Vertika Shukla · Narendra Kumar
Editors

Environmental Concerns and Sustainable Development

Volume 2: Biodiversity, Soil and Waste Management

Springer

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ISBN 978-981-13-6357-3 ISBN 978-981-13-6358-0 (eBook)
https://doi.org/10.1007/978-981-13-6358-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

During the last two centuries, most parts of the world have witnessed significant depletion in natural resources, due to increasing urbanization and industrialization. Major drawback associated with rapid/unplanned urbanization and industrialization involves loss of biodiversity and generation of different types of hazardous toxic wastes to the ecosystem, while with the population rise, demand for food has resulted in over-exploitation of soil for agricultural purposes. Recent extreme climatic events have grabbed considerable attention of the scientific fraternity regarding conservation of natural resources.

Conservation is the protection, preservation, management or restoration of natural resources such as forests and water, which involves integrated perspective from in situ to ex situ conservation strategies involving interdisciplinary approaches. Forest canopies support about 40% of extant species, of which 10% are predicted to be canopy confined. The epiphytic environment represents a unique habitat, which contains a multitude of microniches.

The present book *Environmental Concerns and Sustainable Development: Biodiversity, Soil and Waste Management* is the compilation of topics contributed by experts of their respective fields. The book intends to address the environmental issues to generate the information on various aspects of biodiversity, soil conservation and waste management primarily important for developing conservation and management strategies.

I congratulate the editors for their endeavour for bringing out this comprehensive compilation on environmental aspects, relevant to ensure sustainable development.

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Preface

Natural and human-induced adverse environmental factors pose a threat to the continuity of the ecosystem equilibrium. Hemerobic events, such as a rapid climate change, should be taken into account while framing environmental protection strategies.

The decline in biodiversity is largely the result of the rise in the global population, rapid industrialization, indiscriminate deforestation, overexploitation of natural resources, pollution, and rapid change in global climate. Therefore, it is of utmost importance that plant biodiversity be preserved including angiosperms and lower plant groups to provide future structural diversity and lead compounds for the sustainable development of human civilization at large.

The study of floristic diversity plays a crucial role to understand plant community structure and function. The study of plant community dynamics and species diversity is an important aspect of forest ecology, which entails the contribution of various species in determining the structure of specific habitat type. To generate the information on diversity and distribution of tree and shrub species is of primary importance for developing the conservation and management strategies.

Biodiversity conservation becomes even more important for developing nations, where well-planned bioprospection coupled with nondestructive commercialization could help in the conservation of biodiversity. According to a recent World Health Organization (WHO) report, around 80% of the global population still relies on medicinal plants for providing drugs. It is interesting to note that the ethnomedicinal uses of plants is one of the most successful criteria used by the pharmaceutical industry in finding new therapeutic agents for the various fields of biomedicine.

With increasing food demand and hazards associated with conventional techniques of synthetic fertilizers, designing the blueprint of next green revolution requires the application of effective and sustainable inoculants, which enhance the yield of plants ensuring the decorum of sustainability. Soil microbes play a crucial role in plant growth promotion and also in stress management. Several bacterial, fungal-based inoculants along with genetically modified organisms have been discussed as key players of future green revolution.

Sodic soil is an important problem that affects soil quality. Sodic conditions are expected to adversely affect soil productivity because these conditions lead to poor ventilation, limited root development, and increased root diseases.

Soil formation is facilitated by lichens and mosses capturing organic residues such as dust coming with the wind, plant fibers, seeds, dead insects, and animal residues on rocks. Biodeterioration (biological weathering) of stone monuments is one of the main interests of researchers working on the conservation of cultural heritage. The most particular biological agents of deterioration on stone surfaces in nature and also on stone monuments and works of art are lichens, mosses, algae, fungi, bacteria, and other microorganisms.

Improper waste management leads to environmental pollution and ultimately to diseases. Waste is classified into five broad categories including solid, industrial, plastic, e-waste, and biomedical wastes. Each class requires specific approach for management, environmental protection, and sustainable development. Organic waste recycling can bring tremendous benefits to crop management and soil conservation with clean environmental development.

With the increasing demand of electronic equipment by the rapidly growing digital population, the problem of e-waste and remediation are gaining attention. A proper management system for e-waste is required to be developed along with strict legal framework for industries and consumers.

The process of upcycling the agricultural waste into an efficient and a multipollutant adsorbing material is an ecosustainable approach of agricultural waste disposal. Adsorbents made from agricultural waste support the "3R" (reduce, reuse, and recycle) rule of waste management strategy and prove to be efficient and revenue generating.

The present book will be beneficial for students, researchers, conservators, and policy-makers.

Lucknow, Uttar Pradesh, India Vertika Shukla
04-10-2018 Narendra Kumar

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Editors

Vertika Shukla holds an MSc in Organic Chemistry and PhD (2003) in Chemistry from HNB Garhwal University, Srinagar (Garhwal). Presently, she is teaching as an assistant professor of Integrated Applied Geology at Babasaheb Bhimrao Ambedkar (Central) University, Lucknow.

During her 17 years of research experience, she has been awarded three fellowships by the DST, New Delhi; two projects were pursued at the NBRI-CSIR and one at BBA (Central) University, Lucknow.

To date, she has published 63 scientific articles in prominent national and international journals, has authored one book (*Lichens to Biomonitor the Environment* (Springer)), and coedited the books *Recent Advances in Lichenology* (Springer) and *Plant Adaptation Strategies in Changing Environment* (Springer Nature).

Her areas of interest include secondary metabolite chemistry, interactions between lichen and the environment, and the role of lichen in the bioremediation of atmospheric fallouts.

Narendra Kumar has obtained his MSc and PhD in Environmental Science from Babasaheb Bhimrao Ambedkar (Central) University, Lucknow, India. An active researcher with 16 years of graduate teaching and research experience, Dr. Kumar began his academic career as a project fellow at the National Botanical Research Institute (NBRI-CSIR), Lucknow, India. In 2002, he joined the Department of Environmental Science, Institute of Bioscience and Biotechnology, CSJM University, Kanpur, India, as a lecturer. Dr. Kumar has been working as an assistant professor at Babasaheb Bhimrao Ambedkar University, Lucknow, since 2005. He has published more than 30 research papers and 10 book chapters with reputed national and international publishers.

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1 Threats and Conservation Strategies for Overlooked Organisms: The Case of Epiphytic Lichens

Paolo Giordani, Renato Benesperi, Elisabetta Bianchi, Paola Malaspina, and Juri Nascimbene

Abstract

In this chapter, the main ecological factors that characterize the epiphytic environment and which determine the composition of epiphytic communities have been described. In particular, emphasis has been made to focus on epiphytic lichens which, due to their ecophysiological characteristics, represent a set of highly specialized organisms that live in a delicate balance in this habitat. The main threats that affect their survival have been analysed along with the conservation actions that have been undertaken to ensure the maintenance of the populations of the most endangered species. Furthermore, some good practices are suggested that can guarantee greater success of future protection actions.

Keywords

Anthropogenic disturbances · Tree-dwelling organisms · Climate change · Forest management · Pollution

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_1

1.1 The Epiphytic Environment

The epiphytic environment represents a unique habitat, characterized by drastic conditions of abiotic factors that lead to a selection of specialized biotic communities. Although it develops apparently on a very small spatial scale, the epiphytic environment contains a multitude of microniches. The trunk base, the tree bole, and branches (Holien 1997; McCune et al. 2000; Lie et al. 2009) differentiate by time for colonization, physical properties, and microclimate and favour the colonization of a remarkable biodiversity (Ellis 2012).

Forest canopies support about 40% of existent species, of which 10% are predicted to be canopy specialists (Ozanne et al. 2003). Among obligate epiphytes, cryptogams (e.g. lichens and bryophytes) are dominant on tree bole and canopy elements in temperate and boreal forests (Ellis 2012), their occurrence varying considerably on different tree species (Liu et al. 2000) and in different ecosystems (Knops et al. 1996; Campbell and Fredeen 2007).

The abiotic factors in the epiphytic environment are controlled by both stand- and tree-scale variables. For example, the effect of stand-scale tree density, size, and canopy cover determines the humidity (Kantvilas and Minchin 1989) and light availability under the forest canopy (Jüriado et al. 2009). On single trees, canopy structure influences the amount of both direct and diffuse solar radiation down to the lower parts of tree bole (Fritz et al. 2009). Access to light may therefore explain vertical differences in the composition of epiphytic community along the trunk, by selecting species in relation to their shade adaptation (McCune et al. 2000; Normann et al. 2010).

Scarcity of water is probably the most important abiotic constraint in the epiphytic habitat. At a tree-level scale, water run-off is mediated by the structure of the canopy, the micromorphology of the bark (e.g. slope, fractures, pits, grooves), and the micro-patterns of shade. Apart from direct effect on run-off direction and intensity, the complexity of bark texture may control microclimatic gradients in moisture (Ranius et al. 2008) and correlates with bark water-holding capacity (Fritz et al. 2009). As an effect, together with light availability, local gradients of water affect fundamental functions of epiphytes, such as the dispersal of reproductive propagules, and consequently drive the biodiversity and the distribution patterns of epiphytic communities at micro-scale (During 1992). Epiphytes adapt to habitats where water supply is intermittent by means of several strategies, for example, poikilohydry (Zotz and Hietz 2001). Because of their particular ecophysiology, poikilohydric organisms (e.g. lichens and bryophytes) are able to survive desiccation, minimizing damages and being able to recover soon after rewetting (Proctor and Tuba 2002; Proctor et al. 2007).

Atmospheric water and stem flow also represent a considerable supply of nutrients by wet depositions for epiphytic organisms. Additionally, nutrients are also conveyed by means of dry depositions (e.g. dust), whose importance is more relevant in arid and semiarid environments, such as Mediterranean ecosystems (Loppi and Pirintsos 2000). Furthermore, the potential source of nutrients from the tree bark is minor but cannot be excluded: major differences in nutrient composition may occur on different types of bark.

The bioavailability of nutrients is affected by pH, which can vary among individual boles, as a function of tree age and size (Kuusinen 1994; Ellis and Coppins 2007; Fritz et al. 2009). However, the relationship between these latter factors and bark pH has not yet been fully clarified, and it seems to be hardly generalizable (Ellis 2012).

Additionally, other micromorphological and physical properties of the bark interactively characterize microniches in the epiphytic environment. The complexity of bark texture generally increases with tree age and size (Fritz et al. 2009), and this variation is particularly evident in some tree species (e.g. *Castanea sativa* or *Quercus ilex*). In turn, bark hardness determines the structural stability of the bark, being higher on stable bark surfaces than on exfoliating ones (Hyvärinen et al. 1992).

In the following paragraphs, it will be explained in detail how these characteristics of the epiphytic environment can influence the diversity, the composition, and the probability of survival of the epiphytic lichen communities and populations and how the knowledge of these factors is fundamental in order to plan effective conservation strategies.

