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GEO-BIOLOGICAL INDICATORS: A BRIEF OVERVIEW

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ABASTRACT

Many organisms (Plants or animals) provide by their presence or abundance an assessment of the quality of the habitat and provide insight what is occurring below the surface or above the surface. They are called geo-biological indicator species. Many of them characterize minerals in soils, called metallocoles or metallophytes. Many of the organisms are helpful in geo-biological mapping or prospecting. This paper briefly provide an overview on some of the indicator species.

Key-words: Geo-biological indicators, Geological mapping and prospecting, and Gold accumulation in plants.

INTRODUCTION

Genetically speaking, heredity determines the characteristics of the organisms. But heredity does not act in vacuum. It acts in conjunction with the environment that includes a multitude of factors. Accordingly organism is the measurement of the environment. After careful studies ecologists have determined that the presence/absence conditions and numerical strength of certain types of organisms may provide accurate information about the health of a certain ecosystem. The organisms, species, or even the communities that may serve as an index of the environmental conditions are referred to as biological or ecological indicators and the vegetation whose characteristics provide information useful in interpreting the geological phenomena are called geobotanical indicators. And if animal species are used for this propose, it is referred to as geo-zoological indicator. An indicator in short, is a sign or signal that relays a complex message. Environmental Protection Agency (EPA) of USA defines it as measure, an index of measures, or a model that characterizes an ecosystem or one of its critical components (http://epa.gov/bioindicators/html/abouthtml).

The concept of bio-indicators has great practical significance. Biological indicators are useful in many ways such as protection, reclamation and management of areas, detection, monitoring and mapping of air and water pollution, water purification, military purposes, nature conservation, geobotanical prospecting, biotic control, utilization of wastelands, ecosystem management and medical sciences. The Environmental Protection Agency (EPA) in USA, The United Nations Economic and Social Council, the United Nations Environment Programme and other agencies have adopted a number of biological variables which could be used periodically to assess pressures on the environment (Spellerberg, 1991). An indicator may reflect biological, chemical or physical attributes of ecological condition and primary use of an indicator may be to characterize current status of a system, and to track or predict significant check. With a foundation of diagnostic research an ecological indicator may be used to identify major ecosystem stress. (US EPA, 2002a). They can show problems either missed or underestimated in an ecosystem (US EPA-2002b).

Bio-indicators are reported to be of diverse nature; lower plants like phytoplanktons, diatoms, algae, and lichens, a host of higher plants, coelenterates, aquatic and terrestrial invertebrates, earthworms, bees, fish, snakes, birds, etc. The dominant species are considered to be better indicators, since they receive full impact of the habitat usually year by year (Weaver and Clements, 1938). The dominant plant community (ies) developing in a certain area(s) is considered to be more reliable indicators than mere individual plants. Moreover, large species are the better indicator species than smaller ones. However, due to some variability inherent amongst populations, the use of presence or absence of the organisms as indicators of the environmental conditions demands some caution. Genetic differentiation amongst some plant species, for instance, can lead to some populations being commonly associated with basic soils but in other parts of the species' range, populations may tolerate slightly acid conditions.

According to Spellerberg (1991) a bio-indicator species may be a sentinel, detector, and exploiter or accumulator type. Miners have long used the behaviour of canary, a sensitive sentinel bird in detection of methane. The detector species show a measurable response to environmental change by their behaviour, mortality or age-class structure, etc. Respiratory and cardiac activity of trout (*Salmon)* has been used in sophisticated and automated biological early warning systems to monitor water quality *(*Evans and Wallwork, 1988). Aztec Environmental

Control Ltd. devised a sophisticated water pollution monitoring system based on bio-sensing capabilities of a detector fish, *Gnathonremus petersi* (Elephant-nosed Mormyrid), which navigates and communicates by emitting sequences of pulses from an electric organ on its tail (Spellerberg, 1991). The exploiter type of bio-indicators, on the other hand, is abundant in polluted environment due to lack of competition as a result of the elimination of sensitive species. Accumulator species, as the name suggests, accumulate chemicals such as metals or oganochlorides, etc. in their bodies in measurable amounts e.g., *Anodonta* spp. accumulated Cadmium in concentration around twenty times higher while living in polluted water of River Thames (Leatherland and Burton, 1974). Bioaccumulation of mercury in 100,000-time greater concentration than in the water is reported by Pyers and Henderson (1997) in seal's body.

