CHAPTER II

PLANT BIOGEOCHEMISTRY
2.1 INTRODUCTION

The usefulness of plants to mankind as food, fodder, fibres, fuels, medicines, spices, timbers and in various other essentialities of life is well known and appreciated since time immemorial. The use of plants to delineate the boundaries of ground water and minerals, however, adds a new dimension to their utility to mankind. The importance of plant cover as an indicator of the ecological and hydro geological studies has been focused by Brooks (1983).

The plant can be viewed as a sophisticated geochemical sampling device, as yet not fully understood. An extraordinary wealth of information as plant chemistry is scattered throughout the literature of botanists, plant chemists and geochemists. In spite of this, although past its infancy. As research progresses on conditions that control the accumulation of elements by plants, and as field studies continue to augment the databases on plant chemistry, the role of the plant in mineral exploration programmes becomes increasingly important. (Brooks, 1983; Kovalievskii, 1987; Brooks et al., 1995; Dunn, 2007)
In recent years, much interest has been shown in supplementing the usual methods of geochemical prospecting of metalliferous sites with examination and analysis of the vegetation. U.S.S.R. greatly surpasses all other countries in the development and use of botanical methods of prospecting in the world today. A geobotanist was included in all major Russian geological expeditions after 1945 and in 1955 the Russian Ministry of Geology and Conservation made geochemical work of one sort or another mandatory for all geological exploration parties (Cannon, 1960, 1964; Kavalevskii, 1987).

Botanical methods of prospecting for minerals incorporate two different techniques, namely geobotanical and biogeochemical. Although it is customary to classify geobotany, involving the visual observation of vegetation cover and biogeochemistry, involving the analysis of the mineral content of the plant cover and its underlying soil as two separate disciplines, they are in reality closely related since nature of vegetation and its elemental content are influenced both by the chemical composition of the soil and the physical features of the environment (Brooks, 1983; Brooks et al., 1995; Dunn et al., 1996; Dunn, 2007).

2.1.1 Geobotany

It is a specialized branch of Applied Ecology and involves the visual observation of the vegetation cover in order to detect mineralization by means of plant distribution, the presence of indicator plants and/or mutational and/or morphological changes induced by the excess of certain elements in the underlying soil strata and the study of any of the above parameters by aero-visual observations, aerial photography and/or satellite imagery (Brooks, 1983).
The Russian geologist, Karpinsky (1841) was the first to recognise that different plant associations exist on varying geological substrata and concluded that greater reliance should be placed on an examination of the whole community rather than one or a few species within. This classical work led to the development of the science of "Indicator Geobotany". During recent times researches in the science of indicator geobotany have been stimulated by satellite imagery and the development of sophisticated computer assisted techniques which allow for through and quick statistical treatment of the raw data.

Most of the geobotanical 'indicator' plants of specific metals occur in the various parts of world, notably in Central Africa (Brooks, 1998). Plant development in cool and cold regions is controlled by physical and chemical conditions. As a result there are far fewer species in cold areas than in warm and moist climate, where plant grown and diversity are not impeded by the harsh physical conditions. In tropics, ground chemistry plays a more dominant role in the distribution of plants, and some species adapt to a chemical niche. In the 1950's some of best examples that guided many explorations activities are the copper/cobalt flora of the Democratic Republic of Congo (DRC) and the Copper flora of the Zambian copper belt (Brooks and Malaisse, 1985, Brooks et al., 1995; Brooks, 1998).

2.1.2 Plant communities as indicator of minerals in the underlying strata

Plant communities have been used as indicator of different mineral deposits. Among the early examples of the discovery of a mineral deposit by the presence of a particular type of plant community was Tyson's discovery (1810) of Chromite, guided by depressed flora on the ore-bearing serpentinities (quoted by Singewald, 1928). Other early workers include Unger (1936) and Tanfleev (1886) who studied the characters of plant communities growing on calcareous rocks. Linstow (1929) referred to such plant's as 'bodenanzeigeniende pflanzan' which literally means 'plants that indicate the soil'.
Phytosociological studies pioneered by Braun-Blanquet (1932) are the best for a semi quantitative classification of plant communities over metal rich soils. The method of classification is based on vegetational composition of the community and hence provides an indirect means of classifying species characteristic of metal rich soils and different workers have provided extensive species list of plants on metal contaminated soils. Certain species are clearly unique component of most metal rich soils. In so doing, different workers have provided extensive species list of plants on metal contaminated soils. Certain species are clearly unique components of most metal rich soils; others are restricted to particular communities of the metal contaminated soils whereas a third group are consistently present in some communities but by no means confined to metal rich soils.