1.2 The Biology of Epiphytic Lichens

Lichens represent a complex and unique symbiotic association between a fungal (the mycobiont) and a photosynthetic partner (the photobiont). Even though the nature of the symbiosis is widely debated (Spribille et al. 2016), it is generally accepted that all the partners gain benefits from the association. The photobiont is protected from intense sunlight and desiccation and receives highly efficient uptake of mineral nutrients by the lichen fungi. On the other hand, the mycobiont obtains sugars and in some cases organic nitrogen from the photosynthetic partner, thus being able to grow also in environments deficient in organic nutrients (Nash III 2008). Since it has been estimated that in the symbiosis the mycobiont biomass represents up to 90–95% of the entire lichen thallus (Hill 2001), lichens are traditionally classified as a lifeform of fungi. In a taxonomic perspective, the fungal partners are mostly Ascomycota (98%); the others belong to the Basidiomycota (0.2%) and to the Deuteromycotina (8%) (Honegger 1991). The most frequent photobionts are represented by the genera *Trebouxia*, *Trentepohlia* and *Nostoc*. The genera *Trebouxia* and *Trentepohlia* have a eukaryotic structure and belong to the green algae (sometimes referred to as "phycobionts", 90% of lichens), while the genus *Nostoc* belongs to the prokaryotic cyanobacteria (called "cyanobionts", 10% of lichens) (Nash III 2008).

In the lichen association, most mycobionts are assumed to have an obligate relationship to lichenization. Differently, several photobiont genera, such as *Nostoc* and *Trentepohlia*, occur commonly both in lichenized and free-living states, whereas the green alga *Trebouxia*, which occurs in approximately 20% of all lichens, has rarely been found free-living.

The lichen thallus is determined by the fungus hyphae containing the photobiont population and usually consists of layers differing in thickness (heteromerous thallus) (Jahns 1988). The peripheral cortical layers (upper and lower cortex), which consist of compact hyphae, are involved in the defence, protection, shielding, and mechanical stabilization processes of the thallus (Jahns 1988), while the medulla is a system of hyphae involved in contact with the cells of the photobiont, in the transfer of water and solutes and in the maintenance of a system for the circulation of the air. The algae are often located in a well-defined layer (the algal layer) placed in the medulla, below the upper cortex. Some lichens, such as *Collema*, which have *Nostoc* as a photobiont, do not form a stratified thallus. In this case, fungal hyphae and photobiont cells form a homogeneous and undifferentiated twine (homoiomerous thallus).

There are three main types of growth forms: crustose, foliose, and fruticose. Crustose lichens generally grow closely attached to the substrate and lack a lower cortex. Foliose thalli have an upper and lower cortex and an algal and medulla layer and are loosely attached to the substrate by structures called rhizine. Fruticose lichens show a three-dimensional development; they have a little contact with the substrate and a great contact with the air, which makes it more exposed to atmospheric agents. They could be upright or hanging, round or flat, and often highly branched.

Based on the photobiont composition, some cyanolichens have been traditionally divided into two groups: bipartite and tripartite species. Bipartite cyanolichens, such as Peltigerales, present a stable symbiosis with one type of cyanobiont, which can be host in a defined layer below the upper cortex, or not, as in the case of gelatinous lichens that have non-stratified thalli. In the tripartite lichens, such as Lecanorales, one lichenized fungus associates simultaneously with both green algal and cyanobacterial symbionts. These types of cyanolichens mainly include forms in which the green alga symbiont occupies the photobiont layer, whereas the cyanobionts are confined in specific structures called cephalodia (Rikkinen 2015).

In contrast to higher plants, lichens are poikilohydric organisms, whose water status varies passively with surrounding environmental conditions. Lacking organs for active water uptake, gas exchange regulatory structures, and protective tissues, they absorb water, nutritive substances, and gases from the atmosphere over their entire thallus surfaces. Thus, they can tolerate prolonged periods of dehydration, and, as soon as the water becomes available again, they can recover the normal metabolic processes (Lange et al. 2001). Chlorolichens with trebouxioid algae as photobionts become metabolically active not only in the presence of rain events or dew but also when exposed to high levels of air humidity. In contrast, cyanolichens require direct exposure to liquid water. The overall structures of the lichen thallus influence the ability to retain water in different amounts and for different periods: thick lichens generally need a relatively long time to fill their internal water storage, but they can also retain it for longer periods after hydration events.

The steady relationship between the photobiont and the mycobiont led to the formation of peculiar organisms provided by high degree of organization and with peculiar features not found in the two separate partners. In the lichen thalli, the algal cells lose their sexual reproduction capacity and reproduce only asexually. The dispersal of the photobiont in the environment is guaranteed, simultaneously to the mycobiont, by the production of vegetative propagules: isidia and soredia. Isidia are corticated thalline protuberances, variable in size and shape, particularly frequent in foliose and fruticose lichens, being rare in crustose species. Contrary to isidia, soredia are never corticated; they consist of a mass of algae cells held by fungal ifae. They have a powdery or grainy appearance and may be present widely in the thallus or only in localized areas. On the other hand, the sexual reproduction interests only the fungal partner and occurs through the dispersion of spores produced within the fruit bodies (apothecia or perithecia). These structures have a layer, called hymenium, composed by asci (fertile hyphae containing the spores) and the paraphyses (sterile hyphae supporting the spores). The apothecia, varying in colour and size, are dispersed throughout the thallus surface or are located on lobes or at the ends of the podetia. They are shaped like a flat, concave, or convex disk and generally have a central disk delimited by a more or less thickened margin.

The close relationship between the fungal partner (the mycobiont) and the photosynthetic partner (the photobiont) results in their ability to survive in a wide range of habitats, where separately they would be rare or not occurring at all.

They occur in all terrestrial habitats, including freshwaters, from the tropics to polar regions, as well as in natural and managed habitats, where they colonize many types of substrata (Nash III 2008; Zedda and Rambold 2015). Additionally, they are physiologically adapted and chemically diverse to survive in extreme environmental condition and to resist to various abiotic and biotic environmental stresses (Upreti et al. 2015).

1.3 Ecosystem Functions

As reported in par. §1, the epiphytic environment is influenced by a set of abiotic factors, which are expected to interact among them and with the biotic component of the ecosystem, shaping the ecological niche of epiphytic organism communities. What would be the consequences of a massive loss of epiphytic lichen species for ecosystems? Can the conservation of these organisms have further objectives besides the preservation of diversity per se? Although higher plants usually account for a large majority of biomass, the relevance of epiphytic lichens in terrestrial ecosystems is not negligible. Epiphytes contribute to determine the functionality of the ecosystem itself by providing a number of ecological functions (Zedda and Rambold 2015; Asplund and Wardle 2017). Several lichen morphological and physiological traits are linked to specific functions (Deane-Coe and Stanton 2017) that mostly act at small-to-medium spatial scale (Cornelissen et al. 2007).

Being poikilohydric, epiphytic lichens have remarkable capacity of water retention that varies from species to species mainly in relation to their growth form, the type of photobiont, and the internal structure of the thallus. Epiphytic lichens are able to intercept water and release it gradually into the surrounding environment, making it available to other epiphytic organisms for a long period after precipitation events occurred. They also help regulate the amount and speed of the run-off along the trunk, affecting the hydration status of the underlying cortex. Porada et al. (2018) calculated that the total evaporation of free water from the forest canopy and soil surface increases by 61% when non-vascular vegetation is included. This resulted in a global rainfall interception flux that is 22% of the terrestrial evaporative flux.

Together with other epiphytic cryptogams, lichens considerably contribute to the carbon cycle and to the fixation of atmospheric nitrogen (Zedda and Rambold 2015). The relative importance of cryptogamic plant covers for CO_2 uptake is more relevant in tropical forests, whereas these organisms play a significant role for N_2 fixation in temperate and boreal forests (Elbert et al. 2012).

Similar to what has been observed for water retention, also the accumulation of some nitrogen compounds by epiphytic lichens increases their bioavailability. For example, it has been estimated that in forests with abundant biomass of epiphytic lichens, the flux rate of nutrients brought from through canopy depositions increases compared to that observed in forests with low lichen coverage (Ellis 2012).

The ecosystem functions provided by epiphytic lichens assume a greater relative importance on a small spatial scale. For example, lichens represent food resources for numerous animals (Zedda and Rambold 2015) and in some cases are non-secondary elements of their food chain. In other cases, lichen thalli are used as nesting or hunting areas for small invertebrates or birds. On an even more fine scale, the presence of secondary metabolites (lichen substances) can act as a deterrent for small herbivores and determines the composition of the intrathalline microbial communities.

As the spatial and temporal extension of ecosystem processes involving epiphytic lichens is still not completely clear, the loss of species could lead to a little predictable loss of functionality. The development of appropriate conservation policies should therefore take into account the scale of effect of these organisms and the possible interactions they undertake with the ecosystem as a whole.

1.4 Conservation Polices

In contrast with their considerable diversity and although lichens were severely threatened in many habitats, non-vascular epiphytes are scarcely represented in international lists for species protections.

For example, in the IUCN red list, at global level, only two lichen species were included, *Cladonia perforata* A. Evans and *Erioderma pedicellatum* (Hue), but only the latter is epiphytic. At European level a red list was proposed for macrolichens by Sérusiaux (1989), but in the Habitat Directive Natura 2000, one of the main European biodiversity conservation programmes, only lichens belonging to the terricolous genus *Cladonia* L. subgenus *Cladina* (Nyl.) Vain. was listed in the annex V. This annex includes species whose collection taking in the wild and exploitation maybe subjected to management measures. Furthermore, nor the Convention on Biological Diversity (CBD) neither the Global Strategy for Plant Conservation included epiphytic lichens in their programmes. This lack of information does not reflect the abundant recent literature indicating that many lichen epiphytic species are severely threatened in Europe. Probably the main reason of this is related to the difficulties in applying IUCN criteria for red listing to lichens (Scheidegger and Goward 2002). To palliate this state, many other red lists were published at national scale: Austria (Türk et al. 1999), Czech Republic (Liška et al. 2008), Estonia (Randlane et al. 2008), Germany (Wirth et al. 2011), Italy (Nascimbene et al. 2012), Norway (Timdal et al. 2006), Sweden (Thor et al. 2010), Switzerland (Scheidegger et al. 2002), and the Netherlands (Aptroot et al. 1998). However, lacking a legislative support for these red lists, their application in compliance with the IUCN criteria is problematic. As an example, the European LIFE Nature subprogramme has been oriented to species included in the Habitat Directive lists. Therefore, many other species of conservation concern not considered by the Directive (e.g. lichens) are often neglected in both conservation policy and financing (Cardoso 2012).

To overcome this obstacle, it would be necessary to implement regular updates and amendments to conservation lists. This process has to be supported by expanding knowledge on endangered species and providing a solid basis for monitoring lichen trends in the future and supporting science-based conservation actions.

1.5 Threats for Epiphytic Lichens

Epiphytic lichens are threatened by several factors acting at multiple spatial scales, from regional, as in the case of climate change, to landscape and local, as in the case of forest management. Usually, different factors simultaneously interplay, determining interactive effects that exacerbate the impact on epiphytic lichens. For example, forest management and land-use changes might interplay with the negative effects of air pollution (e.g. Geiser and Neitlich 2007) and climate change (e.g. Ellis et al. 2007) resulting in a severe decline of several sensitive species (e.g. Nascimbene and Tretiach 2009; Scheidegger and Werth 2009).