Some practical applications of the concept of bio-indicator species are given as under:

Indicators of Ground waters

Vitruvius who lived about the time of Christ wrote about ground water and called attention to the value of certain plants in locating water supplies (Meinzer, 1926). Pliny in first century AD quoted Vitruvius. Then German and French worked on ground water importance. Since that time, a host of publication appeared on ground water ecological characteristics and growth of phreatophytes (Coville, 1893; Cannon, 1911; 1914; 1923; Meinzer, 1926, 1927; Cannon, 1971, 1982; Hamblin, 1998; Verma, 2015; Huang *et al*., 2019; Šenfelder *et al.,* 2021). The dependence of certain species on groundwater in contrast to the ability of other species of desert to survive on rainfall was pointed out by Meinzer (1926, 1927). He gave the name phreatophytes to those plants that use water from the zone of water saturation, xerophytes to drought resistant plants and halophytes to salt resistant plants. *Prosopis juliflora, P. glandulosa, Chrysothamnus nauseosus, Atriplex canescens, Accia greggi, Populus sp. Tamarix aphylla, Salix sp., Eymus condensatus* and *Sarcobatus vermiculatus* are typical phreatophytic species. Such plants are also the indicators of the quality and the depth of the groundwater as evident by the root penetration and groundwater analysis. Khudyakov (1965) reported best quality water under associations with dominance of *Alopecurus pratensis, Agropyron pectiniforme* and *Stipa capillata*. Halophytes have been especially useful in locating the buried salt domes (Cannon, 1982). Table 1 describes the ground Water depths associated with some species or species associations.

Table.1. Ground water relations of some species.

S. No.	Plant species	Ground water depth (m)
1	*Allenrolfea occidentalis**	Near surface, sometimes deep
2	*Chrysothamnus graveolens **	Ground water depth: 0.6 – 5m
3	*Distichlis spicata **	Ground water depth : 3 - 4m
4	*Eragrostis obtusiflora**	Ground water depth: 5m
5	*Mesquite**	Less than 3m – 15 m.
6	*Pluchea sericea **	3-8 m
7	*Sporobolus airioides*, ***	2-12m
8	*Acacia indica –Prosopis cineraria-Salvadora oleioides ****	12-20m
9	*Acacia senegal – Anogeissus pendula ****	12-18m
10	*Capparis decidua*	12-20m
11	*Crotalaria burhia – Leptadenia pyrotechnica ****	6-20m
12	*Euphorbia caducifolia ****	12-18m
13	*Panicum turgidum Ziziphus complex ****	6-18m
14	*Prosopis cineraria – Ziziphus nummularia – Capparis decidua ****	6-18m
15	*P. turgidum – Calligonum polygonoides ****	6-18m
16	*Salvadora oleioides – C. decidua ****	6-12m
17	*Salvadora oleioides and Prosopis cineraria ****	10-20m
18	*Salvadora persica – Tamarix spp. ****	6m
19	*S. oleioides – Z. nummularia ****	18-28m

*, Meinzer (1927); **, Coville (1893), ***, Central arid zone research Institute (Jodhpur, India) as reported in https://old.amu.ac.in;

Indicators of Productivity of land

Forests serve as good indicators of productivity e.g., vegetative growth of *Quercus* species such as *Q. marilandica, Q. stellata)* is comparatively poor on lowland or sterile sandy soil than the normal soil in which they grow normally. Such soils have unbalanced fertility, pH below 5.1 or above 7.3 uncommon). P is limiting factor and K is typically limiting. Such soils may have *Pseudognaphalium obtusifolium, Rumex acetosilia, Diodia virginiana, Andropogon virginicus, Anthoxanthum odoratum, Leucanthemum vulgare, Panicum* spp., *Achillea millefolium*, etc. in US pasture of low fertility (Greg Brann – https:gregbrann.com. Cereal rye, Lespedezas and other grasses are associated with pasture soils which are deficient in nutrients like N_2, P, K, Ca, Mg, Fe and Zn. Compacted soils are low in Oxygen, have high soil bulk density, poor infiltration and increased run off. *Polygonum arenastrum, Juncus spp., Eleusine indica, Helenium capillifolium, Ranunculus, Rumex crispus* characterize such soils (Greg Brann-https:gregbrannan.Com).

Indicators of Climate

Plant communities characteristic of a particular area provide information regarding climate of the area. Evergreen forests indicate high rainfall in winter as well as in summer; sclerophyllous vegetation indicate heavy rainfall in winter and low during summer; grasslands indicate heavy rainfall during summer and low during winter; xerophytic vegetation is indicative of very low rain or no rain in the year. Climate change has influenced almost all ecosystems of the World. Climate – driven zooplankton shifts is known to cause large-scale decline in food quality for fish (Haneghan *et al.* (2023). Marine phenology (annual recurring life cycle events) can provide particularly sensitive indicators of climate change (Hughes, 2000; Krishnakumar, 2008). Changes in phytoplankton species composition has been used as global warming indicators by monitoring of warm water non-native species by Edwards and Richardson (2004). Temperature is probably the single most important physical variable structuring marine ecosystem (Richardson, 2008). Effect of thermal stress was studied in temperate water by Mallin *et al.* (1994) and in tropical coastal water by Poornima *et al.* (2005, 2006) due to thermal discharge of power plants in India.

Indicators of the soil characteristics

There exists close relationship between plant types and the soil characteristics of an area. The West Africans have long recognized good soil by the presence of the Gau tree (*Acacia albida)*, the Gaya grass (*Andropogon gayanus*) and also the Raon Antelope (*Hippotragus equinus*) (Zonneveld, 1983). Some useful plant indicators to the soils characteristics are outlined in Table 2.

Indicators of Fires

Some plants such as *Agrostis heimalis, Epilobium spicatum, Pinus contorta, Populus trematoides, Pteris aquilina and fungus Pyronema confluens* dominate in areas destructed by fires. In particular, *Pteridium* spp. indicates burnt and highly disturbed coniferous forests.

Indicators of Petroleum deposits

Some protozoans such as Fusilinds indicate petroleum deposits in the area (https:// old.amu.ac.in).

Indicators of Pollution

The sensitiveness of long-lived perennial organisms like lichens and mosses to air borne pollutants is well known. In case of lichens, pollutant such as SO_2 affects the algal component of the lichen and thus the symbiotic relationship of alga and fungus is broken down. Lichens have, therefore been employed as bio-indicator of air pollution for over more than a century (Hawksworth and Rose, 1976) specifically for levels of sulphur dioxide in air. Such use of lichens in N. America and Europe as detector, exploiter and accumulator type of indicator of air pollution is well described (Le Blanc and Sloover, 1970; Johnsen and Sochting, 1973; Pilegaard, 1978; Rose and Hawksworth, 1981). Such use of lichens may, however, be confounded due to factors such as microclimate, droughts and buffering effects caused by substrata (Skye, 1979).

An interesting example of monitoring and mapping air pollution involving the use of a mite, *Humerobates rostrolamellatus,* is that of Andre *et al.* (1982), where confounding effects of micro-climates are not involved. The method was simple. The adult mites collected from orchards were placed in vials and left at twenty-four pollution monitoring sites in Brussels. The mites were retrieved after a few weeks of exposure. The mortality contours of mites were found to be closely correlated with the contours of mean SO_2 level in air.

The aquatic plants like *Utricularia, Chara, Wolffia,* are reported to prefer to grow in polluted waters (Sharma, 1981). Bacteria like *Escherichia coli* also indicate water pollution. The presence of diatoms in water indicates its pollution by sewage. The movement of fish like *Catla catla, Labeo gonius, L. bata, L. rohita* and *Natopterus natopterus* moving away from the site indicates industrial pollution of water.

The insect group Ephemeroptera (Mayflies) has aquatic larvae. Its species, with few exceptions, are generally intolerant to organic enrichment, and so they have been incorporated into programmes monitoring water quality (Hawkes, 1979). Caddisfly larvae (order Trichoptera), Dobsonfly larvae (Family Corydalidae), water penny Beetle larvae (Family Psephenidae), Riffle Beetles (Family Elmidae) and Stonefly Nymphs (order Plecoptera) are other pollution sensitive insect taxa. Beetle larvae (order Coleoptera) Damselfly Nymphs (order Odonata), Dragonfly Nymphs (order Odonata), Sends (order Amphipoda), Crayfish (order Decapoda), Clams (class Bivalvia (Pelecypoda)), Cranefly larvae (family Tipulidae) are moderately tolerant to pollution and taxa such as Aquatic worms (phylum Annelida and others), Pouch snails (class Gastropoda), Blackfly larvae (family Simuliidae), Leeches (class Thirudinea), and midge larvae (family Chironomidae) dwell polluted water as they are pollutant tolerant organisms. Their presence in water immediately indicates high degree of pollution. (US, EPA-2002c).

In coastal areas, the increase of *Cerithium* and decrease of *Perna viridis* (green mussel, a bivalve) in back water environment indicates sewage and oil pollution. (Personal communication: Sohail Aslam, Govt. National College, Karachi).

According to Buikema *et al.* (1982) and some other workers, the desirable properties of detector and exploiter type of bio-indicators in connection with monitoring pollution are as follows:

1) The organism should be of narrow ecological amplitude and preferably long-lived so that different age classes may be available. Stenothermal or stenohaline organisms are better indicators than eurythermal or euryhaline ones.
2) The organism should be sedentary or of limited dispersal. The plants are sedentary and easy to sample. It is probably the reason that plants have widely been employed as detector and exploiter type of bio-indicator.
3) The organism should be easy to sample. A dominant species would be an added advantage.
4) Unless mortality of the bio-indicator is employed as a bio-variable, the accumulation of pollutant (s) should not be toxic enough to kill the indicator species.
5) Hairs, shells, bones and internal organs such as liver, kidneys and muscles from a wide range of higher animal indicator species have been used in biological monitoring of environmental contaminants. The work of Sawicka-kapusta (1979) indicated that Roe deer antlers can be used as bio-indicators of environmental pollution with metals such as Pb, Cd and Cr.

It follows from the above that the concept of biological indicators is a useful one. With respect to the pollution it may help us to develop bio-criteria in relation to our ecological systems; to assess, conserve or enhance their health. Biological assessment of our terrestrial and aquatic ecosystems should provide a basis for determining their ecological potential and to measure success in achieving the potential under a management action. Researches pertaining to the biological integrity of systems *(Sensu* Kar and Dudley, 1981*)* shall, of course, be pre-requisite to such goals as:

i) Protecting and restoring ecosystems,
ii) determining what to monitor and for what cause,
iii) how to monitor,
iv) how to interpret what is obtained as a result of monitoring
v) stress-identifying, prioritizing and its removal,
vi) assessing the effectiveness of management action and defining future plans with respect to an ecosystem (See http://www.epa. gov/ost/biocriteria/basics/index.html).

There has been much research on the nature of bio-indicators but the work done on the role of bio-indicators in pollution monitoring programmes is somewhat limited due to disappointing amount of research made in the field of pollution monitoring. The reason to it is apparently cheaper methods of pollution detection by sophisticated technology. Machines may be more reliable than biological organisms. Also great care is needed to interpret technical data on physiology, behaviour or ecology of biological indicators. The cause and effect relations are never easy to confirm without good research (Spellerberg, 1991).

Indicators of Overgrazing

Overgrazing results in definite modifications of grassland. *Weaver and Clements (1929)* cites the results of studies of red prairies of Texas by Smith (1899). Before overgrazing these ranges were generally composed of *Andropogon.* After pasturing and subsequent trampling and hardening of soil, *Aristida* spread over the whole country. Further with overstocking and trampling *Hilaria* and *Buchloe* became the prominent species. It was concluded by the studies that occurrence of any one of these as dominant is to an extent index of state of land deterioration reached. Overgrazed soils lack plant cover. The effects of overgrazing are similar to that due to compactness of the soil. Population of weeds is high. Such species as *Solanum* spp., *Helenium amarum, Amaranthus spinosus, Cyanodon dactylon, Poa annua, Poa pratensis, Digitaria ischaemum, Vernonia (V. gigantea*) is predominant (Https:gregbrann.Com). Callaway *et al.* (2005) found that *Cirsium obalatum* and *Veratrum lobelianum*, two large native perennial herbs that invade after heavy grazing in subalpine meadows of Caucasus Mountains of Georgia, had strong facilitative effects on communities through their indirect effects on livestock herbivores. These unpalatable invaders protect tasty plants from herbivores and increase plant diversity of the meadows. A host of publications have appeared regarding effects of grazing on grasslands or pastures in various countries (Harikawa and Itow, 1958; Emmerson and Facelli, 1996; Breceda et al., 2005; Callaway *et al.,* 2005; Wang, Z. *et al.,* 2017, 2021; Wang, Y. *et al.,* 2019; Kamali *et al.,* 2022). Cosgrave *et al.* (2001) have suggested a score sheet to evaluate pasture conditions (Evaluation of current pasture productivity and the stability of its communities, soil, water resources) and identify what treatment needs, if any, are required to improve a pasture's productivity and protect soil, water and air quality.

Table 2. Some useful phytoindicators of soil types. *****

Plant species	Soil Characteristics
Deep-rooted *Psoralea Grass, Andropogon scoparium*	Sandy, Sandy loam type of soil
Rumex acetosella	Acid grassland soil
Spermacoce stricta	Iron- rich soil
Chrozophora rottleri	Low lying land
Heliotropium supinum	Low lying land
P*olygonum plebejum, Chrozophora rottleri*	Low lying land
Cassia obtusifolia	Properly aerated soil
Geranium sp.	Properly aerated soil
Impatiens sp.	Properly aerated soil
Saccharum spontaneum	Poorly drained soil
Capparis spinosa,	Intensely eroded soil
Carissa spinarum	Intensely eroded soil
Artemisia tridentale, Kochia restita, Salicornia & several halophytes	Saline soils
Acacia senegal,	Calcarious soil
Euphorbia caducifolia	Calcarious soil
Gossypium stocksii	Calcarious soil
Rhazya stricta	Calcarious soil
Vernonia cinerescens	Calcarious soil
Kicxia ramossissima	Calcarious soil
Pullicaria hookerii	Calcarious soil
Pines	Podsolic soil
Ericaceous plants	Podsolic soil
Quercus durata	Serpentine soil
Caeonothus jepsoni	Serpentine soil
Garrya congdoni	Serpentine soil
Cupressus sargentii	Serpentine
Urtica dioica, Alnus rubra, Viola glabelle, Picea sitenensis, Malnus fusca, Lonicera involucrate, Clinhtonia uniflora, Coptis asplenifolia Rubus pedatus, Vaccinium spp.	Nitrogen – rich soil
Chamaenerion angustifolium	Disturbed soil
Campanula sp.	Alkaline soil
Pteridium aquifolium	Low K, Low P, acidic soil
Anthemis arvensis	Low K, Wet soil, alkaline soil
Stellaria media	High fertility, cultivated soil
Trifolium sp.	Low Nitrogen, uncultivated soil
Medicago lupulina	Low Nitrogen, Alkaline soil
Trifolium pretense	Low P
Fumeria officinalis	High K
Erigeron Canadensis, Convolvulus sepium, Malva moschata, Carex spp., *Juncus* spp. *Eleocharis* spp. *Diodia virginiana, Phlaris*	Wet soil, which are low in O_2. Poor pore spaces affect the soil structure.

arundinacea.	
Chamomila pecutila	Hard pan, acid soil
Potentilla argentea	Acid soil
Argemone Mexicana	Flooded & recently disturbed soils
Pinus and Juniperus	Uranium rich soils
Saccharum spontaneum	Poorly drained soils
Shorea robusta, Cassia obtusifolia, Geranium spp., *Impatiens* sp.	Poorly aerated soils
Salvadora oleioides	High Ca and Boron – good soil for crops
Ziziphus nummularia	Good soil for agriculture
Peganum hermala	Nitrogen rich soil. Good for agriculture
Prosopis cineraria	Good soil for irrigated crops
Lippia nodiflora, Rumex spp.	NO_3 rich soils
Escherichia coli	Water pollution
High population of diatoms	Water pollution with sewage
Migration of catla catla , Labeo gonius, Notoperus notoparus	Industrial pollution in water
Grass *Narenga porphysocoma (*a sand binder*)*	Indicate that *Shorea robustus* may be grown in the soil.
Monotropa, Neoltia and some mushrooms	High humus content in soil.

*, Source: (Sharma, 1981; Khan, 1987, 1994, Khan and Ahmad, 1992; Khan *et al.*, 2003; (Shaukat *et. al.*, 1981; Whittaker, 1954; Spellberg, 1991; Methewson *et al.*, 2003); http://old.amu.ac.in (100010921.pdf).

**, A large number of halophytic species are known, which vary with respect to their distribution. A few widely known halophytes of Pakistan are: *Aeluropus lagopoides, A. macrostachys, A. littoralis, Arthrocnemum indicum, Atriplex griffithii, Bienertia cycloptera, Cressa cretica, Ennicostoma hyssopifolium, Halocnemum strobilaceum, Halopyrum mucronatum, Launaea resedifolia, Halostachys belangerana, Helopeplis perfoliata, Heliotropium curassavicum, Limonium stocksii, Salsola baryosma, Salsola drummondii = Seidlitzia drummondii, Suaeda fruticosa, S. nudiflora, S. vermiculata, S. monoica, Urochondra setulosa, Sporobolus arabicus, S. virginicus, Salvadora persica, Tamarix aphylla, T. indica,* etc.

***, Source: www.oregonbd.org/class/weeds.htm

Generally, the predominance of annual weeds and short-lived unpalatable perennials indicate severe overgrazing. *Amaranthus, Chenopodium* and *Polygonum, Sophia, Bromus spp., Aristida spp.*, etc. are reported to grow better in overgrazed areas. A frequent visit to an area by grazing animals also indicates intense grazing. In forest and scrub the signs of overgrazing may consist of damage to tree reproduction.

Geologic Mapping

Variations in plant species are often useful in mapping the distribution of specific rock formations. A significant relationship between vegetation and the underlying rock types are commonly evident in arid regions. For example, *Euphorbia caducifolia* Haines, a cactoid shrub, which is abundant on the calcarious foothill and mountain slopes of Sindh and Balochistan, is opined to provide a way of identifying Pleistocene or older materials. It is found only on more indurated, stabilized materials. It grows on the cones along the base of the Pleistocene cliffs, but very rarely occurs on the recent coastal or central alluvial plains of Lasbela (Snead, 1966). Such studies of vegetation as floristic composition of the vegetal cover, pattern of plant distribution, and the presence of deformities or growth anomalies resulting from underlying soil conditions as evident from aerial and ground surveys have been useful to mark the location of buried faults or formations contacts (Cannon, 1982).

Geo-biological Prospecting

One of the very interesting facet of biogeography is the use of plants as indices of mineral deposits (Cole, 1964). Agricola (1556) was one of the first to recognize that plants growing over mineralization can have a different species composition and morphology than those growing on non-mineralized substrates. A few year later, Thalius (1588) observed the presence of the mineral indicator plant *Minuartia verna*, an invariable colonizer of zinc / lead mineralization in the Harz Region of Germany.

The use of plant form, its distribution and anomalies in its growth in prospecting the ore deposits is called geobotanical prospecting (Cannon, 1982). Cole (1964) emphasized that - " ... an anomalous and specialized plant community or lode assemblage may spotlight areas where high metal concentration in the soil emanating from ore bodies create conditions which are too toxic for the species of the background vegetation which therefore cuts out.

The species of the assemblage [community] may be metal accumulators able to thrive only in metal rich soils or they may be metal indicators able to resist toxic conditions by non-absorption of the metals. They make indicate one specific metal and a given range of metal content or they may be indicative of several. Usually their distribution is related to the dispersion pattern in the surface soil but deep- rooting species may reveal anomalies where bedrock is masked by overburden. Biochemical analysis of both widely distributed and indicator species may detect and delineate metal anomalies." Plants provide an added advantage in prospecting (third dimensional advantage) because roots may extend through many meters of superficial material for contact with mineralized water or rock (Cannon., 1982). Brooks *et.al.* (1995) have reviewed the subject of geo-botany in mineral exploration.

Application of plant indicators has been employed in location of over 70 different minerals. Erdman and Olson (1985) have reported the use of indicator plants in prospecting for gold. Some useful indicator plant species in mineral prospecting of Cu, Zn, Co, Ni, Si and U are outlined in Table 3. As early as 1880s, R.W. Raymond described *Viola lutea v. calamineria* to be restricted entirely to the zinc-rich soils of Aachen in Westphalia. The occurrence was so consistent that successful mining operations were undertaken in the areas of this indicator species. In the Pyrenees, *Armeria halleri* and *Hutchinsia alpina* occur singly or together at several places, all of which have indication of zinc mineralization. These indicators have been used in relocating the lost mines and to discover the new areas of mineralization.

Table 3. Some phyto-indicators employed in mineral prospecting.*****

Plant Species	**Ore Element**	**Area**
Salsola nitrata, Eurotia cerutoides	Boron	-
Silene cobalticola	Cobalt	Congo
Eriogonum ovalifolium v. ovailifolium	Cu	Montana
Gypsophila patrinii	Cu	Soviet Union
Polycarpaea spirostylis	Cu	Australia
Tephrosia sp.	Cu	Australia
Elscholtzia haichowensis	Cu	China
Haumaniastrum robertii	Cu	Katanga
H. katangense	Cu	Zaire / Zambia
Becium hambelei	Cu	Sweden
Merceya ligulata	Cu	Sweden
Mielichhoferia macrocarpa	Cu	Sweden / Alaska
Viscaria alpina	Cu	Norway
Gymnolea acutiloba	Cu	USSR
Damara ovate, Dacrydium caledonicum	Fe	Scotland
Stellaria setacea	Hg rich soils	Spain
Lycium , Juncus, Thalictrum	Lithium	-
Armeria maritima	Zn	Wales
A. halleri	Zn	Pyrenees
Hutchinsia alpina	Zn	Pyrenees
Thalaspi alpestre v. calaminare	Zn	Aachen
Stellaria verna	Zn	Aachen
Viola lutea v. calamineria	Zn	Aachen
Silene cobalticola	Co	Katanga
Crotalaria cobalticola	Co	Katanga
Dicoma niccolifera	Ni	Zambia
Hybanthus caledonicus	Ni	New Caledonia
Astragalus bisulcatus	Se	USA
A. pattersoni	Se & U	USA
A. garbancillus	Se & U	Peru
Astragalus, Neptunia amplexicaulis, Stanleya pinnata, Onopsis condensator	Se	-
Lychnis alpina	Ni	Sweden
Mechovia grandiflora	Mn	Katanga
Vallozia candida	Diamond	Brazil
Equisetum arvense, Lonicera confuse, Papever, libonofoliun, Alpinia speciosa, Thuja spp.	Gold	-
Eriogonium ovalifolium	Silver in soil	USA

Sources: Cannon (1982) and http://old.amu.ac.in (100010921.pdf).

Many of the strongly mineralized areas are entirely bare or have reduced flora. Mineral prospecting in such areas for lead in Norway and copper in USA, Australia and Zambia has been done with the help of adventitious herbaceous highly metal-tolerant species forming ground cover in the treeless landscape. Herbaceous *Eriogonum ovalifolium v. ovalifolium* is also characteristic of high copper containing soils in treeless area of Montana.

Indeed as early as 1889, Bailey reported that the occurrence of *Polycarpea spyrostylis* was of a great success in prospecting for copper in Australia (Cannon, 1982). Similarly, *Gypsophila patrinii* in Soviet Union, associated with soils containing up to 1% Copper where as copper was not more than 10 ppm in soils devoid of this species. Large reserves of Cu ore were located on the basis of profuse growth of *Becium homblei* (*Ocimum homblei)* in Rhodesia (now Zimbabwe) by Rhodesian Selection Trust in 1949. *Becium hambleia* associated with soils containing not less than 100 micro gram per gram (ppm) copper. That is why it was popularly referred to as “copper flower.”

The study of collection localities of herbarium specimen of some species of mosses of genus *Merceya* and *Meilichhoferia*, generally called copper mosses, was helpful in discovering three new copper deposits in Sweden (Cannon, 1971; 1982). The tropical African “Copper Flower”, *Haumaniastrum katangense*, is known to hyperaccumulate copper (> 1000 ppm in drier tissues). The distribution of this plant has been used by exploration geo-botanists to delineate several mineralized areas in Zaire and Zambia Paton et al, 1996). In a collaborative study with Professor R.R. Brooks of Massey University, New Zealand, herbarium samples of this plant collected from its entire distribution area were analyzed for Cu accumulation, it was reported that although it may not be rated as universal indicator of Cu, but still has value as a geo-botanical indicator of Cu and Co in the Shaban Cu arc of S. Zaire (Paton, 1997; www.rbgkew.org.uk/kewscientists/ks_oct96/collections.html Or see Kew Scientists (1997). Issue 10; Royal Bot. Gardens, Kew, UK). Eid *et al.* (2012) reported *Typha domingensis* (Pers.) Poir. Ex Steud to uptake Ag, Co, and Ni in lake Burullus and ranked it as contamination indicator.

Some group of plants requires selenium in such quantities that plants become toxic to livestock. Such plants are universal indicators of selenium. The most widely known selenium indicator species belong to genera *Astragalus* and *Stanleya.* Since selenium commonly accompanies uranium in Carnotite deposits of Colorado Plateau, in this region selenium prospecting also indicated for uranium. *Astragalus pattersonii* is the most useful species in this respect.

A comparison of plant data with drilling data in the yellow Cat district showed plant grew over 81% of the ore that occurred within 9.6 m of the surface (Cannon, 1982). The work of Colin E. Dunn has largely centered on gold and uranium (Brooks, 1998). He was responsible for discovery of very large uranium deposits situated about 150 m below the surface at Wollaston in Northern Saskatchewan. The surface soil gave no indication but twigs of *Picea marina* delineated the deposit very accurately. In Canada and U.S.A. about US $ 1 million is spent annually for analyzing gold in plant material. Dr. Dunn has been actively, engaged in collecting and analyzing Conifers’ growing tips for this purpose.

Karipatta (curry patta*; Murraya koenigi* (L.) Spreng) has been used as a geo-botanical guide to delineate manganese deposits in North Kanara district of Karnataka, India. This plant with dark green leaves is likely to indicate manganese ore deposits, whereas with light green leaves can show the presence of iron ore deposits (Dr. H. Kariyanna, GSI, Bangalore Division – www. blonnet.com/businessline/ 2001/08/16/ 14163406.htm).

The use of dogs for mineral prospecting was proposed by Orlov *et al.*, (1969), also later developed in Finnoscandia and Canada - with their keen sense of smelling dogs can detect Sulphide minerals due to characteristic sulphur smell emanating from the deposits (see Brooks, 1998). Dunn (1990) has shown that various seaweeds could be used to detect a zone of copper/Gold mineralization on the shores of Texada Island, British Columbia. Rabbits and ants have been used in South Australia to locate Kimberlite occurrences (D.M. Colhester- 1999- http: //www.austgem.gil.com.au/ab20-6.html).

Termites as geo-zoological indicators of gold

Termites are soil miners, soil engineers and soil architect. Study of termite mounds in tropics has been an important tool in the exploration of gold in Zimbabwe and for other minerals (Cr, Cu and Pb) in other countries (West, 1965, 1970).Various species of termites build impressive nests and mounds in Africa, Asia, Australia and S. America. Mound samples can sometimes be used in prospecting of various metals deposits including tin, silver, gold, uranium, and diamonds. Termites go deep down to obtain wet clay and bring up indicator minerals of the ore. (West, 1970); T.G. Myles, N.W. Milner and J. Tilslely- www.utoroanto.ca/forest/termite/goldpage.htm). As a result of West’s work in Zimbabwe several gold anomalies have been discovered, the first of these was very appropriately called “Termite Mine”. According to Prasad *et al.* (1987) gold concentration at 19 sites termite mounds of Ramagiri Gold Field (India) ranged from < 4.0 ppb to 1040 ppb. They concluded that their study confirmed Varahamihira observation made as early as the 6th century AD (505-587AD) – pointed out that termites mound is an important bio-indicator of economically important mineral deposits in tropical soil generally covered with thick soil mantle.

Accumulation of gold in plants

Gold is widely distributed in the biosphere. It was detected in plant tissues as early as 1900 (Lungwitz, 1900). Various organisms display ability to accumulate gold (Korobushkina *et al.* (1983). They reported that Sea urchins, Sea stars, and Crabs may accumulate gold. Thiocyanate containing umbelliferae (Mossnam *et al.,* 1999), *Typha* (Boyle, 1979), *Equisetum pallustre* (Babricka, 1943), *Mairreana* species (Lintern, *et al.*, 1997), Bark of *Eucalyptus* spp. (Arne *et al.*, 1999) and Some fungi of genus *Penicillium* (Boyle, 1979) may also accumulate gold differentially. In her geo-microbiological method of prospecting Parduhn (1985, 1991, 1995 - see review of Reith (2003) have used cultures of *Bacillus cereus* for gold exploration in desert terrain where conventional methods are of limited effectiveness due to leached soil or deposit located under a thick over burden. Warren and Delavault (1950) reported on the gold contents of both deciduous and evergreen trees of British Columbia. They were reported to carry between 15 and 25 ppb, and *Equisetum* sp. carrying as much as 75 ppb. Mountain *Phacelia seriosa* was reported to accumulate 10 to 15 times its normal quota of gold when growing in gold enriched area (Warren, 1979). Girling *et al.* (1979) mentioned following plants to accumulate gold - *Phacelia sericea* (deep rooted perennial), *Oxytropis campestris* (Late yellow locoweed) var. *gracilis* (deep rooted), *Sedum lanceolatum* (stone crop) shallow root fleshy succulent, *Cerastium arvense* 6.4 ppb, *Polemonium pulcherrinum* 2.5 ppb, *Arctostaphylos uva-uvsi* 2.5 ppb, *Catileja miniata* 2.3 ppb, *Dryas octopetala* 1.8 ppb and *Lupinas latifolia* 1.7 ppb

Transects studied at Watson Bar in the Stirrup Creek region of Southern British Colombia, Canada led to the discovery of *Pinus contorta* to accumulate gold (0.7 ppb) by Shewry and Peterson, 1976). The accumulation of gold by plants is found to associate with the accumulation of Arsenic also. Recently, Vural (2017) reported that plant parts (roots, stem-leaves and flowers) of *Helichrysum arenarium* from Gümüshane, NE Turkey accumulated Au and Ag in differential proportion (Table 4) with significant variation in elements with organ types. The plant, however, had elevated levels of gold and silver – gold in stem-leaves whereas the silver accumulated in roots.

Table 4. Gold and silver content (ppb) in *Helichrysum arenarium* (Vural, 2017).

Parameters	Root		Stem-leaves		Flower	
	Ag	Au	Ag	Au	Ag	Au
N	34	34	34	34	16	33
Mean	16.24	1.77	8.50	4.39	4.0	2.82
SE	1.48	0.19	1.02	1.13	0.7	0.52
Minimum	4.0	0.4	2	0.20	2	0.3
Maximum	47	5.8	36	32.4	13	14.6
Variance	74.61	1.16	35.29	43.41	7.87	8.0
CV (%)	159.4	90.40	415.2	988.8	19.68	286.7

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