Two features of the abstract plant community, 'constancy' (the degree of which a species constantly occurs in a community) and fidelity (the degree of exclusive occurrence of species in a community) have been determined by considering the total occurrence of each species in different plant communities of the study area.

2.1.3 Plant indicators

Plant indicators of ore deposits are species that are adapted to live exclusively on rocks or soils that supply unusually high amount of a particular element or have acquired tolerance to high concentrations by being able to reject the metal at the root site or may be species of wide distribution that favour mineralized ground under certain local conditions because of a change in acidity, water conditions or availability of major plant nutrients (Cannon, 1960; Brooks, 1983). One of the earliest examples of an indicator plant is the ‘copper plant’ (kisplant), probably *Viscarta alpina* which was used by medieval miners in Scandinavia in their search for copper and other pyrite ores (Vogt, 1942). A comprehensive list of indicator plants was given by Tiagi and Aery (1985).
2.1.4 Classification of indicator plants

Malyuga (1964) distinguished two types of indicator plants, namely, 'Universal' and 'Local'. The former are those species which require a particular concentration of an element in the soil for healthy growth and fail to grow in soils containing lesser amount than the threshold and the letter are species, adapted to tolerate mineral rich ground but at places can grow equally well, provided that competition from other species is not too intense.

2.1.5 Morphological and mutational changes in plants affected by excessive mineralization

It is a well known fact that most minerals, especially the heavy metals are needed by the plants in very small quantities. However, the level of toxicity varies from species to species, the presence of other elements whose effects may be synergistic or antagonistic and physical structure of soils. Ecological conditions also affect the level of toxicity of an element. Bowen (1966) classified the elements into three groups, depending upon their toxicity as under:

a) Very toxic: Symptoms of toxicity appear at concentrations lesser than one ppm in the substrate. This group includes elements like beryllium, copper, mercury, tin and silver.

b) Moderately toxic: Symptoms of toxicity appear at concentrations between 1-100 ppm in the substrate. This includes the transitional elements and most of the elements of groups III, IV, V and VI of the periodic table.

c) Scarcely toxic: Symptoms of toxicity rarely appear at concentrations usually present in the substrate. Examples are the alkali metals, alkaline earths, halogens, nitrogen, phosphorus, sulphur and titanium.
Changes in the morphology of plants, caused by excessive amounts of minerals have been useful field guides in their prospecting. These symptoms are highly varied and may appear in the form of chlorosis or mottling of leaves, abnormal shape of fruits, changes in colour of flowers, dwarfism or gigantism in habit. Considerable experience and skill is required for recognising these changes vis-à-vis the mineral in excess which is the cause of such changes unless the changes are too obvious. The excess of certain elements such as the heavy metals copper, nickel, zinc etc. may cause chlorosis which is also caused by deficiencies of nitrogen, phosphorous, calcium etc. Important morphological changes induced in plants caused by the excesses of certain elements in the substrate were reviewed by Tiagi and Aery (1985).

2.2 BIOGEOCHEMISTRY

2.2.1 Introduction

The credit for the development of the "Biogeochemistry" is mainly assigned to Brundin (1939). Following the pioneering work of Tkalich (1938, 1952, 1953, 1956, 1959), U.S.S.R. has remained the pivot of biogeochemical prospecting for minerals in the world. A number of workable ore-deposits in USSR and elsewhere in the world have been located by the biogeochemical method. The extensive literature on this subject has been excellently reviewed by Malyuga (1964), Chikishev (1965), Brooks (1972, 1983); Kovalevskii (1979, 1987), Brooks et al., (1995) and Dunn (2007).

The interaction of elements between geosphere and biosphere, the central concept is adaptation of various organisms giving rise to the development of a discipline called, "biogeochemistry". It deals with mineral exploration, agricultural geochemistry and environmental geochemistry, including public health (Thornton 1983; Bowie and Thornton, 1985; Brooks et al., 1995; Adriano et al., 1997).
In modern times, biogeochemistry has grown enormously to include several geological and biological factors influencing the source, dispersion, and distribution of elements in surficial environment their pathways into food materials and water supplies and their possible effects on health and disease in plants, animals, and man. Nutritional elements of an environment and the related health aspects involved in the field of applied ecology - variously designated as biogeochemistry, nutritional ecology, and applied environmental ecology, is of unique importance in the realm of life on the Earth and in the affairs of man. These problems of applied environmental geochemistry also constitute a field called "geochemical ecology" (Peterson, 1971; Kovalcvskii, 1987).

Geochemical ecology deals with mineral exploration, agricultural geochemistry, and environmental geochemistry including public health. Vinogradov (1964) introduced an important concept called 'biogeochemical province'. It is influenced by local enrichment of metals due to the existence of ore bodies and their associated dispersion halos. In such provinces plants and animals conspicuously exhibit indicator characteristics which may be morphological or physiological. On this basis, termites, cattle, dogs, fish, and birds are also employed as bioindicators in mineral exploration (Brooks, 1972, 1983, 1987, 1998; Brooks et al., 1995; Pett et al., 2009).

There is further development of biogeochemistry involved in applied environmental geochemistry which is concerned with complex interactions in the rocks-waters-gases gives rise to a wide range of chemical characteristics in the surface environment affecting the biosphere in various ways. In these studies, the samples commonly employed are soils, sediments, surface and ground waters and plants.
Plants absorb metals from the medium in which they grow, and distribute them among tissues according to metabolic requirements and tolerances. Many metals in the substrate area present in excess of growth and health requirements. Plants cope with this excess either by creating barriers to metal uptake at the plant-soil interface, or by passively accepting these metals and storing them in a chemical form and location where they will not interfere with normal plant functions. In areas of extreme metal concentration, seeds will either not germinate, leaving ground devoid of its normal vegetation cover, or a plant may be develop one or more of the many signs of toxicity that can occur. These 'barren' or 'kill' zones are obvious to the seasoned prospector and they have been exploited for millennia. Such use of botanical indicators falls into the realm of geobotany (i.e., visual approach), whereas biogeochemistry involves the chemical analysis of plant tissues that show no obvious signs of stress from the uptake of mostly small, but geochemically significant concentrations of metals and other chemical elements (Dunn, 1995, 2007).

Prasad and Freitas (2003) have mentioned in a review that about 400 plants belonging to Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunoniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Violaceae and Euphobiaceae hyperaccumulate metals. Among Brassicaceae 11 genera and 87 species have the ability to accumulate metals. Ni hyperaccumulation is reported in 7 genera and 72 species and Zn in 3 genera and 20 species of Brassicaceae. Thlaspi species are capable of hyperaccumulating numerous metals, *T. caerulescense* (Cd, Ni, Pb, Zn), *T.goesthingense* and *T. ochrolecum* (Ni, Zn) and *T. rotundifolium* (Ni, Pb, Zn). The ability of a plant to restrict the uptake of a toxic element whatever its amount in the soil is known as exclusion mechanism (Brooks, 1983), which may operate at soil-root interface, within the roots, or at a higher level in plant (Peterson, 1971).
The biogeochemical sampling must ensure that a consistent plant tissue is sampled e.g., leaf, root or branch, and take into account of the age and health of the plant etc. In addition, comparison between the geochemistry of soil and vegetation should be considered with care, since the soil horizon sampled may not necessarily reflect the zone utilized by plant species for their nutrients and water. The location of the root system of plants in semi arid areas predominantly reflects the availability of water, i.e., soil moisture and soil structure (Lintern et al., 1997).

The lead mining activities at Bandalamottu has generated vast amounts of waste over years; amplify the trace element concentrations, which pose catastrophic effects on the surrounding environment due to their non biodegradable nature. The excess presence of these hazardous elements in and near and mine dumps hampers the existing plant life. The freshly excavated dumps serve as a new substrate for plants and comprise of various mixtures of topsoil and substrate rock. The fresh unweathered rocks brought to the surface release greater concentrations of elements to the soil, than existed in original soil and therefore may affect the plant growth (Ebens and Shacklett, 1982). Though the mining habitat does not support healthy plant growth, however certain plant organisms thrive well in these metal enriched environments, which may be due to their adaptative capabilities and tolerance to metals.

Mine reclamation and biogeochemical prospecting depends on the exploration of metal tolerant plant species with unique abilities of accumulating and retaining elements in their plant tissues without toxic effects. This will represent a very practical and cost effective strategy to rehabilitation and remediate such contaminated areas. Restoration of a vegetation cover with such exclusive plant species can fulfil the objectives of
stabilization, pollution control, visual improvement and removal of threats to human beings. Thus, remediation of mine tailings, surroundings and biogeochemical prospecting at Bandalmottu would rely on the appropriate selection of the plant species. Based on the field observations plant species which are actively and abundantly thriving in the study area are identified. In the present study, we focussed on plant associations growing on Pb mine spoils of Bandalmottu area of Agnigundala region of Andhra Pradesh, India. The dominant native plant species occurring in spoils are Albizia amara, Erthroxylum monogynum, Calotropis gigantea, Zizyphus numelaria, Acacia torta, Helecreres isora, Grewia Flavescens, Wrightia tinctoria, and Azadirachta indica (Plates 1, 2 and 3).

2.2.2 Materials and Methods

Composite samples of leaves and twigs of nine different plant species were collected from the Bandalmottu lead mine dumps together with the soils on which these plants were growing. Four samples of leaves and twigs of each species were selected for analysis. The topsoil horizon (0-20 cm below the topographic surface) was sampled. All the plant samples were washed thoroughly with distilled water. The moisture from these samples was then eliminated by keeping them at 110°C in a hot air oven for eight hours.

Further plant samples were ashed by placing them at 400°C in a muffle furnace for three hours. Soil samples were oven dried (at 110°C) and sieved through a 2 mm mesh screen. About 0.2 g of sample of the finer fraction plant ash/soil was digested in 1:1 HNO₃ and H₂O₂ and dried in tubes in a water bath. The solutions were made up to 10ml with distilled water. Both the soil and plant samples were analyzed by atomic absorption spectrometry for Pb, Cu, Zn, and As. For the arsenic determination, 1ml of the
solution was mixed with 9ml of 10% HCl containing 10% KI and 5% ascorbic acid. Arsenic concentrations in the samples were determined by hydride-generation atomic absorption spectrometry. The average concentrations of elements in the ash of certain native plant species and their associated are shown in Table 2.1 and Figure 2.1.

2.3 ELEMENTAL DISTRIBUTION IN PLANTS AND SOILS

The results of present study, clearly shows that leaves and twigs of plant species showed variation in concentration of the heavy metals and the elemental accumulation for different elements is as follows:

Pb, Zn and As were concentrated to a lesser degree in plant parts than in their corresponding soil concentrations. There was no consistent pattern in the case of Cu in relation to soil and plant concentrations. Further more Pb and Cu were found at higher concentrations in twigs than in leaves. The converse is true for Zn and As.

Lead: Very high concentrations of lead with a mean value of approximately 690 (µg/g) and 1783 (µg/g) were accumulated in the leaves and twigs of *Wrightia tinctoria*. Xiong (1997) has observed in certain plant species of *Sonchus oleraceus* L that the leaves contained much lower Pb than stems and roots. This worker also state that Pb concentrations in leaves, stems, and roots were positively correlated with one another. Barry and Clark (1978) found Pb concentrations even up to 20,000 mg kg⁻¹ in shoots of *Minuartia* and up to 41250 mg kg⁻¹ metal mining complex of the Yorkshire Pennines, England. In the present study, the average concentrations of Pb ranged from 1332 to 95533 (µg/g).
Table 2.1 Average concentrations of various heavy metals in certain plants and their soils growing on mine spoils

<table>
<thead>
<tr>
<th>S.No</th>
<th>Species</th>
<th>Pb (μg/g)</th>
<th>Cu (μg/g)</th>
<th>Zn (μg/g)</th>
<th>As (μg/l)</th>
</tr>
</thead>
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<td></td>
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<td>Leaf</td>
<td>Twig</td>
<td>Soil</td>
<td>Leaf</td>
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<td>4.71</td>
<td>5.53</td>
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<td>3.24</td>
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<td>2</td>
<td>Erthronyctum monoecynum</td>
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<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td></td>
<td>6.38</td>
<td>9.81</td>
<td>40.99</td>
<td>4.26</td>
<td>5.34</td>
</tr>
<tr>
<td>3</td>
<td>Zizyphus numalrixa</td>
<td>±</td>
<td>±</td>
<td>±</td>
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<tr>
<td></td>
<td>5.34</td>
<td>6.42</td>
<td>33.36</td>
<td>1.78</td>
<td>1.87</td>
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<tr>
<td>4</td>
<td>Acacia Torta</td>
<td>±</td>
<td>±</td>
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<td>±</td>
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<tr>
<td></td>
<td>4.26</td>
<td>12.03</td>
<td>75.15</td>
<td>4.43</td>
<td>12.96</td>
</tr>
<tr>
<td>5</td>
<td>Helicteres Isona</td>
<td>±</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td></td>
<td>18.20</td>
<td>35.22</td>
<td>628.50</td>
<td>2.27</td>
<td>6.01</td>
</tr>
<tr>
<td>6</td>
<td>Ceratonia Flavelascens</td>
<td>±</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td></td>
<td>10.11</td>
<td>45.14</td>
<td>1330.64</td>
<td>7.76</td>
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</tr>
<tr>
<td>7</td>
<td>Wrightia Tinctoria</td>
<td>±</td>
<td>±</td>
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<td></td>
<td>9.02</td>
<td>37.79</td>
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<td>Calotropis Gigantea</td>
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<td>406</td>
<td>95533</td>
<td>159</td>
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<tr>
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<td>Azadirachta indica</td>
<td>±</td>
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<tr>
<td></td>
<td>19.31</td>
<td>14.70</td>
<td>888.41</td>
<td>2.27</td>
<td>2.94</td>
</tr>
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</table>

Concentrations are average of 4 samples ± standard error
Figure 2.1 Trace element concentration of different plant species (average values)
The lead tolerance potential of six legume species, namely bengalgram (Cicer arietinum L.), blackgram (Vigna mungo L.), cowpea (Vigna unguiculata L.), greengram (Vigna radiata L.), horsegram (Macrotyloma uniflorum Lam.) and redgram (Cajanus Cajan L.) grown on lead ore tailings was studied by Sudhakar et al., (1992).

Root and shoot growth data revealed that bengalgram and cowpea adapted to high lead concentrations better than the other legumes. Furthermore, the availability of Pb to plants is low, and relatively large differences in soil contents result in only small increases in plant concentrations (Thornton, 1983).

**Zinc:** Zinc is an essential element in all organisms and plays an important role in the biosynthesis of enzymes, auxins, and some proteins. Typical concentrations of Zn in plants are in the range of 10 to 100 ppm (Allen 1989; Kabata-Pendias and Piotrowska, 1984). In the present study, very high concentrations of Zn with a mean value of about 671 (μg/g) were accumulated in the leaves of Helicteres isora. Zn concentrations in soils are ranging from 245 to 1305 (μg/g). Reeves and Brooks (1983) found considerable accumulation of Zn in leaves of Thlaspi rotundifolium ssp. cepaeifolium in the vicinity of Pb-Zn mine in the Cave de Predile (Raibl) area of Northern Italy.

**Copper:** Copper is required in very small amounts, about 5 to 20 ppm in plant tissue being adequate for normal growth (Jones, 1972), while less than 4 ppm is considered deficient and above 20 ppm is considered toxic. In the present study, very high concentrations of copper about 350 and 608 (μg/g) were accumulated in leaves and twigs of W. tinctoria. The twigs generally contained more copper than leaves. Similarly copper concentrations have been found to be higher in twigs than needles (Warren et al., 1959).
In soils, the concentrations of Cu ranged from 50 to 184 (μg/g). In the present study, Pb and Cu concentrations exhibited similar trends among the species and organs. Dahmani-Muller et al., (2000) have also observed such trends in the plant species *Armeria maritima* spp. *halleri* near a metal smelter.

**Arsenic**: Higher concentrations of arsenic were accumulated in leaves than twigs in all the plant species studied. The concentration of 5358 (μg/l) was accumulated in the leaves of *C. gigantea*. Further more, *A. indica* also accumulated high concentrations of arsenic in both organs. Nagaraju and Gururajesh (2003) have also reported high concentrations of heavy metals in these two plant species from the Mangampeta baryte mining area. Arsenic concentrations in plants from areas influenced by mining activities have already been reported (Bech et al., 1997). It has also been reported that arsenic bioaccumulates in oak leaves from the Colline Mealifere (Tuscany) mining area of Italy (Bargagli et al., 2003). Arsenic accumulation were found in *Prosopis laevigata* and *Acacia farnesiana* in the Zimapán mining area of México (Armiental, et al., 2008). Arsenic concentrations in soils are ranged from 11582 (μg/l) to 45395 (μg/l). The arsenic present in arsenopyrite is readily available to plants (Bech et al., 1997).

Arsenic is known for its toxic properties, but the naturally occurring forms of As are not the most toxic (O’Neill, 1993). Arsenic is widespread in sulphide mineralisation, mostly as pyrite or as trace elements in chalcopyrite and pyrite (Levinson, 1974). It is also present in easily detectable concentrations in almost every type of soils and rocks. The most abundant forms in surface environments are oxianion i.e complexes with As (III) and As (V). The occurrence of hydrated Fe and Al oxides is known to reduce the mobility of arsenic forms, particularly arsenate (Kabata-Pendias, 2001).
Plants under natural conditions take up metals only to an extent that does not exceed the pool of the metals in the soil that is readily accessible for plant roots. This plant-available metal pool in the rhizosphere of hyperaccumulator species is likely to be sustained by recycling of metals via sequence of the shoot system. In addition to genetic variation, differential uptake of metals by specimens of the same species may therefore be related to the amount of readily available metals in the soil (Wenzel and Jockwer, 1999). The vegetation growing on tailings is subjected to a harsh environment, especially the various adverse edaphic factors in addition to besides the elevated heavy metals. Heavy metals can cause severe phytotoxic action, and may act as a powerful force for the evolution of tolerant populations. It is easy to identify metal tolerant species from the natural vegetation of metalliferous minewastes (McNeilly and Bradshaw, 1968; Baker and Proctor, 1990; Wu, 1990; Mains et al., 2006).

Mine tailings impose various adverse effects on plant growth through high levels of various heavy metals and other elements in toxic concentrations, low amounts major plant nutrients, acidity, salinity and alkalinity. (Bradshaw and Chadwick, 1980). This suggests that populations of plant species growing on Pb mine tailings can tolerate elevated metal concentrations. Therefore, selection of such appropriate plant species which can establish, grow and colonise metal-contaminated soils is important for successful reclamation of degraded mine sites (Wong, 2003). Although some tolerant plants are now commercially available for restoration of metalliferous wastelands, there has been continuous interest in searching for native tolerant plants which can adapt to local climatic conditions and are able to colonise metal-enriched soils for use in land reclamation (Williamson et al., 1982; Sudhakar et al., 1992; Monni et al., 2000; Tordoff et al., 2000; Bell and Donnelly, 2006; Dunn, 2007; Salas-Luévano et al., 2009).
Successful establishment and colonization of several pioneer plant species tolerant to Pb/Zn mine spoils have been demonstrated. The tolerant species have included grasses viz., *Vetiveria zizanioides*, (Shu et al., 2000), the shrubby legume *Sesbania rostrata* (Yang et al., 1997), the woody legume *Leucaena leucocephala* (Zhang et al., 2001) and mesquite and huizache in Zimapán mining area of Mexico (Armiental, et al., 2008). The plants must be tolerant to toxic metals and should be ideal pioneer species to accelerate ecological succession of man-made habitats (Bradshaw, 1993; Mendez and Maier, 2008).

The presence of the heavy metals in tailings and waste rock impoundments may require an innovative remediative practice, to ensure that metal escape to the environment is limited (EPA, 1995; McConchie et al., 1998).

Biogeochemical methods comprise another tool that explorationists have at their disposal. Data should be interpreted in conjunctions with all other available geological, geochemical and geophysical information, because the technique is not a panacea and in some environments there may be little or no biogeochemical response to mineralization and so it may not be the best tool to use. However, the case history examples demonstrate that a number of mines have been developed long after the recognition of a biogeochemical signature, attesting to the value of method.

Pattern recognition of element distribution patterns and their spatial relationships is a significant factor in successful application of biogeochemistry to mineral exploration. There is now sufficient knowledge of the application and usefulness of biogeochemical methods for the thoughtful explorationist to consider using biogeochemistry as an integral part of a comprehensive mineral exploration program. Frequently vegetation chemistry can provide information on the substrate that can not be obtained by other means.
2.4 BIOLOGICAL ABSORPTION COEFFICIENT (BAC)

Biological absorption coefficient (BAC) is used to characterize the absorption intensity of chemical elements by plants from their soil substrate. Kovalevskii (1969) has defined the biological absorption coefficient as follows.

\[
BAC = \frac{C_p}{C_s}
\]

Where \(C_p\) is the concentration of an element in plant ash and \(C_s\) is the concentration of the same element in the soil substrate. The range of BAC values varies widely from 0.001-100. It is an important biogeochemical parameter used in mineral investigations. Perelman (1966), Brooks (1983) and Kovalevskii (1987) have discussed the significance of this parameter in biogeochemical prospecting. Alloway et al., (1988) defined it as Biological Accumulation Coefficient and stated that the plant uptake can be evaluated using this simple index. Further, they suggested that the water soluble fraction is likely to represent a metal fraction available for plant uptake.

Perelman (1966) has classified BAC values into five groups. These are intensive absorption (BAC 10-100); strong absorption (BAC 1-10); intermediate absorption (BAC 0.1-1); weak absorption (BAC 0.01-0.1); and very weak absorption (BAC 0.001 -0.01).

The BAC values of all the native plants occurring in the study area are illustrated in Table 2.2. Based on the classification of BAC values suggested by Perelman (1966), the behaviour of plants studied in study areas are represented as follows.

Generally in the mining area, the leaves and twigs of all plants for copper and zinc elements are falling in the category of strong absorption (BAC 1-10) and intermediate absorption (BAC 0.1-1). Further the elements lead and arsenic are occurring in the weak absorption category (BAC 0.01-0.1).
Table 2.2 Biological absorption coefficient of the plants.

<table>
<thead>
<tr>
<th>Species</th>
<th>Pb (µg/g)</th>
<th>Cu (µg/g)</th>
<th>Zn (µg/g)</th>
<th>As (µg/l)</th>
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<tbody>
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<td></td>
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<td>Twig</td>
<td>Leaf</td>
<td>Twig</td>
</tr>
<tr>
<td>Albizzia amara</td>
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<td>0.15</td>
<td>0.34</td>
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</tr>
<tr>
<td>Erthroxylum monogynum</td>
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<td>0.07</td>
<td>1.96</td>
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<td>0.03</td>
<td>0.04</td>
<td>0.93</td>
<td>1.28</td>
</tr>
<tr>
<td>Acacia Torta</td>
<td>0.01</td>
<td>0.01</td>
<td>1.92</td>
<td>2.45</td>
</tr>
<tr>
<td>Helicteres isora</td>
<td>0.01</td>
<td>0.02</td>
<td>0.38</td>
<td>0.90</td>
</tr>
<tr>
<td>Grewia Flavescens</td>
<td>0.01</td>
<td>0.01</td>
<td>0.42</td>
<td>1.15</td>
</tr>
<tr>
<td>Wrightia Tinctoria</td>
<td>0.02</td>
<td>0.05</td>
<td>2.82</td>
<td>4.90</td>
</tr>
<tr>
<td>Calotropis gigantea</td>
<td>0.01</td>
<td>0.01</td>
<td>0.92</td>
<td>1.40</td>
</tr>
<tr>
<td>Azadirachta indica</td>
<td>0.01</td>
<td>0.01</td>
<td>0.73</td>
<td>0.78</td>
</tr>
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</table>
Dinelli and Lombini (1994) studied the geochemical behaviour of some elements (Cr, Fe, Ni, Cu and Zn) in iron and copper sulphide mine spoil dumps of the Vigozzone northern mining area of Northern Apennines by adopting this parameter. It is concluded that the different organs of a species exhibit different behaviour with respect to elemental concentrations and their mobility. Most plants establish at their root tips, barriers to absorption of some elements, and each plant species has a different requirement for, and tolerance to, trace elements (Dunn et al., 1996; Dunn, 2007).

In arid regions, such as in Bandalamottu lead mining area, root penetration may be deep, allowing the extraction of metals from the underlying bedrock and the soil. The result is that a plant does not extract elements from just the surface soils, but from the entire soil profile, groundwater and sometimes bedrock. Thus, the evaluation of plant metal concentrations gives information about specific plant behaviour in this environment or to gather data about metal dispersion and their mobility to the biomass. Therefore such plants can be tried for reclamation and revegetation of the mine affected areas.

The existence of plants on the mine wastes and metal contaminated soil leads to the belief that metal tolerant species grow by natural selection. Most waste materials are relatively infertile and are toxic. They do not have a single, clear cut substrate factor responsible for reducing growth. The most successful populations at each site are those with highest tolerance to the metals occurring on the waste, provided the species was appropriately adapted to the other soil conditions (Berry, 1986). The plants very greatly in their ability to accumulate elements from the soil (Brooks 1983). In the present investigations, the variation in the composition of soils and plants in the study area attributed to the bioavailability of these elements, genesis of the ore body and its associated rock types.
Further, mining activity degrades the environment both directly and indirectly. The mine wastes or dumps are toxic to the biological organisms and are one of the inhibitory ecological factors affecting plant growth (Salomons, 1995). The physiological function of each element is different, and in many cases the purpose for which the element enters the plant, is also unique because different elements have different functions within the plant and the content of the nutrients varies from organ to organ (Brooks 1998; Siegel, 2002). The activities of plants solubilize and mobilize nutrients, making them potentially more susceptible to erosion. It can be concluded that the strategies adapted by plants to avoid, restrict or alleviate, make it unlikely that a unifying adaptive principle lies behind the development of tolerance throughout the Plant kingdom (Kabata-Pendias, 2001)

To enhance the fertility and aesthetic value of a contaminated land, the goals of a reclamation scientist should comprise cost effective ways to alleviate the elevated metal concentrations in mining areas and reduce the spreading of contaminants to the surrounding environment. Therefore to restore these adversely affected mining areas for the welfare of the society and environment, the plant species with ability to successfully germinate, grow and reproduce under adversely affected environments need to be identified and utilized for reclamation and re-vegetation programs.
To meet these basic requirements of restoring the affected areas, the present investigation work has clearly demarcated the remediation potential of actively thriving plant species viz., Albizia amara, Erthroxylum monogynum, Calotropis gigantea, Zizyphus numelaria, Acacia torta, Helecteres isora, Grewia Flavescens, Wrightia tinctoria, and Azadirachta indica. The most successful plant populations at each site were those with highest tolerance to the metals occurring on the waste. In higher plants, the ability to accumulate the elements and survive on mine soils and mine relics containing toxic quantities of various heavy metals occurs sporadically throughout different genera (Peterson, 1971). Hence it can be justified that the plant species investigated must have developed a tolerance mechanism, which enables them to survive on these contaminated soils (Bell and Donnelly, 2006). Using these accumulator plants, re-vegetation programmes can intensified to rehabilitate the contaminated areas in Bandalamottu mining area.