1.5.1 Climate Change

Although there are not yet sufficient direct evidences of the impact, recent works pointed out that climate change will seriously affect epiphytic lichens in the next decades. Epiphytic lichens are among the most sensitive organisms to climate and there is mounting evidence that changes in temperature and rainfall can severely affect epiphytic communities, leading to the local extinction of several species (e.g. Aragón et al. 2012) and biomass loss (Root et al. 2015). The poikilohydric nature of lichens provides the main basis for their sensitiveness to climate that directly controls relevant eco-physiological processes influencing growth rates and species distribution (Insarov and Schroeter 2002). In particular, their physiology is closely coupled to ambient temperature and moisture conditions (Green et al. 2008) that influence thallus water saturation and desiccation. Since lichens are photosynthetically active when wet, their growth rate, biomass accumulation and diversity are directly influenced by precipitation amount and regime (e.g. Giordani and Incerti 2008; Marini et al. 2011), even if other hydration sources may be important, such in the case of dew and air humidity (Gauslaa 2014). Increasing ambient temperature negatively affects lichens due to increased respiratory carbon losses (Schroeter et al. 2000). High temperatures influence the process of rewetting and thallus water content, inducing frequent and severe desiccation events that hinder photosynthetic activity of these poikilohydric organisms (Insarov and Schroeter 2002). These effects could be exacerbated by poor precipitations (interaction between water and energy climatic factors), predicting a stronger effect of temperature in dry areas (modified conjecture of Hawkins et al. 2003; see also Nascimbene et al. 2014a, b).

The response of lichens to climatic factors is mediated by different functional traits (e.g. photobiont type, growth form, thallus thickness) that determine the performance of the species under given environmental conditions (Bässler et al. 2015; Diaz and Cabido 2001; Ellis and Coppins 2006, 2010; Giordani et al. 2012; Gauslaa 2014; Marini et al. 2011; Nascimbene and Marini 2015; Rapai et al. 2012; van Herk et al. 2002). For example, contrasting responses can be expected between crustose trentepohliod and foliose cyanobacterial species. The former are enhanced by warming conditions, while the latter are related to temperate-humid conditions. A recent study modelling the occurrence of three *Lobaria* species across Italy (Nascimbene et al. 2016) revealed that in the next decades climate change will impact their distribution range exposing them to a high extinction risk in this region where genetic differentiation is higher than in other European regions (Widmer et al. 2012). On the other hand, studies exploring the species-elevation relationship of epiphytic lichens in spruce forests of the Alps (Nascimbene and Marini 2015; Nascimbene and Spitale 2017) and lichen diversity patterns along climatic gradients (Esseen et al. 2016) stressed the sensitivity of beard forming lichens to both temperature and precipitation increase.

1.5.2 Atmospheric Pollution

In Europe, atmospheric pollution is supposed to have played a major role in the reduction of epiphytic diversity starting from the end of nineteenth century. Actually, lichens are highly dependent on the atmosphere for nutrients and are lacking a waxy cuticle and stomata allowing many contaminants to be absorbed over the whole thallus surface. In this perspective, the biodiversity of epiphytic lichens proved to be a robust bioindicator of the air pollution caused by phytotoxic substances (Giordani and Brunialti 2015). In recent literature, eutrophication is addressed among the most impacting air pollution types (e.g. Van Herk 1999; Dise et al. 2011) causing shifts in lichen communities composition (i.e. oligotrophic species are replaced by nitrogen-tolerant species; Frati et al. 2007; Pinho et al. 2012; Giordani and Malaspina 2017; Giordani et al. 2018) and loss of community diversity and species cover across different ecosystems (Dise et al. 2011; Giordani et al. 2014). Empirical patterns of community changes and species distributions in relation to nitrogen pollution are likely to be related to differential physiological species responses (Johansson et al. 2011, 2012). Using an experimental approach, Johansson et al. (2011, 2012) evaluated the response of selected species to increasing nitrogen deposition across time slices. They also provided an eco-physiological basis for interpreting the mechanism behind the observed decrease of the lichen *Alectoria sarmentosa* with increasing nitrogen loads, invoking reduced thallus stability (by increasing the photobiont/mycobiont ratio; Johansson et al. 2011) or increased susceptibility to diseases enhancing the development of parasitic fungi that damage the cortical layer (Johansson et al. 2012) as plausible drivers. These experimental results are reflected in bio-geographical patterns of some species. For example, *Alectoria sarmentosa* is most probably extinct in north-western central Europe due to excessive eutrophication (Hauck et al. 2013). *Bryoria fuscescens* is nearly extinct in the Netherlands where it is currently restricted to remote sites far from nitrogen pollution sources (van Herk et al. 2003). In Pacific Northwest, McCune and Geiser (2009) found a frequency peak of some *Bryoria* species at low levels of nitrogen deposition. Van Herk et al. (2003), exploring lichen patterns in forest monitoring plots across Europe, found a decrease of the probability of occurrence of *Bryoria* and *Usnea* species with increasing nitrogen loads.

1.5.3 Land-Use Change

The effects of land-use changes on epiphytic diversity have been reported as a major threat especially at small spatial scale, where they can drastically affect the probability of survival of several endangered populations of species with restricted habitat range (Stofer et al. 2006).

Dramatic patterns of land-use changes occurred during the last two centuries in most parts of Europe due to increasing urbanization and soil demand for agriculture. For example, native oak forests were either completely eradicated and transformed into agricultural landscapes or replaced by second-growth formations mainly dominated by black locust (*Robinia pseudoacacia* L.), an alien species introduced in the late 1700s from the southeastern United States (see, e.g. Caprio et al. 2009; Motta et al. 2009). A study comparing historical and recent data on the lichen biota occurring in a hilly landscape of northern Italy (Nascimbene and Marini 2010) revealed that almost all the species recorded during the nineteenth century are now extinct, being replaced by species adapted to well-lit, dry conditions and tolerating air pollution and eutrophication. In this case, land-use change likely triggered also a process of biotic homogenization decreasing lichen diversity among bioclimatically different regions (Nascimbene et al. 2012).

Similar results were found in lowland Britain (Yahr et al. 2014) analysing the effects of land-use changes that occurred after the Industrial Revolution. These authors pointed out that c. 31% of species recorded from the pre-industrial landscape had disappeared from the post-1960 landscape.

1.5.4 Forest Management

Forest management is probably among the major causes of epiphytic species loss at the local and landscape level (e.g. Hedenås and Ericson 2008; McCune 2000; Giordani 2012; Johansson 2008; Nascimbene et al. 2010a, b; Neitlich and McCune 1997; Rogers and Ryel 2008), since several environmental factors relevant to the dispersal, establishment, and maintenance of epiphytic lichens are affected by forest management. The main negative effects of forestry are related to the lack of old trees; short rotation cycles; excessive canopy cover or excessive exposure to direct light in the final part of the rotation cycle; lack of substrate, particularly for dead wood dwelling species; decrease of structural diversity; lack of forest continuity and forest fragmentation; and edge effect (i.e. changes in environmental conditions of a forest stand due to cutting of a bordering stand; Nascimbene et al. 2013a).

As a consequence, in boreal regions many lichens are threatened by the use of clear-cuts and short rotation cycles in industrial forestry (Johansson 2008). Also in temperate deciduous forests, timber production is threatening epiphytic lichens, and dramatic losses of species caused by forest management are, for example, documented by Hauck et al. (2013). A literature review focused on temperate deciduous forests (Nascimbene et al. 2013a) revealed that forest management, and especially the shelterwood system, is a source of threat for many forest lichens indicating that selective cutting should be preferred to the shelterwood system whose negative effects could be mitigated also by the extension of the rotation period and by the retention of groups of mature trees at the final harvest.

In general, higher lichen diversity is related with lower management intensity, even if in some cases non-intensively managed forests (e.g. selective cutting) may provide better conditions for epiphytic lichens than recently abandoned forest (e.g. Nascimbene et al. 2013a; Paltto et al. 2008).

1.5.5 Pasture

Pasture and grazing activities seem to have contrasting effects on lichen diversity, depending on the environmental and management context. For example, in open woodlands across Mediterranean landscapes, lichen diversity decreases with management intensity along a gradient including agriculture, grazing of sheep, and grassland grazed by wild ungulates, and it is higher in abandoned sites covered by shrubs (Aragón et al. 2010). Similarly, Hauck and Lkhagvadorj (2013) found an impact of livestock density on epiphytic lichen diversity in larch forests of the Mongolian forest steppe. They concluded that the detrimental effects are mainly related to fertilization by the animals and mechanical abrasion. Also in wooded larch pastures of the Alps, fertilization was found to cause severe community compositional shifts, from assemblages dominated by acidophitic species to assemblages dominated by nitrogen-tolerant species (Nascimbene et al. 2014a, b). On the other hand, this last study indicated that also management abandonment could negatively affect lichen diversity, suggesting a response of lichen communities according with the intermediate disturbance hypothesis predicting that lichen diversity peaks at intermediate disturbance levels.

Despite the fact that the most negative effects were related to management intensification, mainly due to the high nitrogen supply, also management abandonment seems to be detrimental to lichen diversity. The negative effects of abandonment of grazing activities in wooded grasslands were also addressed by Johansson et al. (2014) in Sweden, indicating that the development of secondary woodland in wooded grasslands has negative impacts on epiphytes. Similar results were found by Paltto et al. (2011), studying lichen diversity in wooded pastures with ancient trees in Sweden. Their results indicate that the richness of the red-listed lichens on ancient oaks growing in open conditions is much higher than on similar trees in secondary woodland conditions. On these bases, they suggest that the development of secondary woodland is a threat to red-listed epiphytic lichens.

1.6 The Importance for Conservation of Fine-Scale Drivers

As already mentioned in the previous paragraphs, the spatial distribution, diversity, and population dynamics of epiphytic lichens are influenced by complex interactions between abiotic and biotic factors that, acting at different spatial and temporal scales, determine the possibility of colonization and survival of lichen species (Giordani 2006).

Although the basic knowledge about the relationship between these organisms and the environmental and autoecological factors is relatively advanced (Ellis 2012; Giordani et al. 2012), its relevance in the planning of operative conservation activities on threatened lichen populations remains less investigated. This situation is probably related to the lack of attention received by these organisms in terms of international conservation policies. However, recent studies have shown that a more in-depth knowledge of the effects of environmental factors, especially those acting at tree and stand scales, can significantly increase the likelihood of success of conservation and reintroduction of threatened epiphytic lichen species (Benesperi et al. 2018).

In this section, the main environmental variables that must be taken into account to ensure the maintenance of healthy conditions for individuals and populations of epiphytic lichens are briefly highlighted, and the main observable effects along the considered environmental gradients are introduced.

Forest habitat fragmentation and tree exploitation cause a complete break in the availability of the primary habitat for epiphytic lichens (Whittet and Ellis 2013; Otálora et al. 2011), causing a dramatic decline in the ecological integrity and affecting habitat structure and dynamics, as well as environmental parameters relevant to the lichen dispersal, establishment, and maintenance (Nascimbene et al. 2013b).

Light received by a lichen photobiont, especially during thallus hydration, influences growth and metabolism of both the symbionts, although hydration during nights may also stimulate lichen growth (Bidussi et al. 2013). At the same time, excessive light may be detrimental to lichens, strongly influencing water loss and air humidity, causing long-term photoinhibition (Gauslaa and Solhaug 2000). Thallus dehydration is a common mechanism to avoid the harmful effects of excessive light. It activates energy-dissipating mechanisms (Heber et al. 2006), reduces the transmission of solar radiation through the upper cortex (Gauslaa et al. 2001), and interrupts dark reactions in photosynthesis (Kranner et al. 2008). The effects of excessive solar radiation on poikilohydric organisms, such as lichens, depend on the state of hydration of the thallus. It has been demonstrated that hydrated thalli are more photoinhibited than dehydrated thalli. However, in sensitive species these mechanisms do not prevent photoinhibition damage in the desiccated state (Gauslaa et al. 2012), since most of the damage occurs under high light intensities (Färber et al. 2014) and involves the formation of harmful reactive oxygen species (ROS). Gauslaa and Solhaug (2004) have shown that species adapted to shady habitats are more photoinhibited by the damage induced by high solar radiation compared to species adapted to sun-exposed environment. These differences are attributed to the reduced structure of the photosynthetic apparatus. When they receive an excess of light, with respect to their optimum, they are not able to obtain the maximum yield from it and disperse it in the form of heat or fluorescence. Thus, a deficit in their photosynthetic efficiency is observed. The species of sun-exposed habitats, on the other hand, have a well-developed photosynthetic apparatus capable of exploiting at best the light regime to which they are subjected and therefore are less susceptible to an increase in solar radiation. However, it has been demonstrated (Gauslaa and Solhaug 2004) that sun-adapted lichens are more sensitive to PAR if they are in a state of hydration, while species that live in the dark are more photoinhibited if dehydrated.

Furthermore, the size of the thalli affects the relationship between thallus hydration and physiological activity as demonstrated by, for example, Merinero et al. (2014). In general, adult thalli can store more water per thallus area (Gauslaa and Solhaug 1998), and their water-holding capacity is higher than in juvenile thalli (Merinero et al. 2014), which tend to reach equilibrium with the surrounding environment much more rapidly (Gauslaa and Coxson 2011).

Habitat fragmentation causes an alteration of water and light regimes, so that both these factors can be detrimental, especially to the establishment and survival of recruits and juvenile thalli that are too small for holding sufficient amounts of water to sustain metabolic activity. In a lichen conservation perspective, even small cutting interventions can profoundly alter the availability of water and light and can lead to negative consequences, especially if operated in the vicinity of fragile, physiologically weak populations with low capacity for resilience and/or near the population propagation core (Paoli et al. 2018). In the case of active transplantation interventions, it has been shown that exposure of propagules transplants or small thalli in conditions of high luminosity can easily determine a low probability of development (Paoli et al. 2018).

1.7 Conservation Case Studies

Specific successful applications of conservation and habitat restoration for epiphytes are sporadic. Most of the literature aimed to assess the environmental influences (e.g. climate change, forest management, habitat fragmentation, land use) on epiphytes diversity, distribution, and dispersal in order to provide useful information about good practices for conservation (Hoegh-Guldberg et al. 2008). One of the major issues concerning transplantation is the risk of introduced species becoming invasive. However, although lichens have natural long-distance dispersal, there are no reported instances of lichens becoming invasive.

In the case of epiphytic lichens, examples of conservation and habitat restoration were mainly related to translocation experiments, a term synonymous of transplant according to Gilbert (1991); of thalli and/or vegetative diaspores, in situ and ex situ; of rare species; or of endangered populations (Smith 2015). Nowadays, conservation translocations of species were considered an effective method for restoring populations of declining and threatened species, especially when the availability of suitable substrates is limiting (JNCC 2003), or for lowering risks of random losses of local endangered populations (Lidén 2009).

Lichen translocation experiments have been successfully carried out for several epiphytic lichen species, in large part foliose members of the Lobarion community (e.g. Hallingbäck 1990; Scheidegger 1995; Gilbert 2002), but numerous examples of fruticose species were published too (e.g. McCune et al. 1996; Gilbert 2001; Lidén et al. 2004; Jansson et al. 2009). Studies concerning crustose epiphytic species are much rare (Allen 2017).

Different means of attachment were used for thalli transplantations, such as adhesive or staples (Lidén 2009; Scheidegger et al. 1995), bark fragments or whole branches (Hilmo 2002), and medical gauze or monofilament loops and silicon sealant (McCune et al. 1996; Scheidegger 1995), and compared (Allen 2017).

In this paragraph, the main results of selected studies are reported (Table 1.1). All the methods used in literature for lichen translocations have pros and cons: in many cases they were successful, while others were tricky. In attaching thalli directly on the substrate, the size of the specimens and the possible impact of adhesive on it should have to be taken into account (Gilbert 1977). Frequently, thalli or asexual reproductive propagules were attached on artificial substrates. The most used was sterile medical gauze (i.e. Kon and Ohmura 2014; Scheidegger 1995), but alternative substrates (air filter, burlap, cheesecloth) were successfully tested (Allen 2017). Moreover, Allen (2017) demonstrated that the success of translocations were affected both by environmental conditions at the transplant location and perhaps the quality of the gauze. Ultimately, few studies have considered transplantation of crustose lichens (Brodo 1961; Hale 1954, 1959; Seaward 1976) and even less epiphytic ones (Allen 2017).

Table 1.1 Main results of the case studies carried out across the globe

Lichen species	Authors and methods	Reported results
Lobaria pulmonaria	Hawksworth (1971) – bark plugs from *Quercus robur* in Western England fastened to the bark of *Ulmus glabra* in Derbyshire	The lichen became detached after 19 months
Lobaria pulmonaria	Gilbert (1977) – 25 transplanted specimens with adhesive	Most part killed by adhesive. Thirty percent survival after 3 years. New colonies produced
Lobaria pulmonaria	Hallingbäck (1990) – sorediate thalli on bark of *Acer platanoides*	After 18 months new thalli had developed. New colony produced
Lobaria pulmonaria	Scheidegger (1995) – transplanted isidioid soredia	Early development
Lobaria pulmonaria	Hazell and Gustafsson (1999) – 2240 transplants on *Populus tremula*	Eighty-nine percent of transplants were successful
Lobaria pulmonaria	Gustafsson et al. (2013) – in 1994, a transplantation experiment was set up on 280 aspens (35 sites in east-central Sweden). 1120 transplants of *L. pulmonaria*	After 14 years 23% of *L. pulmonaria* transplants remained, with a significantly higher survival on retained aspens than on aspens in the surrounding forest, especially on the northern aspect
Lobaria pulmonaria	Scheidegger et al. (1998) – reintroduction and augmentation experiment of vegetative diaspores (with surgical gauze + staples) and fragment of thalli (with staples)	Fifteen was the rough minimum estimated number of colonized trees for long-term persistence of *Lobaria* population. The major concerns of the authors were a lack of information about *L. pulmonaria* life cycle in relation with climatic conditions
Lobaria pulmonaria	Gauslaa et al. (2006) – 600 thalli transplanted to three successional boreal forest	The discrepancy between potential and realized ecological niches is probably caused by a long-term risk to be killed in open habitats by high light during long periods with no rain
Lobaria pulmonaria + *Ricasolia amplissima*	Gauslaa et al. (2018) – portion of thalli transplanted onto *Acer platanoides* and *Quercus petraea* trees Some thalli treated by a phosphorus treatment	*L. pulmonaria* grew faster than *L. amplissima*. Reintroduction of *L. amplissima* was unsuccessful because gastropods caused significant loss. *Acer platanoides* had more grazing than those on the more acidic *Quercus petraea*
L. pulmonaria + *Lobaria scrobiculata*	Larsson et al. (2014) – lichens were transplanted in boreal clear-cut patches. Each species was fastened with flax thread (Gauslaa	Less than 6% transplanted specimens (22 *L. pulmonaria* and 28 *L. scrobiculata*) were lost during transplantation. Mid-winter were more successful

(continued)

Table 1.1 (continued)

Lichen species	Authors and methods	Reported results
	and Goward 2012) to each of 60 plastic nets. The nets were attached by plastic staples to five aspects	than the suggested period for transplantation in clear-cut
L. pulmonaria + *Parmelia sulcata*	Gauslaa et al. (2001) – three replicates of each of the two species were fastened to each of the bark-covered walls facing south, west, north, and east and the tilted top of an artificial box. The basal part of each lobe was fixed by a thin plastic-covered paper clip (0.8 × 2.5 cm) that was subsequently nailed to the bark	Adverse effects were irradiance dependent, especially for *L. pulmonaria* as compared with *P. sulcata*. Excess irradiance may limit the spatial distribution of *L. pulmonaria* within intact forests (Gauslaa and Solhaug 2000) and may be one instrumental factor in reducing populations subsequent to logging
L. pulmonaria + *Sticta sylvatica* + *Parmotrema crinitum*	Scheidegger et al. (1995) – transplantation of adult thalli (staples) and vegetative diaspores (surgical gauze + staples) of the tree species for in situ conservation	Fifty percent successful transplantations of adult thalli of *L. pulmonaria*, only at 2 of 5 localities was successful regeneration of the vegetative diaspores. Very slow development of vegetative diaspores and juvenile thalli for *S. sylvatica* were recorded; *P. crinitum* diaspores were not easily immobilized
Lobaria pulmonaria, *Lobaria oregana*, *Hypogymnia inactiva*	Sillett et al. (2000) – two experiments. I) Surface-sterilized branches were repeatedly inoculated with propagules and compared 1 year after the last inoculation II) Translocation of thalli of the two species	Establishment of *Lobaria oregana* was higher on inoculated branch segments than on controls. *Lobaria oregana* was more sensitive to age class effects than either *L. pulmonaria* or *H. inactiva*
Lobaria pulmonaria, *L. oregana*, *Letharia vulpina*, and *Usnea scabrata*	Antoine and McCune (2004) – three lichen transplant experiments examined the effect of height in the growth rates of the four lichen species	Treetop is ideal for *Usnea*, but both *L. oregana* and *L. pulmonaria* increased in biomass too
Evernia prunastri, *Lobaria pulmonaria*, *Usnea longissima*, *Pseudocyphellaria rainierensis*, *Lobaria oregana*	McCune et al. (1996) (attaching a thallus fragment to a nylon monofilament loop with silicone sealer)	Hanging specimens from monofilament was successful. Different growth rates for examined species were reported. *Evernia prunastri* > *Lobaria pulmonaria* = *Usnea longissima* > *Pseudocyphellaria rainierensis* = *Lobaria oregana*

(continued)

Table 1.1 (continued)

Lichen species	Authors and methods	Reported results
L. scrobiculata, *Platismatia glauca*, and *P. norvegica*	Hilmo (2002) – growth and morphological response of 120 thalli transplanted into a young and an old *Picea abies* forest	Ninety-five percent successful transplantations (only five were lost during 14 months of transplantation)
L. scrobiculata, *Platismatia glauca*, and *P. norvegica*	Hilmo and Ott (2002) – translocation of twigs with sown diaspores. Four-year period of observation	All three species developed juvenile thalli. As low rate of development was observed for all the studied species
L. oregana, *Pseudocyphellaria rainierensis*	Sillett and McCune (1998) – transplantation of 1000 mature thalli of the two species (labelled loops of nylon monofilament with silicone) in 13 forest stands representing four age classes	After 1 year, both species grew at least as well in younger as they did in old growth (20–30% increase in mass), but growth rates were significantly lower in clear-cuts with high mortality percentage (50–90)
Ricasolia amplissima	Gilbert (1991, 2002) – 14 thalli translocated (glued) on oak, ash, and sycamore maple in Lowther Park in 1980 and after monitored for 20 years	Best results observed on *Acer pseudoplatanus* (40%)
Ricasolia amplissima, *L. Scrobiculata*	Hallingbäck and Ingelög (1989) – translocation of whole pieces of thalli of *R. amplissima* and *L. scrobiculata* on a thin slice of the substrate (tree bark). The slice of bark was glued to the new phorophyte	Any sign of reproducing showed for 2 years. The slow growth rate of *L. scrobiculata* made the specimens vulnerable and exposed to snails, winter snowslide, and birds pecking for insects
Teloschistes flavicans	Gilbert (2001) – in 1997 transplantation of flakes of bark supporting *T. flavicans*, using adhesive or insertion into bark crevices	After 4 years some translocated colonies had been lost, but others had grown, and new colonies had formed. Gluing bark flakes was a more successful method for translocating *T. flavicans* than tucking thallus fragments into bark cracks
Seirophora villosa	Benesperi et al. (unpublished) – ten specimens of *S. villosa* were transplanted in *Juniperus* shrubland during the restoration of a dunal system	Eighty percent of transplant was successful after 1 year No dispersal observed
Parmotrema perlatum, *Ramalina fastigiata*, *R. fraxinea*	Gilbert (1977) – transplanted between *Fraxinus* trees in localities where they were rare	All survived and showed considerable positive growth, but no new colonies were observed in the first 5 years

(continued)

Table 1.1 (continued)

Lichen species	Authors and methods	Reported results
Evernia divaricata and *Ramalina dilacerata*	Lidén et al. (2004) – fragments of *Evernia divaricata* and *Ramalina dilacerata* were attached to receptor branches	One year later, levels of survival were high. Covering transplanted fragments with an artificial shield enhanced fragment vitality
Parmotrema clavuliferum, *Ramalina yasudae*	Kon and Ohmura (2010) – vegetative propagules were transplanted onto trees using two methods	Juvenile thalli successfully developed from transplanted soredia in both cases
Pseudocyphellaria aurata	Kon and Ohmura. (2014) – transplantation studies on *P. aurata* using soredia and thallus fragments (multilayered gauze sheet) attached by stainless steel nails onto the east side of a *L. tulipifera* trunk	For *P. aurata* cultivation purposes in situ, transplantation of thallus fragments may be more effective compared to methods starting from soredia and isidia
Usnea longissima	Johansson et al. (2009) – healthy thalli were collected from *Picea abies* and attached to wooden sticks. The sticks were mounted on *P. abies* stems and harvested after a year	Growth responses of *U. longissima* were related to transplant size and other factors
Graphis sterlingiana, *Hypotrachyna virginica*, *Lepraria lanata*, *Lepraria finkii*, *Usnea angulata*	Allen (2017) – three experiments were conducted to test new and established methods for lichen transplantation	In the first two experiments, medical gauze did not withstand local weather conditions, and nearly all gauze fell from the trees within 6 months. The plastic air filter and burlap performed best as artificial substrates for transplants, with a 60% and 80% success rate, respectively. Cheesecloth remained attached to the trees, but only 20% of lichen fragments remained attached to the substrate after 1 year
		In the third experiment, *U. angulata* grew 3.5 ± 1.4 cm in the first 5 months and 1.8 ± 1.5 cm in the next 4 months
Heterodermia leucomelos, *Usnea* sp., *Orthostichella rigida*, *Orthostichella capillicaulis*, *Squamidium brasiliense*, *Plagiochila* sp.	Stam et al. (2017) – six epiphyte species (558 specimens) at three sites in moist Afromontane forests of Taita Hills, Kenya. 558 pendant	Epiphyte transplants can be successfully used for documenting growth of epiphytic bryophytes and lichens in tropical forests. Growth responses of different epiphyte

(continued)

Table 1.1 (continued)

Lichen species	Authors and methods	Reported results
	transplants; we documented the growth of four bryophytes and two lichens over 1 year	species collected from upper montane forests clearly differed when transplanted into upper and lower montane forests

1.8 Good Practices for Efficient Conservation

In a general scenario in which global change is probably becoming one of the main sources of threat to epiphytic lichen communities, lichen conservation could be improved implementing some good practices that are expected to mitigate global impacts. These practices should be targeted at multiple spatial scales, from the landscape to the tree level, to effectively cover multiple mechanisms and processes that contribute to lichen diversity. In this perspective, the integrative approach (Kraus and Krumm 2013) seems to be a promising avenue to promote lichen conservation across spatial scales.

At the landscape level, conservation practices should maintain heterogeneous forest landscapes that (a) include well-connected patches of set-asides (e.g. Boch et al. 2013; Ellis et al. 2009; Fritz et al. 2008), (b) prudently protect all the currently known hotspots of lichen diversity that are unique sources of propagules for triggering the colonization of surrounding stands, and (c) include different forest types subjected to different management intensity and canopy closure (e.g. Nascimbene et al. 2014a, b; Sitzia et al. 2017). In this context, the use of indicator species to identify sites worthy of lichen conservation should be promoted (e.g. Nascimbene et al. 2010a, b; Selva 2002).

At the stand level, the main task for effective conservation is the mitigation of the impacts of timber production, also adopting habitat-specific practices (Nascimbene et al. 2013b). In this perspective, recent literature summarized in Nascimbene et al. (2013b) indicates that (a) for forest lichens, selection cut is less impacting than shelterwood system. However, in shelterwood stands the impact could be mitigated by the prolongation of the rotation period and by the retention of groups of mature trees; (b) stands should have a diverse horizontal and vertical forest structure (e.g. Boch et al. 2013; Moning et al. 2009). This could be achieved by maintaining scattered overmature large trees, different types of dead wood (i.e. snags, logs, and stumps) which are relevant for specialized forest lichens, and tree species diversity in mixed stands; (c) excessive shading should be avoided which is particularly harmful for lichen communities of anthropogenic, lichen-rich, open forests (e.g. Nascimbene et al. 2014b; Paltto et al. 2011).

At the tree level, effective conservation depends on the prioritization of individuals that, beside tree age and size (see, e.g. previous stand level guidelines), would allow maximizing lichen diversity or the occurrence of endangered/rare forest lichens. In this perspective, trees that provide diverse microhabitats, as rot holes, deep cervices and growth anomalies (e.g. Fritz and Heilmann-Clausen 2010), and moss cover (Benesperi et al. 2018; Fritz et al. 2008), should be retained. However, recent research focused on the flagship forest lichen *Lobaria pulmonaria* (Benesperi et al. 2018) indicates that the prioritization of retention trees should also account for the developmental stage of the thalli and the demographic structure of the target lichen population, for example, avoiding to cut trees that host large, reproductive thalli.

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Biodiversity and Therapeutic Potential of Medicinal Plants

2

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Abstract

The nature is the best combinatorial chemistry and possibly possesses solutions to all ailments for mankind. A strong body of evidence suggests that two-thirds of the world's herbal species harbor therapeutic values, and these plants have been used in the traditional system of medicine since the advent of human civilization. Various plant species provide a rich source of bioactive molecules/compounds (although many whose functions have not been meticulously investigated as yet) that are used to treat and prevent several human disorders all over the world. According to the World Health Organization (WHO), a large population (~80%) of developing countries depend upon the herbal medicines for its survival. The development of purified medicinal products from natural sources is encouraged since it is estimated that among thousands of plant species that exist in the world, only 10% have been explored to determine their pharmacological potential. Studies demonstrating the usefulness of various medicinal plants are being accomplished worldwide. These studies have reported that the bioactive compounds extracted from plants are generally effective in nature and possess high-quality, safety, and cost-effective profiles as compared to synthetic chemical drugs. Moreover, these plant derivatives are usually accepted across different

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_2

cultures and ethnic groups. The field of "herbomics" which is at the infant stage of its development may help us in formulating individually tailored herbal interventions in this era of precision and personalized medicine. The aim of this book chapter is to provide an overview on the therapeutic and curative importance of different medicinal plants for treating common human diseases that include cancer, neurodegenerative diseases, major depressive disorder, bacterial and viral infections, and periodontitis. We believe that the natural products may be used as potential alternatives to standard drugs.

Keywords
Medicinal plants · Therapeutic potential · Bioactive compounds · Human diseases · Angiogenesis · Cancer · Infections

2.1 Introduction

Biodiversity contributes considerably toward human livelihood and growth and thus plays a predominant role in the welfare of the global population. According to a recent World Health Organization (WHO) report, a significant part of human populace (~80%) still depends on medicinal plants for meeting their need for basic healthcare. Natural substances such as digitalis (from foxglove), ergotamine (from contaminated rye), quinine (from cinchona), and salicylates (willow bark) have long served as sources of therapeutic medicines. Drug discovery from natural sources involves an intricate methodology that comprises of botanical, phytochemical, biological, and molecular techniques. Recent development in the molecular modeling and combinatorial chemistry has further stimulated the advancement of using phytochemicals in cure, control, and management of physiological, deficiency, infectious, and hereditary diseases. The field of "herbomics" is an exciting and evolving area of genetic science that may have long-term implications for developing precision and personalized medicine. The "herbomics" may help in understanding pharmacodynamics, pharmacokinetics, safety/toxicity profile, synergistic effects, and clinical efficacy of medicinal plants by decoding which genetic processes and molecular pathways are activated in an individual. The likelihood of side effects or inadequate response to a herbal medicine may also be evaluated.

Paradoxically, the potential benefits of plant-based medicines have led to unscientific exploitation and misutilization of the natural resources. This decline in biodiversity is largely responsible for the rise of rapid industrialization, indiscriminate deforestation, pollution, and fast changes in global climate in the past few years. Therefore, it is of utmost importance that plant biodiversity be preserved, to provide future structural diversity and lead compounds for the sustainable development of human civilization at large. This becomes even more important for developing nations, where well-planned bioprospecting coupled with nondestructive commercialization could help in the conservation of biodiversity.

In this brief chapter, we will present biodiversity and therapeutic potentials of different plant products involved in combating angiogenesis (a normal physiological process) and against various human diseases that include cancer, neurodegenerative disorders, major depressive disorder, bacterial and viral infections, and periodontitis.

2.2 Angiogenesis

The formation of new blood vessels from existing vasculature is defined as angiogenesis (Risau 1997). Angiogenesis is a normal process that has a central role in various physiological processes within human body. Angiogenesis also plays a crucial part in the pathogenesis of several diseases, including various kinds of cancers. Therefore, natural or synthetic compounds that target angiogenetic processes may help in successfully treating these cancers (Folkman 1996). At present, most of the antiangiogenic agents comprises of mostly synthetic chemicals or humanized monoclonal antibodies that specifically target tight regulation of multiple signaling pathways (Kubota 2012). Despite promising findings and significant progress, the role of synthetic antiangiogenic drugs has been limited secondary to high cost, serious systemic toxicities, and development of resistance necessitate associated with these drugs. Therefore, efforts should be made at identifying other novel and effective anti-angiogenic molecules that are inexpensive and have minimal or no side effects (Samant and Shievde 2011). A high number of studies have indicated that natural plant products such as alkaloids, terpenoids, tannins, and polyphenols have angiogenesis-modulating properties. For instance, Castanospermine, an alkaloid, is present in *Castanospermum australe*, and the pods of *Alexa leiopetala* is a glucosidase inhibitor (Clark et al. 2001). A previous research report (Pili et al. 1995) suggested that castanospermine suppresses migration and invasion of endothelial cells through the basement membrane. In addition, it has also been reported that this molecule prevents the morphological differentiation of endothelial cells by altering the structural arrangement of oligosaccharides present on their cell surfaces (Pili et al. 1995). Another bioactive compound, sanguinarine (a benzophenanthridine alkaloid), that is derived from the roots of *Sanguinaria canadensis* has been described to markedly suppress vascular endothelial growth factor (VEGF)-induced migration of endothelial cells in a dose-dependent manner process. Similarly, brucine, an indole alkaloid derived from *Strychnos nux-vomica*, inhibits VEGF-mediated angiogenesis both in vitro and in vivo by suppressing downstream protein kinases. Colchicine and vinblastine are two other biologically important alkaloids that are derived from *Colchicum autumnale* and *Catharanthus roseus*, respectively (Stafford et al. 2005). Although colchicine is an excellent source of stabilizing vasculature in vitro at a moderate concentration of 10^{-6}~10^{-8}M, the effective anti-angiogenic dose is reported to be toxic to humans, putting a question mark in their clinical applications (Stafford et al. 2005). However, a high-quality study reported that a continuous administration of vinblastine at an approximate dose of 2.0 mg/kg/week produces inhibitory effects on VEGF-mediated angiogenesis in mammalian models; nevertheless, the precise mechanisms underlying the anti-angiogenic actions of these compounds are still undefined (Albertsson et al. 2008). Ginsenosides (a terpenoid) including ginsenoside-Rg3 and ginsenoside-Rb2 are found in the roots of red ginseng (*Panax ginseng*). These natural agents significantly are known to decrease the number of newly formed blood vessels in murine B16 melanomas. Taxol is a complex polyoxygenated diterpene that is isolated from bark of the Pacific yew tree (*Taxus brevifolia*). Taxol is a well-known and natural cancer drug possessing cytotoxic activities especially at low concentrations that ranges between 25 and 100 nM. This natural therapeutic agent is used in the treatment of breast, lung, and ovarian cancers. The proposed mechanism involves downregulation of VEGF expression and the upregulation of hypoxic induced factor-1 proteins (Escuin et al. 2005).

Polyphenols are members of a large family of chemical compounds that are found in several plants and fruits, including the catechins found in tea, curcumin in *Curcuma longa*, and resveratrol in grapes and berries (Manach et al. 2004). These natural compounds have antiproliferative effects. Resveratrol, a polyphenol present in grapes, berries, and other plant sources, affects tumor angiogenesis via many mechanisms (Brakenhielm et al. 2001). Using murine models of fibrosarcoma, some studies have suggested that oral administration of resveratrol might inhibit tumor growth by severely restricting endothelial cell migration, proliferation, and formation of new blood vessels. The most likely primary action mechanism of resveratrol is through the inhibition of FGF2 and VEGF receptor-mediated activation of MAPK in endothelial cells (Brakenhielm et al. 2001). Catechin derivatives, such as epicatechin (EC), epigallocatechin (EGC), epicatechin-3-gallate (ECG), and epigallocatechin-3-gallate (EGCG), are present in green tea (Wang et al. 2015). Thearubigins and theaflavins are found in black tea (Wang et al. 2015). Together, these compounds are known to inhibit both VEGF upregulation and capillary endothelial cell proliferation. In another study, EGCG was shown to inhibit migration of neutrophils and thus polymorphonuclear neutrophil-induced angiogenesis in a dose-dependent manner (Donà et al. 2003). Flavonoids, including flavones, flavonols, flavanones, anthocyanins, and isoflavones, comprise another class of polyphenols that demonstrate anti-angiogenic properties (Fotsis et al. 1997). Genistein, an isoflavonoid derived from *Genista tinctoria*, may prevent bFGF-mediated endothelial cell tube development by downregulating the expression of plasminogen activator factors (Fotsis et al. 1993).

Another example of natural product that has potent anti-angiogenic property is Triphala churna (THL) which is an equimolar mixture of three myrobalan fruits that comprises of *Emblica officinalis* Gaertn (Amla), *Terminalia chebula* Retz (Haritaki), and *Terminalia belerica* Roxb (Bibhitaki). Interestingly, recent studies have demonstrated that THL and particularly its active tannin compounds chebulinic acid and chebulagic acid significantly inhibit VEGF-induced angiogenesis by blocking VEGFR-2 phosphorylation (Lu and Basu 2015).

In conclusion, compared with currently available anti-angiogenic synthetic drugs, plant products not only have comparable therapeutic potential but more importantly are less toxic in nature, inexpensive, and easy to administer. However, novel and effective strategies are necessary to improve the bioavailability and processing of natural products for their optimal clinical use.

2.3 Cancer

Cancer is one of the most lethal diseases worldwide, and the incidences of various cancers are continuously growing in both developing and developed countries over the past several decades. The current standard of care to treat various cancers includes surgery followed by concurrent chemoradiation therapy. Despite multimodality therapeutic interventions, prognosis of patients with cancer is generally dismal. Even advent of strategies such as tumor-treating fields and immunotherapy has not substantially improved the disease-free and overall survivals of cancer patients. Therefore, development of novel, cost-effective, and efficient treatment methods is required. The anticancer characteristics of a number of plants are still being actively explored, and some herbs have even shown encouraging results. Many of the bioactive compounds have demonstrated potential antioxidant, antiproliferative, anti-inflammatory, and anti-angiogenic effects in the fight against several cancers. Emerging studies have also shown that plant-derived molecules may be used in targeting different signaling pathways for cancer drug discovery. Taken together, these studies have reported that compounds that modulate these oncogenic processes may be potential candidates for cancer therapy and may eventually make it to clinical applications in the near future.

Some of the most common plants harboring anticancer properties are discussed below:

(a) *Tinospora cordifolia* efficiently destroys HeLa cells in vitro, signifying its potential as an anticancer agent. In a seminal study, a dose-dependent increase in cell death was observed in HeLa cells treated with *T. cordifolia* extract as compared to the controls (Jageti et al. 1998) providing the foundation for future research. Additionally, the anticancer action of dichloromethane extract of *T. cordifolia* in the mice transplanted with Ehrlich ascites carcinoma has been demonstrated. *T. cordifolia* extract showed a dose-dependent increase in tumor-free survival with highest number of survivors observed at 50 mg/kg dose (Jagetia and Rao 2006).

(b) Betulin and betulinic acid are potential anticancer phytochemicals that are widely distributed within the bark and stem of *Z. nummularia* and have been shown to have antitumor activity. In fact, betulinic acid glycosides produce differential cytotoxicity, such that cancer cell lines are more sensitive than normal cells (Gauthier et al. 2006). Similarly, betulinic acid, a naturally occurring pentacyclic triterpenoid, shows selective cytotoxicity against a variety of tumor cell lines (Eiznhamer and Xu 2004). Betulinic acid has been suggested to hold anticancer properties through a variety of mechanisms that include induction of apoptosis (program cell death) by generation of free radicals and reactive oxygen species, inhibition of topoisomerase I, activation of the mitogen-activated protein kinase cascade, inhibition of angiogenesis, and modulation of progrowth transcriptional activators and aminopeptidase-N activity. Furthermore, it was shown that betulinic acid induces apoptosis via a direct effect on mitochondria. These processes may be responsible for the ability of betulinic acid to effectively destroy cancer cells that are resistant to other chemotherapeutic agents (Eiznhamer and Xu 2004).

(c) *Centella asiatica* is another plant that has demonstrated its potential utility as an anticancer agent. The whole plant or its leaves are regularly used for their remedial activities. Partially purified fractions of *C. asiatica* inhibit the proliferation of transformed cell lines, including Ehrlich ascites tumor cells and Dalton's lymphoma ascites tumor cells (Babu et al. 1995). Importantly, no toxic effects have been noticed in normal human lymphocytes. Additionally, partially purified fractions of *C. asiatica* significantly suppress the rapidly dividing of mouse lung fibroblast cells in culture. Moreover, oral administration of *C. asiatica* extracts has been shown to slow down the development of solid and ascites tumors and increase the overall survival time of tumor-bearing mice. The mechanism underlying the antitumor activity of *C. asiatica* seems to be the inhibition of DNA synthesis (Babu et al. 1995).

(d) The plant-derived curcumin exerts potent anticancer effects in vitro and in vivo with its ability to inhibit cell proliferation in a wide range of tumors (Shao et al. 2002). The anticancer properties of curcumin are generally related to its capability to downregulate the expression of a number of genes such as NF-kappa B, activator protein 1 (AP-1), epidermal growth receptor 1 (EGR-1), cyclooxygenase 2 (COX2), lysyl oxidase (LOX), nitric oxide synthase (NOS), matrix metallopeptidase 9 (MMP-9), and tumor necrosis factor (TNF). Moreover, turmeric that contains curcumin as an important component is known to reduce the expression of various chemokines, cell surface adhesion molecules, cyclins, and growth factor receptors, including epidermal growth factor receptor (EGFR) and human epidermal growth factor receptor 2 (HER2) (Aggarwal et al. 2003). In addition to its effects on gene expression, turmeric inhibits the activity of c-Jun N-terminal kinase, protein tyrosine kinases, and protein serine/threonine kinases. The anticancer properties of turmeric also inhibit tumor cell invasion and metastasis to the remote areas from the areas of tumor origin by reducing MMP-2 activity and by inhibiting HEp2 (epidermoid carcinoma cell line) cell invasion (Mitra et al. 2006).

(e) A landmark study reported that active constituents extracted from *P. amarus* plant result in a significant decrease in n-nitrosodiethylamine-induced tumor incidence (Jeena and Kuttan 1999). Additionally, a decline in tumor marker enzymes and liver injury markers has been reported. *P. amarus* extract has been shown to inhibit DNA polymerase of hepatitis B virus and related hepatitis viruses and has been shown to downregulate hepatitis B virus mRNA transcription and translation (Lee et al. 1996). It is also reported that the extract of *P. amarus* inhibits aniline hydroxylase, a P450 enzyme that is responsible for the activation of some carcinogens. In a study, it was found that the extract of *P. amarus* inhibited the activity of tyrosine phosphatase, a key enzyme involved in the regulation of cell mitosis. It was also observed that the extract of *P. amarus* resulted in the inhibition of the activity of topoisomerase I and II in *Saccharomyces cerevisiae* mutant cell cultures. Additionally, *P. amarus* extract has been reported to have anti-angiogenic effects in mice harboring Lewis lung carcinoma (Huang et al. 2006).

The role of phytochemicals as cytotoxic agents against cancer cell lines has frequently been reported. Various plant molecules including nutraceuticals, such as allicin, apigenin, berberine, catechin gallate, celastrol, curcumin, epigallocatechin gallate, fisetin, flavopiridol, gambogicacid, genistein, plumbagin, quercetin, resveratrol, silibinin, taxol, derived from spices, legumes, fruits, nuts, and vegetables have been shown to modulate inhibitory effects against tumor cells (Chirumbolo 2012). Several other molecules from medicinal plants are already clinically established for cancer treatment. These include alkaloids such as vinblastine and vincristine isolated from *Catharanthus roseus* (Gullett et al. 2010), combretastatins isolated from *Combretum caffrum* (Cirla and Mann 2003), paclitaxel obtained from *Taxus brevifolia* (Luduena 1998), camptothecin isolated from *Camptotheca acuminata*, and homoharringtonine isolated from *Cephalotaxus harringtonia* (Aboul-Enein et al. 2014).

The isoquinoline alkaloid, isotetrandrine isolated from *Xylopia aethiopica*, is among the most active alkaloids described. This compound has been shown to display interesting cytotoxic effects against several cancer cell lines. In a previous study (Kuete et al. 2015), this compound was not shown to modify the integrity of the mitochondrial membrane in CCRF-CEM cells. However, its mode of induction of apoptosis was chiefly by increased production of reactive oxygen (ROS) species.

Phenolics have been the most studied group of secondary metabolites isolated from medicinal plants. Several compounds such as benzophenones, flavonoids and isoflavonoids, naphthyl butenone, quinones, and xanthones with fascinating cytotoxic activities have been identified.

It is also widely accepted that cancer inhibition by natural dietary agents is perhaps one of the best strategies in preventative medicine (Kuno et al. 2012). Specifically, tea polyphenols can potentially affect numerous molecular targets that are known to relate with cell proliferation, thus inhibiting tumor cell growth. Green tea polyphenols composed mainly of gallocatechin, epicatechin, epigallocatechin, epigallocatechin gallate, and caffeine inhibit the mitotic rate and hence decrease the growth and viability of human hepatocellular carcinoma cells probably by inducing apoptosis in these cells in a dose-dependent manner (Hessien et al. 2013). The same effect has also been observed in an important study in which green tea extracts were reported to induce apoptosis in the cell lines of gastric carcinomas (Gonzalez 2014). This could be attributed to the fact that green tea works synergistically with other proteasome inhibitors to retard the growth of neoplastic cells.

There are many reports on the antitumor and cancer prevention activity of black tea and green tea. However, a meta-analysis (Tang et al. 2009) indicated that an increase in green tea consumption may lead to reduced incidences of lung cancers, while the similar effect of black tea was not found to be true. Analogous results were reported (Goldbohm et al. 1996) in a prospective cohort study, which suggested that the consumption of black tea did not have any protective effect against colorectal, lung, and breast cancer. However, we believe that these results may not necessarily negate the effect of black tea in other types of cancer such as ovarian cancer and bladder cancer in females in which positive anticancer effects were observed

(Wu et al. 2013). Collectively, these studies indicate that the combination of green tea with black tea may have a positive effect against cancer.

Black tea polyphenol combination with resveratrol has been reported to synergistically inhibit established skin tumor growth compared to either of these agents alone, showing a decrease in tumor volume and number. The combination of curcumin, a major polyphenol in turmeric spice and green tea catechin, exhibited a synergistic colon cancer-preventative effect (Xu et al. 2010). There is an observed benefit in combining green tea with herbs or other nutrients that have greater combined benefits than that of green tea extract alone. Li et al. (2010) determined the synergistic effect of theaflavin-3,3-digallate (TF3) from black tea and ascorbic acids on cell viability and cell cycles of the human lung adenocarcinoma cell line SPC-A-1 and concluded that the synergistic effect enhances anticancer activity.

In summary, medicinal plants provide a broad spectrum of sources for developing novel and potent anticancer treatments. We strongly believe that some of the aforementioned natural products will end up being marketed as herbal medicines in treating various cancers in the near future. However, more work is required in order to isolate useful compounds that can be used as anticancer drugs. Likewise, it will be important for investigators to understand the different cancer-developing pathways in order to recognize what proteins and genes are required to be targeted.

2.4 Neurodegenerative Diseases

Neurodegenerative diseases such as Alzheimer's disease (AD), Parkinson's disease (PD), Huntington's disease (HD), and amyotrophic lateral sclerosis (ALS) are chronic disorders of central nervous system (CNS) that are characterized by neuronal loss, axonal degeneration, demyelination, and gliosis. Several studies have demonstrated that physicochemical properties of some proteins are altered causing deposition of these misfolded proteins in the human brain leading to neuronal degeneration. Well-established as well as novel therapeutic agents have been explored and tested to treat patients with neurodegenerative diseases; however, these drugs provide only short-term symptomatic benefits. Therefore, natural molecules from the plants and other sources are being discovered to substitute available synthetic medicines. Now, it is well documented that phytochemicals from medicinal plants can provide better and safer alternatives to synthetic molecules.

Berberine (BBR), a multicomponent herbal preparation, belongs to the isoquinoline class of alkaloids. It is generally isolated from several plants including *Hydrastis canadensis* (goldenseal), *Berberis vulgaris* (barberry), *Coptis chinensis* (copies or golden thread), and *Berberis aristata* (tree turmeric). It is recognized that BBR has several pharmacological effects like anti-inflammatory, antihypertensive, antioxidant, antidepressant, anticancer, antimicrobial, anti-diarrheal, cholesterol, and glucose-lowering properties. A few studies have reported that it is useful in a number of neurodegenerative disorders. BBR also possesses monoamine oxidase (MAO)-inhibiting property (Panahi et al. 2013) as well as AChE-inhibiting property as both are involved in the advancement of AD. In PD disease, BBR enhances the motor stability and synchronization by inhibition of neuronal damage of dopaminergic neurons. It also improves short-term memory by inhibiting apoptosis and improving neurogenesis in dentate gyrus of hippocampal region (Huang et al. 2017). It was also observed that BBR significantly prohibited both balance and memory loss in PD patients and there was a constant decline in substantia nigra (SN) dopaminergic neuronal loss and rate of apoptosis processes in the hippocampus.

Morphine is an opiate alkaloid which exhibits widespread narcotic and analgesic effects and is used in the reduction of both acute and chronic pain. Morphine mediates its analgesic activity through the μ-opioid receptor (Kaur and Arora 2015). Various experimental models have revealed that morphine can exhibit beneficial role against CNS disorders (Ye et al. 2014). It is well documented that morphine plays a vitally important role in the treatment of AD through binding to MOR which increases the levels of gamma-aminobutyric acid (GABA, a neurotransmitter) in the synaptic clefts. This mechanism provides protection from oxidative stress mediated neurotoxicity (Cui et al. 2011).

Montanine is an isoquinoline alkaloid belonging to Amaryllidaceae family which is isolated from an ornamental plant named *Hippeastrum vittatum* (Moraga et al. 2016). It possesses anticonvulsant properties. Alongside, AChE-inhibiting activity of montanine has been reported. However, dose-response relationship is not fully known.

Salsoline is an isoquinoline alkaloid belonging to Chenopodiaceae family (Pagliosa et al. 2010). The genus *Salsola* (Chenopodiaceae) is known to include more than hundred species mainly found in moderate and subtropical areas of several countries. It is considered to possess neuroprotective potential through its cholinesterase inhibitory action and is frequently used to treat patients with AD.

Another natural product, piperine (PIP), is a chief alkaloid found in long pepper (*Piper longum*) and black pepper (*Piper nigrum*). It belongs to the Piperaceae family (Ghavami et al. 2014). It has been reported that piperine possesses a multiplicity of pharmacological effects which include anti-inflammatory, antifungal, insecticidal, antihypertensive, antipyretic, antitumor, and analgesic effects. Additionally, it possesses many neuroprotective characteristics such as antioxidant, antidepressant, anticonvulsant activities (Yeggoni et al. 2015). The ethanolic extract of *Piper longum* fruits exerts anti-snake venom activities as neurotoxins present in the snake venom cause deadly effects on CNS (Vasavirama and Upender 2014). Research studies have also suggested that PIP dramatically reduces memory impairment at all dosage.

Vascular dementia is generally characterized by memory deficits and cognitive impairment that result from cerebrovascular diseases. Some studies have shown that medicinal plants, predominantly Sancaijiangtang and *Ginkgo biloba*, might improve behavioral and psychological symptoms, executive functions, working memory, and overall quality of life in patients with vascular dementia (Ghorani-Azam et al. 2018).

Overall, clinical data on phytochemicals against neurodegenerative diseases are still not adequate. Therefore, additional human prospective studies should be conducted to explore the possibility of using combined therapeutic approach that may provide further insights on the possible treatment of these patients.

2.5 Major Depressive Disorder

Depression is the recurrent, common, and leading risk factor for suicide cases that is attributable to multiple psychological causes. Conventional antidepressant therapy can help in relieving symptoms associated with depression and prevent relapse of the illness. However, most of these antidepressant drugs have undesirable side effects, thus limiting their daily use in curing these patients. Consequently, more specific agents with lesser side effects are necessary as a new therapeutic modality for the rational treatment of depression. One potential complementary method with conventional antidepressants involves the use of medicinal herbs and phytochemicals that provide therapeutic benefits. St. John's wort's (*Hypericum perforatum*) has a 2000-year history of use as a medicinal herb. Its modern application as a plant extract for alleviating the condition of depression has undergone scientific investigation over the last decade, and its effectiveness has been shown in studies comparing it with placebo and reference antidepressants (Vorbach et al. 2000) Therefore, extracts from St. John's wort's are widely used as phytopharmaceutical agents to reduce symptoms in elderly patients with depressive disorder. In a previous study (Oztürk 1997), antidepressant effects of other *Hypericum* species on animal models were also reported. The beneficial effects of medical herbs and phytochemicals on depression and their central nervous system mechanism have been described in many research studies. Based on accessible information (Lee and Bae 2017; Yeung et al. 2018), black cohosh, chamomile, chasteberry, lavender, passionflower, and saffron appear promising in mitigating depression with favorable risk-benefit profiles compared to standard-of-care treatment comprising of synthetic drugs.

Recently, Khan et al. (2018) reported significant medicinal potential and clinical possibility of glycosides as antidepressant agents. Through preclinical tests, it has been observed that efficacy of glycosides is mediated by the modulation of brain-derived neurotrophic factor (BDFN) in the hippocampus, an important brain structure for promoting synaptic efficacy, neuronal connectivity, and neuroplasticity. Thus, any physiological process or molecular pathway that helps to upregulate the expression of BDNF may be a novel therapeutic strategy for the treatment of depression. Several human clinical trials have shown positive antidepressant effects of *Echium amoenum*, *Crocus sativus*, and *Rhodiola rosea* (Sarris et al. 2011). However, a caution should be taken while interpreting these exciting findings as many of these published studies in the literature have not been replicated and reproduced in the subsequent studies. Moreover, therapeutic potential of several herbal medicines still remains unexplored in clinical trials. Thus, future studies are required to explore and confirm the efficacy of medicinal plants in curing patients with depression.

2.6 Bacterial Infections

Pyogenic infectious diseases are a significant cause of morbidity and mortality worldwide, accounting for approximately 50% of all deaths in tropical countries and as much as 20% of deaths in the developed countries. Despite the significant progress made in developing mechanisms to control microbial growth and transmission of infectious diseases, sporadic episodes of epidemics owing to presence of drug-resistant microorganisms and unknown disease-causing pathogens cause a widespread threat to the public health. Over the past several years, the active compounds isolated from medicinal plants have served as structural and functional ingredients for many clinically proven drugs. Numerous plant species have been tested against several bacterial strains, and many medicinal plants are active against a wide range of gram-positive and gram-negative bacteria. Unfortunately, a very few of these medicinal plant extracts have been examined in preclinical or clinical studies to determine their true reliability and degree of effectiveness.

More than half of the world population is infected with *Helicobacter pylori* pathogen. This bacterium causes peptic and duodenal ulcers. Anti-*H. pylori*-induced gastric inflammatory effects of plant products include quercetin, apigenin, carotenoid-rich algae, tea product, garlic extract, apple peel polyphenol, and fingerroot extract (Wang 2014). These purified natural products have anti-H. pylori-induced inflammation activity, and they cause suppression of nuclear factor-κB and mitogen-activated protein kinase pathway activation and inhibition of oxidative stress.

Diarrhea is a common ailment which causes pain and may become lethal if remains untreated, especially in the developing countries. A great number of plant species such as *Diospyros peregrina*, *Heritiera littoralis*, *Ixora coccinea*, *Pongamia pinnata*, *Rhizophora mucronata*, *Xylocarpus granatum*, and *Xylocarpus moluccensis* (Wangensteen et al. 2013) are used in the treatment of diarrhea. Among these compounds, the most promising components are the barks from *D. peregrina*, *X. granatum*, and *X. moluccensis* which contain tannins. These valuable compounds have shown strong results in anti-diarrheal mice models. The leaves of *P. pinnata* also show great potential against diarrhea. However, more work is required to study efficacy, optimal dosage, and safety profiles of these useful compounds in treating patients with diarrhea.

In an earlier study, Ullah et al. (2017) reported positive and beneficial anti-mycobacterial effects of *Citrullus colocynthis*, *Calotropis procera*, *Ricinus communis*, *Capparis decidua*, and *Fagonia cretica* plants' extracts against rifampicin-sensitive (H37Rv) and rifampicin-resistant (TMC331) strains of *Mycobacterium tuberculosis* as possible therapy against tuberculosis. In a seminal work, Komape et al. (2017) stated that plant species *C. lemon*, *C. heroroense*, and *A. dimidiata* possess compounds with antioxidant activity, suggestive of their significance in the scavenging of free radicals that may accumulate in a disease condition. In that study, all the extracts of plants were tested, and findings established some degree of anti-mycobacterial activity of these individual extracts, and this effect was potentiated when a combination of different extracts were employed suggesting this desired effect was possible because of synergistic interactions among different components. The investigators of this study also reported that hexane and butanol sub-fractions of *A. dimidiata* exhibited potent anti-mycobacterial activity.

In spite of encouraging results, there is a further need for the development of more powerful anti-mycobacterial drugs against multidrug-resistant (MDR) bacteria that are largely responsible for the cases of therapeutic failure. Results obtained from a recent study (Voukeng et al. 2017) highlight the antibacterial potential of the tested plants and the possible use of *Euphorbia prostrata* to combat bacterial infections including MDR phenotypes, thus raising a hope of providing cure to patients infected with MDR bacteria.

There also exists a great variety of plant species whose extracts have shown potential anthelmintic properties. One of the most potent extracts obtained from *Piper chaba* is dichloromethane fruit, that is usually called “Dee Plee” in Thailand and has been used collectively as an antiflatulent expectorant, antitussive, antifungal, uterus-contracting agent, sedative-hypnotic, appetite enhancer, anthelmintic, and counterirritant agent (Tewtrakul et al. 2000). Moreover, the aqueous acetone extract from the fruit of *Piper chaba* has been found to have hepatoprotective effects (Matsuda et al. 2009). Some amides have been isolated from the methanol extract of the *P. chaba* fruit (Morikawa et al. 2009) from the chloroform extract of the *Piper chaba* root. These amides such as Bornyl piperate and piperlonguminine have been found to possess potent antifungal and cytotoxic activities. Bornyl piperate and piperlonguminine demonstrated weak activity against *Leishmania donovani* promastigotes when compared against the standard drug, pentamidine (Tewtrakul et al. 2000). Other potent extracts include hydroalcoholic leaves of *Musa paradisiaca* (banana), which is known to inhibit *H. contortus*. Other activities have been described for the peel or the fruit of *Musa paradisiaca* including anti-leishmaniosis activity, anti-oxidative properties, and antimicrobial properties (Gachet et al. 2010).

In vitro, the anti-leishmanial activities of triterpenes and sterols isolated from *Musa paradisiaca* fruit peel have also been widely studied. The stem and root extracts of *Trianthema portulacastrum* are effective against the eggs of *H. contortus*; the dichloromethane bark of *Michelia champaca* is effective against *S. mansoni*; and the dichloromethane root extract of *Plumbago indica* is useful when tested with *C. elegans*. It is expected that preclinical studies are adequately reliable, and conclusions drawn from these studies are often transferable to clinical settings. Moreover, some studies have reported a significant correlation between in vitro tests and in vivo clinical studies of anthelmintic and parasitic drug resistance. Although studies using animal models are labor-intensive, expensive, time-consuming, and often difficult to scale up, they provide valuable insights into the action mechanisms, efficacy, and safety profiles of the potential drugs. In line with this argument, some studies (Adamu et al. 2016) are ongoing with the aim of assessing the cytotoxic effects of segments that are responsible for the antimicrobial activities.

2.7 Periodontitis

Periodontal disease has been recognized as a major health problem worldwide. Periodontal disease is an infectious disease caused by bacteria present in dental plaque (Chaturvedi 2009), and there exists a direct relationship between the presence of dental plaque and development of gingivitis (Powell 1965). Periodontitis is a complex disease in which disease expression involves intricate interactions of the biofilm with the host inflammatory response and subsequent modifications in bone and connective tissue metabolism.

Plant extracts and various natural products such as *Curcuma zedoaria*, calendula, *Aloe vera*, and other herbs have been used successfully to treat oral diseases. *A. vera*, star anise oil, myrrh gum, calendula extract, fennel oil, tea tree oil, and neem extract are some of natural products that are used to control periodontal disease (Maxwell 1995). Additionally, *Psidium guajava* is one such plant that has been used to control periodontal health (Ravi and Divyashree 2014). Other examples, *Centella asiatica* and *Punica granatum*, are medicinal plants that have been reported to promote tissue healing and modulate host responses.

It has also been demonstrated that curcumin, a component of turmeric which is used as a dietary spice, exerts a potent anti-inflammatory activity against LPS-induced periodontal disease (Guimarães et al. 2012). Another study (Moradi et al. 2014) suggested that anethole may have a strong inhibitory effect on periodontal disease through suppression of pro-inflammatory molecules. Anethole is a monoterpene and the main component of essential oils from aromatic plants including anise, star-anise, and fennel. An in vitro study showed the antimicrobial activity of lemongrass essential oil against periodontal pathogens, especially the strains *Actinomyces naeslundii* and *Porphyromonas gingivalis*, which were resistant to tetracycline hydrochloride. Lemongrass essential oil in the form of mouthwash was shown to be an effective aide to SRP as a part of nonsurgical therapy for the treatment of gingivitis (Warad et al. 2013). At the end, we would like to emphasize that all these medicinal herbs may be used in conjunction with the scaling and root planning or any other periodontal therapy as recommended by a certified dentist.

2.8 Viral Infections

The viruses cause a large number of human diseases. Currently, viral infections are clinically managed through administration of available antiviral regimens with poor therapeutic outcomes. The recalcitrant viral infections that remain generally resistant to accessible antiviral drugs are serious health concerns. For example, the available interferon and vaccine therapies for treating viral hepatitis are not definitive solutions due to high mutation and recurrence rates associated with hepatitis C virus. Owing to the growing incidences of viral infections because of globalization and ease of travel, the available therapeutic modalities are not sufficient to treat patients. As a result, there is an urgent need to discover novel antiviral agents to combat refractory viral infections. It is widely accepted that medicinal plants are repository of antiviral metabolites. These medicinal plants preserve a variety of bioactive products that harbor powerful therapeutic index and thus assist in inhibiting viral growth and possible elimination of viruses.

Several studies (Jassim and Naji 2003; Naithani et al. 2008; Ma et al. 2002; Ho et al. 2010) have shown the therapeutic potential of medicinal plants in the eradication and management of various viral diseases such as influenza, human immunodeficiency virus (HIV), herpes simplex virus (HSV), hepatitis, and coxsackievirus infections. These studies have documented several medicinal plants belonging to different families possessing useful antiviral properties. Taken together, *Sambucus nigra*, *Caesalpinia pulcherrima*, and *Hypericum connatum* hold promising specific antiviral activities that have been scientifically tested using experimental animal models. Though most of the clinical trials have reported some benefits from use of antiviral herbal medicines, the adverse effects of these natural products in the clinical trials have not been well documented in the literature (Martin and Ernst 2003). We believe that larger, stringently designed, randomized clinical trials are required to provide definite evidence of efficacy and safety profiles of natural antiviral drugs.

2.9 Current Challenges

Of a large number of flowering plant species identified until the present time, only about 10% of these species have been investigated for deciphering biological activities and that too not systematically. This condition suggests that a vast majority of the phytochemical diversity still requires further exploration. However, there are some stumbling blocks that need to be addressed before basic scientific findings in a laboratory setting could be successfully translated into clinics for potentially treating diseases and life-threatening conditions. The major obstacles that impede the growth of herbal medicine include loss of biodiversity, overexploitation and unscientific usage of medicinal plants, industrialization, and biopiracy, along with absence of regulatory mechanisms.

There also exist some pitfalls that prevent proficient and consummate utilization of phytochemicals in therapeutics. The main challenge is the short bioavailability associated with these phytochemicals. As large number of phytochemicals are readily digested and excreted from our body, they exert a transient therapeutic effect. New technologies and methods such as development of stabilizers and coating or capping of bioactive molecules into microparticles or nanoparticles are required to potentially increase the absorption, biostability, and efficacy of important phytochemicals. Another challenge is the absence of specific target sites for phytochemicals to act. Since phytochemicals have a pleiotropic effect, the neoplastic cells very frequently initiate different molecular and signaling pathways resulting in the failure of targeted therapies. To address these issues, alternative strategies including novel formulations of targeted delivery of these phytochemicals are being explored.

2.10 Conclusory Remarks

Medicinal plants shape an eco-friendly, bio-friendly, cost-effective, and safe mode of alternate healthcare system. Crude plant extracts encompass a variety of constituents that may employ their therapeutic effects either alone or synergistically if these different components are used together. However, detailed screening of medicinal plants is required for the further detection and progress of novel natural compounds that would help in combating many human diseases.

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Tree Ferns and Giant Ferns in India: Their Significance and Conservation

3

Niranjan Mishra and Sandip Kumar Behera

Abstract

Tree ferns are widely distributed in different habitats from damp, sheltered slopes and moist gullies to high altitudes in cloud forests and from cool temperate forest to tropical rain forest. In India tree ferns are represented by 12 species, out of which 11 belong to the genus *Cyathea* of Cyatheaceae and 1 belongs to the genus *Cibotium* of Cibotiaceae. And the giant fern is represented by three species belonging to the genus *Angiopteris* of family Marattiaceae. This chapter elucidates the taxonomy, distribution, ecology and conservation status of the tree ferns and giant ferns of India and some of their uses.

Keywords

Ferns · *Cyathea* · *Cibotium* · *Angiopteris* · Conservation

3.1 Introduction

Ferns and lycophytes constitute about 250 different genera (Chang et al. 2011) and about 12,000 species (Paul et al. 2015) which are distributed in a wide range of habitats globally. More than 1200 species of ferns and fern allies have been reported in India (Dixit 1984; Chandra 2000). Recently Fraser-Jenkins et al. (2017) listed 1157 taxa of ferns and their allies of India, excluding the hybrids. India is one of the 34 global biodiversity hotspots identified in the world because of the diversified species richness along with a high level of endemism (Mittermeier et al. 2005). The

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_3

Eastern Himalayas, Western Ghats, Indo-Burma and Sundaland are four hotspots in India with a rich pteridophytic flora. Pteridophytes grow well in tropical, subtropical and temperate forests.

Tree ferns always attract the fern enthusiasts and some growers because of their distinctive arborescent growth habit with woody or fibrous trunk topped by a beautiful crown of spreading fronds. Many tree ferns are massive, some species are slow growing and some have a creeping or prostrate trunk. Young tree ferns are notable for their rounded crown of fronds. Tree ferns are distributed in a wide range of habitats from damp, sheltered woodland slopes and moist gullies to high altitudes in cloud forests and from cool temperate forest to tropical rain forest which sometimes dominate the vegetation. Some species grow in shade and others occur in very open situation. Many species grow as shade plants in young condition, but when they become older, the crowns emerge from the forest canopy and are exposed to full sun. They are abundant in lowland, moist shady place condition and have a very high regeneration potential. Kramer and Green (1990) listed about 624 species of living tree ferns belonging to 17 genera grouped under 9 families. According to Tryon and Gastony (1975) and Conant et al. (1996), it consists of about 700 species worldwide with a range of distributions in tropical rain forest, subtropical and temperate regions and montane to alpine regions from the wet lowlands to mid elevations. However, some species are also belonging to high mountain areas in the tropics at elevations up to 3500 m (Bystriakova et al. 2011; