	Celastraceae	Straggler
175	<i>Chenopodium ambrosoides</i> L.	Chenopodiaceae	Herb
176	<i>Cochlospermum religiosum</i> (L.) Alston	Cochlospermaceae	Tree
177	<i>Anogeissus latifolia</i> (DC.) Wallich ex Beddome	Combretaceae	Tree
178	<i>Combretum roxburghii</i> Spreng.	Combretaceae	Climber
179	<i>Terminalia alata</i> Heyne ex Roth	Combretaceae	Tree
180	<i>Terminalia arjuna</i> (DC.) Wight & Arn.	Combretaceae	Tree
181	<i>Terminalia bellirica</i> (Gaertner) Roxb.	Combretaceae	Tree
182	<i>Terminalia catappa</i> L.	Combretaceae	Tree
183	<i>Terminalia chebula</i> Retz.	Combretaceae	Tree
184	<i>Terminalia coriacea</i> (Roxb.) Wight & Arn.	Combretaceae	Tree
185	<i>Commelina benghalensis</i> L.	Commelinaceae	Herb
186	<i>Commelina longifolia</i> R. Br.	Commelinaceae	Herb
187	<i>Cyanotis tuberosa</i> (Roxb.) Schult. & Schult.f.	Commelinaceae	Herb
188	<i>Argyreia arakuensis</i> N.P. Balakr.	Convolvulaceae	Straggler
189	<i>Argyreia cuneata</i> (Willd.) Ker Gawl.	Convolvulaceae	Straggler
190	<i>Argyreia daltonii</i> C.B. Clarke	Convolvulaceae	Straggler
191	<i>Argyreia nervosa</i> Burm.f.) Bojer.	Convolvulaceae	Straggler
192	<i>Argyreia roxburghii</i> Arn. ex Choi	Convolvulaceae	Straggler
193	<i>Erycibe paniculata</i> Roxburgh	Convolvulaceae	Climber
194	<i>Evolvulus alsinoides</i> (L.) L.	Convolvulaceae	Herb
195	<i>Evolvulus nummularius</i> (L.) L.	Convolvulaceae	Herb
196	<i>Hewittia scandens</i> (Koen. ex Milne) Mabb.	Convolvulaceae	Straggler
197	<i>Ipomoea barlerioides</i> (Choisy) Benth. ex C. B. Clarke	Convolvulaceae	Straggler
198	<i>Ipomoea hederifolia</i> L.	Convolvulaceae	Straggler
199	<i>Ipomoea muricata</i> (L.) Jacq.	Convolvulaceae	Straggler
200	<i>Ipomoea nil</i> (L.) Roth	Convolvulaceae	Straggler
201	<i>Ipomoea turbinata</i> Blanco	Convolvulaceae	Straggler
202	<i>Merremia vitifolia</i> (Burm.f.) Hallier f.	Convolvulaceae	Climber
203	<i>Ehretia acuminata</i> R. Br.	Cordiaceae	Tree
204	<i>Ehretia laevis</i> Roxb.	Cordiaceae	Tree
205	<i>Costus speciosus</i> (J. Koenig) Smith	Costaceae	Herb
206	<i>Kalanchoe cherukondensis</i> G.V.Subba Rao & G.R. Kumari	Crassulaceae	Herb
207	<i>Kalanchoe laciniata</i> (L.) Willd.	Crassulaceae	Herb
208	<i>Diplocyclos palmatus</i> (L.) C. Jeffrey	Cucurbitaceae	Climber

209	<i>Solena amplexicaulis</i> (Lam.) Gandhi	Cucurbitaceae	Climber
210	<i>Trichosanthes tricuspidata</i> Lour.	Cucurbitaceae	Climber
211	<i>Cyperus iria</i> L.	Cyperaceae	Herb
212	<i>Cyperus rotundus</i> L.	Cyperaceae	Herb
213	<i>Fimbristylis falcata</i> (Vahl) Kunth	Cyperaceae	Herb
214	<i>Pycnus pumilus</i> Nees	Cyperaceae	Herb
215	<i>Scleria lithosperma</i> (L.) Sw.	Cyperaceae	Herb
216	<i>Dillenia indica</i> L.	Dilleniaceae	Tree
217	<i>Dioscorea oppositifolia</i> L.	Dioscoreaceae	Climber
218	<i>Dioscorea pentaphylla</i> L.	Dioscoreaceae	Climber
219	<i>Drosera burmannii</i> Vahl	Droseraceae	Herb
220	<i>Diospyros melanoxylon</i> Roxb.	Ebenaceae	Tree
221	<i>Diospyros montana</i> Roxb.	Ebenaceae	Tree
222	<i>Diospyros ovalifolia</i> Wight	Ebenaceae	Tree
223	<i>Diospyros sylvatica</i> Roxb.	Ebenaceae	Tree
224	<i>Elaeagnus kologa</i> Schldl.	Elaeagnaceae	Straggler
225	<i>Eriocaulon polycephalum</i> Hook.f.	Eriocaulaceae	Herb
226	<i>Acalypha alnifolia</i> Klein ex Willd.	Euphorbiaceae	Herb
227	<i>Acalypha indica</i> L.	Euphorbiaceae	Herb
228	<i>Antidesma menasu</i> L.	Euphorbiaceae	Shrub
229	<i>Breynia vitis-idaea</i> (Burm.f.) C. Fischer	Euphorbiaceae	Shrub
230	<i>Bridelia crenulata</i> Roxb.	Euphorbiaceae	Tree
231	<i>Cleistanthus collinus</i> Wall.	Euphorbiaceae	Tree
232	<i>Croton sparsiflorus</i> Morong	Euphorbiaceae	Herb
233	<i>Euphorbia hirta</i> L.	Euphorbiaceae	Herb
234	<i>Glochidion ellipticum</i> Wight	Euphorbiaceae	Tree
235	<i>Macaranga pelata</i> (Roxb.) Mueller	Euphorbiaceae	Tree
236	<i>Mallotus philippinensis</i> (Lam.) Muell. Arg.	Euphorbiaceae	Tree
237	<i>Phyllanthus amarus</i> Schum. & Thonn.	Euphorbiaceae	Herb
238	<i>Phyllanthus emblica</i> L.	Euphorbiaceae	Tree
239	<i>Phyllanthus narayanaswamii</i> Gamble	Euphorbiaceae	Herb
240	<i>Phyllanthus urinaria</i> L.	Euphorbiaceae	Herb
241	<i>Phyllanthus virgatus</i> Forster f.	Euphorbiaceae	Herb
242	<i>Putranjiva roxburghii</i> Wallich	Euphorbiaceae	Tree
243	<i>Rhynchosia rothii</i> Benth. ex Aitch.	Euphorbiaceae	Climber
244	<i>Rhynchosia rufescens</i> (Willd.) DC.	Euphorbiaceae	Climber
245	<i>Richardia scabra</i> L.	Euphorbiaceae	Herb
246	<i>Ricinus communis</i> L.	Euphorbiaceae	Shrub
247	<i>Sapium insigne</i> (Royle) Trimen	Euphorbiaceae	Tree
248	<i>Securinega leucopyrus</i> (Willd.) Muell. Arg.	Euphorbiaceae	Shrub
249	<i>Synadenium grantii</i> Hook.f.	Euphorbiaceae	Shrub
250	<i>Alysicarpus monilifer</i> (L.) DC.	Fabaceae	Herb

251	<i>Alysicarpus rugosus</i> (Willd.) DC	Fabaceae	Herb
252	<i>Alysicarpus vaginalis</i> (L.) DC.	Fabaceae	Climber
253	<i>Butea monosperma</i> (Lam.) Taubert	Fabaceae	Tree
254	<i>Cajanus cajan</i> (L.) Millsp.	Fabaceae	Shrub
255	<i>Cajanus cajanifolius</i> (Haines) L.J.G.van der Maesen	Fabaceae	Shrub
256	<i>Cajanus crassus</i> (Prain ex King) Maesen	Fabaceae	Climber
257	<i>Cajanus scarabaeoides</i> (L.) Thouars	Fabaceae	Climber
258	<i>Crotalaria albida</i> Heyne ex Roth	Fabaceae	Herb
259	<i>Crotalaria bialata</i> Schrank	Fabaceae	Herb
260	<i>Crotalaria calycina</i> Schrank	Fabaceae	Herb
261	<i>Crotalaria ferruginea</i> Graham ex Benth.	Fabaceae	Herb
262	<i>Crotalaria hirsuta</i> Willd.	Fabaceae	Herb
263	<i>Crotalaria juncea</i> L.	Fabaceae	Herb
264	<i>Crotalaria medicaginea</i> Lam.	Fabaceae	Herb
265	<i>Crotalaria micans</i> Link	Fabaceae	Herb
266	<i>Crotalaria mysorensis</i> Roth	Fabaceae	Herb
267	<i>Crotalaria pallida</i> Aiton	Fabaceae	Herb
268	<i>Crotalaria prostrata</i> Rottler ex Willd.	Fabaceae	Herb
269	<i>Crotalaria spectabilis</i> Roth	Fabaceae	Shrub
270	<i>Crotalaria triquetra</i> Dalzell	Fabaceae	Herb
271	<i>Dalbergia lanceolaria</i> L.f.	Fabaceae	Tree
272	<i>Dalbergia paniculata</i> Roxb.	Fabaceae	Tree
273	<i>Dalbergia volubilis</i> Roxb.	Fabaceae	Tree
274	<i>Delonix regia</i> (Hook.) Raf.	Fabaceae	Tree
275	<i>Derris scandens</i> (Roxb.) Benth.	Fabaceae	Straggler
276	<i>Desmodium caudatum</i> (Thunb.) DC.	Fabaceae	Herb
277	<i>Desmodium gangeticum</i> (L.) DC.	Fabaceae	Herb
278	<i>Desmodium heterocarpon</i> (L.) DC.	Fabaceae	Herb
279	<i>Desmodium laxiflorum</i> DC.	Fabaceae	Herb
280	<i>Desmodium triflorum</i> (L.) DC.	Fabaceae	Herb
281	<i>Desmodium velutinum</i> (Willd.) DC.	Fabaceae	Herb
282	<i>Erythrina stricta</i> Roxb.	Fabaceae	Tree
283	<i>Flemingia macrophylla</i> (Willd.) Prain ex Merr.	Fabaceae	Shrub
284	<i>Flemingia strobilifera</i> (L.) R.Br.	Fabaceae	Shrub
285	<i>Gliricidia sepium</i> (Jacq.) Kunth ex Walp.	Fabaceae	Tree
286	<i>Indigofera astragalina</i> DC.	Fabaceae	Herb
287	<i>Indigofera cassioides</i> Rottler ex DC.	Fabaceae	Shrub
288	<i>Indigofera glabra</i> L.	Fabaceae	Shrub
289	<i>Indigofera karnatakana</i> Sanjappa	Fabaceae	Herb
290	<i>Indigofera linifolia</i> (L.f.) Retz.	Fabaceae	Herb
291	<i>Indigofera prostata</i> Willd.	Fabaceae	Herb
292	<i>Indigofera spicata</i> Forsskal	Fabaceae	Shrub

293	<i>Indigofera wightii</i> Graham ex Wight & Arn.	Fabaceae	Shrub
294	<i>Millettia extensa</i> (Benth.) Benth. ex Baker	Fabaceae	Climber
295	<i>Millettia racemosa</i> Benth.	Fabaceae	Climber
296	<i>Mucuna nigricans</i> (Lour.), Steud.	Fabaceae	Straggler
297	<i>Mucuna pruriens</i> (L.) DC.	Fabaceae	Straggler
298	<i>Ougeinia oojeinensis</i> (Roxb.) Hochr.	Fabaceae	Tree
299	<i>Peltophorum pterocarpum</i> (DC.) Backer ex K. Heyne	Fabaceae	Tree
300	<i>Phyllodium pulchellum</i> (L.) Desv.	Fabaceae	Shrub
301	<i>Pongamia pinnata</i> (L.) Pierre	Fabaceae	Tree
302	<i>Pterocarpus marsupium</i> Roxb.	Fabaceae	Tree
303	<i>Pueraria tuberosa</i> (Willd.) DC.	Fabaceae	Climber
304	<i>Rothia indica</i> (L.) Druce	Fabaceae	Herb
305	<i>Sesbania sesban</i> (L.) Merr.	Fabaceae	Tree
306	<i>Shutteria involucrata</i> (Wallich) Wight & Arn.	Fabaceae	Climber
307	<i>Tephrosia maxima</i> (L.) Pers.	Fabaceae	Herb
308	<i>Tephrosia pulcherrima</i> (Baker) Gamble	Fabaceae	Herb
309	<i>Tephrosia purpurea</i> J.K. Morton	Fabaceae	Herb
310	<i>Tephrosia roxburghiana</i> J.R. Drumm	Fabaceae	Herb
311	<i>Tephrosia tinctoria</i> Pers.	Fabaceae	Herb
312	<i>Teramnus labialis</i> (L.f.) Sprengel	Fabaceae	Straggler
313	<i>Teramnus mollis</i> Benth.	Fabaceae	Straggler
314	<i>Uraria lagopodioides</i> (L.) Desv.	Fabaceae	Straggler
315	<i>Uraria rufescens</i> (DC.) Schindler	Fabaceae	Straggler
316	<i>Vigna trilobata</i> (L.) Verdc.	Fabaceae	Herb
317	<i>Zornia gibbosa</i> Spanoghe	Fabaceae	Herb
318	<i>Casearia elliptica</i> Willd.	Flacourtiaceae	Tree
319	<i>Casearia graveolens</i> Dalzell	Flacourtiaceae	Tree
320	<i>Flacourtia indica</i> (Burm.f.) Merr.	Flacourtiaceae	Tree
321	<i>Homalium napaulense</i> (DC.) Benth.	Flacourtiaceae	Tree
322	<i>Hydnocarpus alpina</i> Wight	Flacourtiaceae	Tree
323	<i>Xylosma longifolium</i> Clos	Flacourtiaceae	Tree
324	<i>Canscora diffusa</i> (Vahl) R.Br.	Gentianaceae	Herb
325	<i>Exacum tetragonum</i> Roxburgh	Gentianaceae	Herb
326	<i>Swertia angustifolia</i> Buch.-Ham ex D. Don	Gentianaceae	Herb
327	<i>Epithema carnosum</i> Benth.	Gesneriaceae	Herb
328	<i>Gyrocarpus americanus</i> Jacq.	Hernandiaceae	Tree
329	<i>Hypericum gaitii</i> Haines	Hypericaceae	Shrub
330	<i>Hypericum japonicum</i> Thunb. ex Murray	Hypericaceae	Herb
331	<i>Curculigo orchoides</i> Gaertner	Hypoxidaceae	Herb
332	<i>Anisomeles indica</i> (L.) Kuntze	Lamiaceae	Herb
333	<i>Colebrookea oppositifolia</i> Smith	Lamiaceae	Shrub
334	<i>Coleus barbatus</i> (Andrews) Benth.	Lamiaceae	Herb

335	<i>Geniosporum indicum</i> Benth.	Lamiaceae	Herb
336	<i>Hyptis suaveolens</i> (L.) Poit.	Lamiaceae	Herb
337	<i>Leucas aspera</i> Sprengel	Lamiaceae	Herb
338	<i>Leucas hirta</i> (Roth) Sprengel	Lamiaceae	Herb
339	<i>Leucas indica</i> (L.) R.Br. ex Vatke	Lamiaceae	Herb
340	<i>Leucas martinicensis</i> (Jacq.) R.Br.	Lamiaceae	Herb
341	<i>Micromeria biflora</i> (Buch.-Ham. ex D.Don.) Benth.	Lamiaceae	Herb
342	<i>Ocimum basilicum</i> L.	Lamiaceae	Herb
343	<i>Plectranthus barbatus</i> Andrews	Lamiaceae	Herb
344	<i>Pogostemon benghalensis</i> (Burm.f.) Kuntze	Lamiaceae	Shrub
345	<i>Litsea deccanensis</i> Gamble	Lauraceae	Tree
346	<i>Litsea glutinosa</i> (Lour.) C. Robinson	Lauraceae	Tree
347	<i>Litsea monopetala</i> (Roxb.) Pers.	Lauraceae	Tree
348	<i>Neolitsea foliosa</i> Gamble	Lauraceae	Tree
349	<i>Neolitsea scrobiculata</i> (Meisner) Gamble	Lauraceae	Tree
350	<i>Persea macrantha</i> (Nees) Kosterm.	Lauraceae	Tree
351	<i>Phoebe paniculata</i> auct. non Nees	Lauraceae	Tree
352	<i>Careya arborea</i> Roxb.	Lecythidaceae	Tree
353	<i>Leea asiatica</i> (L.) Ridsdale	Leeaceae	Tree
354	<i>Leea indica</i> (Burm.f.) Merr.	Leeaceae	Tree
355	<i>Asparagus racemosus</i> Willd.	Liliaceae	Straggler
356	<i>Chlorophytum tuberosum</i> (Roxb.) Baker	Liliaceae	Herb
357	<i>Smilax perfoliata</i> Lour.	Liliaceae	Climber
358	<i>Smilax zeylanica</i> L.	Liliaceae	Climber
359	<i>Lagerstroemia reginae</i> Roxb.	Lythraceae	Tree
360	<i>Rotala rotundifolia</i> (Buch.-Ham. ex.Roxb.) Koehne	Lythraceae	Herb
361	<i>Woodfordia fruticosa</i> Kurz	Lythraceae	Shrub
362	<i>Michelia champaca</i> L.	Magnoliaceae	Tree
363	<i>Hiptage benghalensis</i> (L.) Kurz	Malpighiaceae	Liana
364	<i>Abelmoschus manihot</i> (L.) Medikus	Malvaceae	Herb
365	<i>Abutilon persicum</i> (Burm.f.) Merr.	Malvaceae	Herb
366	<i>Hibiscus lobatus</i> (Murray) Kuntze	Malvaceae	Herb
367	<i>Hibiscus lunariifolius</i> Willd.	Malvaceae	Shrub
368	<i>Hibiscus vitifolius</i> L.	Malvaceae	Shrub
369	<i>Kydia calycina</i> Roxb.	Malvaceae	Tree
370	<i>Malvastrum coromandelianum</i> (L.) Garcke	Malvaceae	Herb
371	<i>Pavonia odorata</i> Willd.	Malvaceae	Herb
372	<i>Sida acuta</i> Burm.f.	Malvaceae	Herb
373	<i>Sida cordata</i> (Burm.f.) Borssum Waalkes	Malvaceae	Herb
374	<i>Sida cordifolia</i> L.	Malvaceae	Herb
375	<i>Sida rhombifolia</i> L.	Malvaceae	Herb
376	<i>Thespesia lampas</i> (Cav.) Dalz. ex Dalz. & Gibson	Malvaceae	Shrub

377	<i>Urena lobata</i> L.	Malvaceae	Herb
378	<i>Phrynium placentarium</i> (Loureiro) Merrill	Marantaceae	Shrub
379	<i>Melastoma malabathricum</i> L.	Melastomataceae	Shrub
380	<i>Osbeckia stellata</i> Buch.-Ham. ex D. Don	Melastomataceae	Herb
381	<i>Azadirachta indica</i> Adr. Juss.	Meliaceae	Tree
382	<i>Cipadessa baccifera</i> (Roth) Miq.	Meliaceae	Shrub
383	<i>Soymida febrifuga</i> (Roxb.) Adr. Juss.	Meliaceae	Tree
384	<i>Toona ciliata</i> Roemer	Meliaceae	Tree
385	<i>Trichilia connaroides</i> (Wright & Arn.) Benth.	Meliaceae	Tree
386	<i>Cissampelos pareira</i> L.	Menispermaceae	Straggler
387	<i>Cocculus hirsutus</i> (L.) Diels	Menispermaceae	Straggler
388	<i>Cyclea peltata</i> (Lam.) Hook.f. & Thomson	Menispermaceae	Climber
389	<i>Hypserpa nitida</i> Miers	Menispermaceae	Climber
390	<i>Parabaena sagittata</i> Miers	Menispermaceae	Climber
391	<i>Stephania japonica</i> (Thunb.) Miers	Menispermaceae	Climber
392	<i>Tinospora cordifolia</i> (Willd.) Hook.f. & Thomson	Menispermaceae	Climber
393	<i>Acacia auriculiformis</i> A. Cunn. ex Benth.	Mimosaceae	Tree
394	<i>Acacia caesia</i> (L.) Willd.	Mimosaceae	Straggler
395	<i>Acacia mearnsii</i> ('mearnsii') De Wild.	Mimosaceae	Tree
396	<i>Acacia sinuata</i> (Lour.) Merr.	Mimosaceae	Straggler
397	<i>Acacia torta</i> (Roxb.) Craib	Mimosaceae	Straggler
398	<i>Albizia amara</i> (Roxb.) Boivin	Mimosaceae	Tree
399	<i>Albizia chinensis</i> (Osbeck) Merr.	Mimosaceae	Tree
400	<i>Albizia odoratissima</i> (L.f.) Benth.	Mimosaceae	Tree
401	<i>Leucaena leucocephala</i> (Lam.) de Wit	Mimosaceae	Tree
402	<i>Mimosa pudica</i> L.	Mimosaceae	Herb
403	<i>Pithecellobium dulce</i> (Roxb.) Benth.	Mimosaceae	Tree
404	<i>Xylia xylocarpa</i> Taub	Mimosaceae	Tree
405	<i>Mollugo pentaphylla</i> L.	Molluginaceae	Herb
406	<i>Artocarpus heterophyllus</i> Lam.	Moraceae	Tree
407	<i>Artocarpus lakoocha</i> Roxb.	Moraceae	Tree
408	<i>Ficus arnottiana</i> (Miq.) Miq.	Moraceae	Tree
409	<i>Ficus auriculata</i> Roxburgh	Moraceae	Tree
410	<i>Ficus carica</i> L.	Moraceae	Tree
411	<i>Ficus exasperata</i> Vahl	Moraceae	Tree
412	<i>Ficus hispida</i> L.f.	Moraceae	Tree
413	<i>Ficus microcarpa</i> L.f.	Moraceae	Tree
414	<i>Ficus racemosa</i> L.	Moraceae	Tree
415	<i>Ficus religiosa</i> L.	Moraceae	Tree
416	<i>Ficus semicordata</i> Buchanan-Hamilton ex Smith	Moraceae	Tree
417	<i>Ficus tinctoria</i> Forster f. spp. <i>parasitica</i> (Willd.) Corner	Moraceae	Tree
418	<i>Ficus tsjakela</i> Rheede ex Burm.f.	Moraceae	Tree

419	<i>Streblus asper</i> Lour.	Moraceae	Tree
420	<i>Musa balbisiana</i> L.	Musaceae	Herb
421	<i>Musa ornata</i> Willd.	Musaceae	Herb
422	<i>Ardisia depressa</i> C.B. Clarke	Myrsinaceae	Tree
423	<i>Ardisia solanacea</i> Roxb.	Myrsinaceae	Shrub
424	<i>Embelia basaal</i> (Roemer ex Schulters) A. DC.	Myrsinaceae	Straggler
425	<i>Embelia ribes</i> Burm.f.	Myrsinaceae	Straggler
426	<i>Eucalyptus citriodora</i> Hook.	Myrtaceae	Tree
427	<i>Psidium guajava</i> L.	Myrtaceae	Tree
428	<i>Syzygium cumini</i> (L.) Skeels	Myrtaceae	Tree
429	<i>Syzygium malabaricum</i> (Bedd.) Gamble	Myrtaceae	Tree
430	<i>Syzygium operculatum</i> (Roxb.) Nied.	Myrtaceae	Tree
431	<i>Nymphaea nouchali</i> Burm.f.	Nymphaeaceae	Herb
432	<i>Jasminum arborescens</i> Roxb.	Oleaceae	Straggler
433	<i>Jasminum auriculatum</i> Vahl.	Oleaceae	Straggler
434	<i>Jasminum cuspidatum</i> Rottler	Oleaceae	Straggler
435	<i>Jasminum roxburghianum</i> Wall.	Oleaceae	Straggler
436	<i>Jasminum sambac</i> (L.) Aiton	Oleaceae	Shrub
437	<i>Jasminum scandens</i> Willd.	Oleaceae	Straggler
438	<i>Linociera ramiflora</i> (Roxb.) Wallich ex Don	Oleaceae	Tree
439	<i>Olea glandulifera</i> Wallich ex Don	Oleaceae	Tree
440	<i>Ludwigia hyssopifolia</i> (Don) Exell	Onagraceae	Herb
441	<i>Ludwigia octavalvis</i> (Jacq.) Raven	Onagraceae	Herb
442	<i>Ludwigia perennis</i> L.	Onagraceae	Herb
443	<i>Ludwigia peruviana</i> (L.) H. Hara	Onagraceae	Herb
444	<i>Xylopleurum roseum</i> Spach.	Onagraceae	Herb
445	<i>Cansjera rheedii</i> J. Gmelin	Opiliaceae	Straggler
446	<i>Aerides ringens</i> (Lindl.) Fischer	Orchidaceae	Herb
447	<i>Dendrobium macrostachyum</i> Lindl.	Orchidaceae	Herb
448	<i>Eria polystachya</i> A. Rich.	Orchidaceae	Herb
449	<i>Goodyera procera</i> (Ker Gawl.) Hook.	Orchidaceae	Herb
450	<i>Luisia zeylanica</i> L.	Orchidaceae	Herb
451	<i>Malaxis rheedii</i> Sw.	Orchidaceae	Herb
452	<i>Nervelia biflora</i> Wight	Orchidaceae	Herb
453	<i>Rhychostylis retusa</i> (L.) Blume	Orchidaceae	Herb
454	<i>Spiranthes sinensis</i> (Pers.) Ames	Orchidaceae	Herb
455	<i>Vanda testacea</i> (Lindl.) Rchb. f.	Orchidaceae	Herb
456	<i>Aeginetia indica</i> L.	Orobanchaceae	Herb
457	<i>Biophytum petersianum</i> Klotzsch.	Oxalidaceae	Herb
458	<i>Biophytum reinwardtii</i> (Zucc.) Klotzsch	Oxalidaceae	Herb
459	<i>Oxalis corniculata</i> L.	Oxalidaceae	Herb
460	<i>Oxalis dehradunensis</i> Raiz.	Oxalidaceae	Herb

461	<i>Argemone mexicana</i> L.	Papaveraceae	Herb
462	<i>Passiflora foetida</i> L.	Passifloraceae	Climber
463	<i>Peperomia tetraphylla</i> (Forster f.) Hook. & Arn.	Piperaceae	Herb
464	<i>Piper attenuatum</i> Buch.-Ham. ex Miq.	Piperaceae	Climber
465	<i>Pittosporum napaulense</i> (DC.) Rehder & E. H. Wilson.	Pittosporaceae	Tree
466	<i>Plumbago zeylanica</i> L.	Plumbaginaceae	Herb
467	<i>Andropogon pumilus</i> Roxb.	Poaceae	Grass
468	<i>Apluda mutica</i> L.	Poaceae	Grass
469	<i>Aristida setacea</i> Retz.	Poaceae	Grass
470	<i>Arthraxon lancifolius</i> (Trin.) Hochst.	Poaceae	Grass
471	<i>Arundinella pumila</i> (Hochst.) Steudel	Poaceae	Grass
472	<i>Arundinella setosa</i> Trin.	Poaceae	Grass
473	<i>Bothriochloa pertusa</i> (L.) A. Camus	Poaceae	Grass
474	<i>Brachiaria ramosa</i> (L.) Stapf	Poaceae	Grass
475	<i>Brachiaria reptans</i> (L.) C. Gardner & C.E. Hubb.	Poaceae	Grass
476	<i>Chrysopogon aciculatus</i> (Retz.) Trin.	Poaceae	Grass
477	<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	Grass
478	<i>Dendrocalamus strictus</i> (Roxb.) Nees	Poaceae	Shrub
479	<i>Digitaria abludens</i> (Roem. & Schult.) Veldk.	Poaceae	Grass
480	<i>Digitaria bicornis</i> (Lam.) Roemer & Schultes	Poaceae	Grass
481	<i>Digitaria ciliaris</i> (Retz.) Koeler	Poaceae	Grass
482	<i>Digitaria longiflora</i> (Retz.) Pers.	Poaceae	Grass
483	<i>Dimeria ornithopoda</i> Trin.	Poaceae	Grass
484	<i>Eleusine indica</i> (L.) Gaertner	Poaceae	Grass
485	<i>Eragrostis atrovirens</i> (Desf.) Trin. ex Steud	Poaceae	Grass
486	<i>Eragrostis ciliaris</i> Link	Poaceae	Grass
487	<i>Eragrostis gangetica</i> (Roxb.) Steudel	Poaceae	Grass
488	<i>Eragrostis japonica</i> (Thunb.) Trin.	Poaceae	Grass
489	<i>Eragrostis tenuifolia</i> Hochst. ex Steudel	Poaceae	Grass
490	<i>Eragrostis unioides</i> (Retz.) Nees ex Steudel	Poaceae	Grass
491	<i>Eragrostis viscosa</i> (Retz.) Trin.	Poaceae	Grass
492	<i>Eulalia wightii</i> Hook. f.	Poaceae	Grass
493	<i>Hackelochloa granularis</i> (L.) Kuntze	Poaceae	Grass
494	<i>Heteropogon contortus</i> (L.) P. Beauv. ex Roemer & Schultes	Poaceae	Grass
495	<i>Imperata cylindrica</i> (L.) Raeusch.	Poaceae	Grass
496	<i>Ischaemum indicum</i> (Houtt.) Merr.	Poaceae	Grass
497	<i>Iseilema antheophoroides</i> Hackel	Poaceae	Grass
498	<i>Melinis repens</i> (Willd.) Zizka	Poaceae	Grass
499	<i>Oplismenus burmannii</i> (Retz.) Beauv.	Poaceae	Grass
500	<i>Oplismenus compositus</i> (L.) P. Beauv.	Poaceae	Grass
501	<i>Panicum notatum</i> Retz.	Poaceae	Grass

502	<i>Paspalum scrobiculatum</i> L.	Poaceae	Grass
503	<i>Pennisetum pedicellatum</i> Trin.	Poaceae	Grass
504	<i>Setaria pumila</i> (Poir.) Roemer & Schultes	Poaceae	Grass
505	<i>Setaria tomentosa</i> (Roxb.) Kunth	Poaceae	Grass
506	<i>Sporobolus indicus</i> (L.) R. Br.	Poaceae	Grass
507	<i>Themeda cymbaria</i> Hack.	Poaceae	Grass
508	<i>Themeda quadrivalis</i> L.	Poaceae	Grass
509	<i>Themeda triandra</i> Forsskal	Poaceae	Grass
510	<i>Thysanolaena maxima</i> (Roxb.) Kuntze	Poaceae	Grass
511	<i>Polygala arvensis</i> Willd.	Polygalaceae	Herb
512	<i>Polygala elongata</i> Klein ex Willd.	Polygalaceae	Herb
513	<i>Polygala persicariifolia</i> DC.	Polygalaceae	Herb
514	<i>Persicaria chinense</i> (L.) Gross	Polygonaceae	Straggler
515	<i>Polygonum hydropiper</i> L.	Polygonaceae	Herb
516	<i>Rumex nepalensis</i> Spreng.	Polygonaceae	Herb
517	<i>Lysimachia alternifolia</i> Wall.	Primulaceae	Herb
518	<i>Lysimachia candida</i> Lindl.	Primulaceae	Herb
519	<i>Lysimachia decurrens</i> G. Forster	Primulaceae	Herb
520	<i>Grevillea robusta</i> A. Cunn. ex R.Br.	Proteaceae	Tree
521	<i>Clematis gouriana</i> Roxb. ex DC.	Ranunculaceae	Climber
522	<i>Clematis roylei</i> Rehder	Ranunculaceae	Climber
523	<i>Clematis smilacifolia</i> Wall.	Ranunculaceae	Climber
524	<i>Gouania leptostachya</i> DC.	Rhamnaceae	Straggler
525	<i>Rhamnus virgatus</i> Roxb.	Rhamnaceae	Shrub
526	<i>Ventilago maderaspatana</i> Gaertner	Rhamnaceae	Straggler
527	<i>Ziziphus oenoplia</i> (L.) Miller	Rhamnaceae	Straggler
528	<i>Ziziphus rugosa</i> Lam.	Rhamnaceae	Tree
529	<i>Carallia brachiata</i> (Lour.) Merr.	Rhizophoraceae	Tree
530	<i>Prunus jenkinsii</i> Hk. f. & Thomas. ex Hk. f.	Rosaceae	Tree
531	<i>Rubus ellipticus</i> Smith.	Rosaceae	Straggler
532	<i>Rubus niveus</i> Thunb.	Rosaceae	Straggler
533	<i>Borreria hispida</i> (Linn.) K. Schum.	Rubiaceae	Herb
534	<i>Canthium dicoccum</i> (Gaertner) Teijsm. & Binnend.	Rubiaceae	Tree
535	<i>Coffea arabica</i> L.	Rubiaceae	Shrub
536	<i>Gardenia latifolia</i> Aiton	Rubiaceae	Tree
537	<i>Hedyotis affinis</i> Roem. & Schlutes	Rubiaceae	Herb
538	<i>Hedyotis auricularia</i> L.	Rubiaceae	Herb
539	<i>Hedyotis corymbosa</i> (L.) Lam.	Rubiaceae	Herb
540	<i>Hedyotis gracilis</i> Wall.	Rubiaceae	Herb
541	<i>Hedyotis nitida</i> Wight & Arn.	Rubiaceae	Herb
542	<i>Hymenodictyon orixense</i> (Roxb.) Mabb.	Rubiaceae	Tree
543	<i>Ixora arborea</i> Sm.	Rubiaceae	Tree

544	<i>Knoxia mollis</i> var. <i>hookeriana</i> R. Bhattacharjee & Deb) V. P. Prasad & Lakshmin.	Rubiaceae	Herb
545	<i>Knoxia sumatrensis</i> (Retz.) DC.	Rubiaceae	Herb
546	<i>Mitracarpus villosus</i> (Sw.) DC.	Rubiaceae	Herb
547	<i>Morinda umbellata</i> L.	Rubiaceae	Straggler
548	<i>Oldenlandia diffusa</i> (Willd.) Roxb.	Rubiaceae	Herb
549	<i>Oldenlandia herbacea</i> (L.) Roxb.	Rubiaceae	Herb
550	<i>Ophiorrhiza hirsutula</i> Wight ex Hook. f.	Rubiaceae	Herb
551	<i>Paederia foetida</i> L.	Rubiaceae	Straggler
552	<i>Pavetta tomentosa</i> Roxb. ex Smith	Rubiaceae	Shrub
553	<i>Randia dumetorum</i> (Retz.) Poiret	Rubiaceae	Tree
554	<i>Randia malabarica</i> Lam.	Rubiaceae	Tree
555	<i>Richardia brasiliensis</i> Kourou	Rubiaceae	Herb
556	<i>Rubia cordifolia</i> L.	Rubiaceae	Straggler
557	<i>Spermacoce ocymoides</i> L.	Rubiaceae	Herb
558	<i>Spermacoce pusilla</i> Wallich	Rubiaceae	Herb
559	<i>Spermacoce ramanii</i> Sivarajan & R. V. Nair	Rubiaceae	Herb
560	<i>Spermadictyon suaveolens</i> Roxb.	Rubiaceae	Shrub
561	<i>Tarenna asiatica</i> (L.) Kuntze ex Schumann	Rubiaceae	Shrub
562	<i>Wendlandia gamblei</i> Cowan	Rubiaceae	Tree
563	<i>Achronychia pedunculata</i> (L.) Miq.	Rutaceae	Tree
564	<i>Aegle marmelos</i> (L.) Corr. Serr.	Rutaceae	Tree
565	<i>Atalantia monophylla</i> (L.) Corr. Serr.	Rutaceae	Tree
566	<i>Chloroxylon swietenia</i> DC.	Rutaceae	Tree
567	<i>Clausena dentata</i> L.	Rutaceae	Shrub
568	<i>Euodia lunu-ankenda</i> (Gaertner) Merr.	Rutaceae	Tree
569	<i>Glycosmis mauritiana</i> (Lam.) Yuich. Tanaka	Rutaceae	Shrub
570	<i>Glycosmis pentaphylla</i> (Retz.) DC.	Rutaceae	Shrub
571	<i>Limonia acidissima</i> L.	Rutaceae	Tree
572	<i>Murraya koenigii</i> (L.) Sprengel	Rutaceae	Tree
573	<i>Murraya paniculata</i> (L.) Jack.	Rutaceae	Shrub
574	<i>Naringi crenulata</i> (Roxb.) Nicolson	Rutaceae	Tree
575	<i>Toddalia asiatica</i> (L.) Lam.	Rutaceae	Straggler
576	<i>Zanthoxylum armatum</i> DC.	Rutaceae	Straggler
577	<i>Meliosma pinnata</i> (Roxb.) Maxim	Sabiaceae	Tree
578	<i>Meliosma simplicifolia</i> (Roxb.) Walp.	Sabiaceae	Tree
579	<i>Salix tetrasperma</i> Roxb.	Salicaceae	Tree
580	<i>Osyris wightiana</i> Wall. ex Wight	Santalaceae	Shrub
581	<i>Santalum album</i> L.	Santalaceae	Tree
582	<i>Cardiospermum halicacabum</i> L.	Sapindaceae	Climber
583	<i>Schleichera oleosa</i> (Lour.) Oken	Sapindaceae	Tree
584	<i>Mimusops elengi</i> L.	Sapotaceae	Tree

585	<i>Xantolis tomentosa</i> (Roxb.) Raf.	Sapotaceae	Tree
586	<i>Vahlia dichotoma</i> (Murray) Kuntze	Saxifragaceae	Herb
587	<i>Bacopa monnieri</i> (L.) Pennell	Scrophulariaceae	Herb
588	<i>Limnophila rugosa</i> (Roth) Merr.	Scrophulariaceae	Herb
589	<i>Lindernia antipoda</i> (L.) Alston	Scrophulariaceae	Herb
590	<i>Lindernia crustacea</i> (L.) F. Muell.	Scrophulariaceae	Herb
591	<i>Lindernia hyssopioides</i> (L.) Haines	Scrophulariaceae	Herb
592	<i>Lindernia nummulariifolia</i> (D. Don) Wettst.	Scrophulariaceae	Herb
593	<i>Mazus pumilus</i> (Burm. f.) Steenis	Scrophulariaceae	Herb
594	<i>Mecardonia procumbens</i> (Miller) Small	Scrophulariaceae	Herb
595	<i>Melasma arvense</i> (Benth.) Hand.	Scrophulariaceae	Herb
596	<i>Micrargeria wightii</i> Benth.	Scrophulariaceae	Herb
597	<i>Scoparia dulcis</i> L.	Scrophulariaceae	Herb
598	<i>Sopubia delphinifolia</i> (L.) Don	Scrophulariaceae	Herb
599	<i>Sopubia trifida</i> Buch.-Ham. ex D. Don	Scrophulariaceae	Herb
600	<i>Ailanthus excelsa</i> Roxb.	Simaroubaceae	Tree
601	<i>Picrasma javanica</i> Blume	Simaroubaceae	Tree
602	<i>Capsicum frutescens</i> L.	Solanaceae	Shrub
603	<i>Datura metel</i> L.	Solanaceae	Shrub
604	<i>Datura stramonium</i> L.	Solanaceae	Tree
605	<i>Lycopersicum esculentum</i> Mill.	Solanaceae	Herb
606	<i>Solanum anguivi</i> Lam.	Solanaceae	Shrub
607	<i>Solanum erianthum</i> D. Don	Solanaceae	Shrub
608	<i>Solanum surattense</i> Burm.f.	Solanaceae	Herb
609	<i>Solanum torvum</i> Sw.	Solanaceae	Shrub
610	<i>Stemona tuberosa</i> Lour.	Stemonaceae	Climber
611	<i>Eriolaena hookeriana</i> Wight & Arn.	Sterculiaceae	Tree
612	<i>Firmiana colourata</i> (Roxb.) R.Br.	Sterculiaceae	Tree
613	<i>Helicteres isora</i> L.	Sterculiaceae	Shrub
614	<i>Pterospermum xylocarpum</i> (Gaertner) Santapau & Wagh	Sterculiaceae	Tree
615	<i>Sterculia villosa</i> Roxb.	Sterculiaceae	Tree
616	<i>Waltheria indica</i> L.	Sterculiaceae	Shrub
617	<i>Corchorus aestuans</i> L.	Tiliaceae	Herb
618	<i>Corchorus trilocularis</i> L.	Tiliaceae	Herb
619	<i>Grewia abutilifolia</i> Vent. ex A.L. Juss.	Tiliaceae	Shrub
620	<i>Grewia bracteata</i> Heyne ex Roth	Tiliaceae	Shrub
621	<i>Grewia hirsuta</i> Vahl.	Tiliaceae	Shrub
622	<i>Grewia orbiculata</i> Rottl.	Tiliaceae	Shrub
623	<i>Grewia serrulata</i> DC.	Tiliaceae	Straggler
624	<i>Grewia tiliifolia</i> Vahl	Tiliaceae	Tree
625	<i>Triumfetta pilosa</i> Roth.	Tiliaceae	Herb
626	<i>Triumfetta rhomboidea</i> Jacq.	Tiliaceae	Herb

627	<i>Celtis tetrandra</i> Roxb.	Ulmaceae	Tree
628	<i>Holoptelea integrifolia</i> (Roxb.) Planchon	Ulmaceae	Tree
629	<i>Trema orientalis</i> (L.) Blume	Ulmaceae	Tree
630	<i>Boehmeria macrophylla</i> Hornem.	Urticaceae	Tree
631	<i>Debregeasia longifolia</i> (Burm.f.) Wedd.	Urticaceae	Tree
632	<i>Callicarpa tomentosa</i> (L.) Murray	Verbenaceae	Tree
633	<i>Clerodendrum philippinum</i> Schauer	Verbenaceae	Shrub
634	<i>Clerodendrum serratum</i> (L.) Moon	Verbenaceae	Shrub
635	<i>Clerodendrum viscosum</i> L.	Verbenaceae	Shrub
636	<i>Gmelina arborea</i> Roxb.	Verbenaceae	Tree
637	<i>Lantana camara</i> L.	Verbenaceae	Shrub
638	<i>Stachytarpheta jamaicensis</i> (L.) Vahl.	Verbenaceae	Herb
639	<i>Tectona grandis</i> L.f.	Verbenaceae	Tree
640	<i>Vitex altissima</i> L.	Verbenaceae	Tree
641	<i>Ampelocissus divaricata</i> (M. Lawson) Planchon	Vitaceae	Climber
642	<i>Ampelocissus latifolia</i> (Roxb.) Planch.	Vitaceae	Climber
643	<i>Ampelocissus tomentosa</i> (Roth) Planchon	Vitaceae	Climber
644	<i>Cayratia auriculata</i> (Wallich) Gamble	Vitaceae	Climber
645	<i>Cayratia pedata</i> (Lour.) A.L. Juss. ex Gagnepain	Vitaceae	Climber
646	<i>Cayratia trifoliata</i> (L.) Domin.	Vitaceae	Climber
647	<i>Cissus arnottiana</i> Benth.	Vitaceae	Climber
648	<i>Cissus repens</i> Lam.	Vitaceae	Climber
649	<i>Tetrastigma lanceolarium</i> (Roxb.) Planchon	Vitaceae	Climber
650	<i>Tetrastigma sulcatum</i> (M. Lawson) Gamble	Vitaceae	Climber
651	<i>Vitis heyneana</i> Roemer & Schultes	Vitaceae	Straggler
652	<i>Glozza marantina</i> L.	Zingiberaceae	Herb
653	<i>Zingiber roseum</i> Rosc.	Zingiberaceae	Herb
654	<i>Zingiber zerumbet</i> (L.) Sm.	Zingiberaceae	Herb
655	<i>Tribulus terrestris</i> L.	Zygophyllaceae	Herb

Appendix 2. Multiple regression analysis model for metals in plant organs/species

Sl. No	Species	Organs	Cu	Ni	Zn
1	<i>E. odoratum</i>	Root	NA	NA	NA
		Stem	NA	$Y = 0.895 + (9.128 * TN)$	NA
		Leaf	NA	NA	NA
2	<i>P. acaulis</i>	Root	NA	NA	NA
		Stem	$Y = 4.258 + (0.01015 * Ca)$	NA	$Y = 39.153 + (-1.003 * Cu)$
		Leaf	$Y = 4.317 + (0.115 * EC)$	NA	NA
3	<i>A. adenophora</i>	Root	NA	$Y = 9.533 + (0.646 * Zn)$	$Y = 9.401 + (13.496 * TN)$
		Stem	$Y = 5.519 + (0.249 * Li) + (0.0617 * Zn)$	$Y = -6.665 + (0.708 * TOC) + (0.676 * Zn)$	NA
		Leaf	$Y = 7.152 + (0.751 * Li) + (-0.0882 * Zn)$	$Y = -32.279 + (0.601 * Zn)$	$Y = 2.796 + (0.552 * Zn)$
4	<i>E. wightii</i>	Root	NA	$Y = -68.522 + (0.721 * Zn)$	NA
		Leaf	NA	$Y = -22.708 + (0.03155 Mg) + (0.720 Zn)$	NA
5	<i>T. roxburghiana</i>	Root	NA	NA	NA
		Stem	$Y = -5.836 + (0.703 * Na)$	NA	NA
		Leaf	NA	NA	NA
7	<i>L. camara</i>	Root	$Y = -138.484 + (89.746 * Zn)$	NA	NA
		Stem	NA	NA	NA
		Leaf	NA	NA	NA
8	<i>T. procumbens</i>	Root	NA	NA	NA
		Stem	NA	$Y = 109.700 + (152.770 * TN)$	NA
		Leaf	NA	NA	$Y = 160.361 + (-0.441 * EC) + (299.589 * TN) + (-14273.588 * TAS) + (0.232 * Na) + (-5.552 * Cu)$

List of papers In Press/Published/Accepted/Under revision/Submitted (Communicated)
during the study duration

- 1) Submitted) R Chandra, BAK Prusty and PA Azeez. "Metal mobility across soil layer in potential bauxite mining areas, Eastern Ghats, India". *Water Air and Soil Pollution*.
- 2) Submitted) R Chandra and PA Azeez. "Alkali and alkaline earth metals distribution in the soils of proposed bauxite mine locations in Araku, India". *Australian Journal of Soil Research*.
- 3) Submitted) R Chandra, N Ganesan and PA Azeez. "Distribution of nutrients in the soils of a tropical montane savannah in the Eastern Ghats of India". *Environmental Monitoring and Assessment*.
- 4) Submitted) R Chandra and PA Azeez "Floral diversity of Kottuli: a wetland of national importance, Kozhikode, Kerala". *Journal of Economic and Taxonomic Botany*.
- 5) In Press) R Chandra and BAK Prusty. "A new record of a fish species, *Rasbora daniconius*, in the wetlands of Keoladeo National Park, Bharatpur, India, and conservation concerns". *Environmental Research Journal*.
- 6) In Press) R Chandra, BAK Prusty and PA Azeez. "A revised checklist of the flora of Keoladeo National Park, a world heritage site in India". *Environmental Research Journal*.
- 7) 2010) TS Kumar, R Chandra and PA Azeez. "The Birds of Araku, Vishakhapatnam, Andhra Pradesh". *Journal of Threatened Taxa*. 2(1): 662-665.
- 8) 2010) BAK Prusty, R Chandra and PA Azeez. "Macronutrients along the sediment core in a subtropical monsoonal wetland in India". *Wetlands Ecology and Management*. 18: 91-105. (doi:10.1007/s11273-009-9151-9).
- 9) 2009) R Chandra and PA Azeez. "Bioaccumulation of metals in different parts of weed species at proposed bauxite mines". *Advanced Materials Research*. 71-73: 609-612. (<http://www.scientific.net>).
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- 13) 2009) BAK Prusty, R Chandra and PA Azeez. "Temporal variation and distribution of select alkali and alkaline earth metals in the sediment of a monsoonal wetland in India". *Fresenius Environmental Bulletin*. 18(6): 917-927.
- 14) 2009) BAK Prusty, R Chandra and PA Azeez. "Distribution of carbon, nitrogen, phosphorus, and sulphur in the soil in a multiple habitat system in India". *Australian Journal of Soil Research*. 47(2): 177-189.
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- 16) 2008) BAK Prusty, R Chandra and PA Azeez. "Vertical and temporal variation of Zn in the soils of a multiple habitat system". *Journal of Food, Agriculture and Environment*. 6(2): 381-387.
- 17) 2007) R Chandra, BAK Prusty, D Mythily, SR Sarimol and PA Azeez. "Nutrients and alkali metal distribution in the top soil of bauxite rich hillocks in Araku Valley, Andhra Pradesh, India". *Environmental Science: An Indian Journal*. 2(3): 145-153.
- 18) 2007) BAK Prusty, R Chandra, PA Azeez and LL Sharma. "New additions to the ichthyofauna of Keoladeo National Park, a world heritage site in India". *Zoos' Print Journal*. 22(10): 2848-2852.
- 19) 2006) R Chandra and BAK Prusty. "Sighting of nest of Dusky Horned Owl (*Bubo coromandus*) in Keoladeo National Park, Bharatpur, Rajasthan". *Newsletter for Birdwatchers*. 46(5): 79.

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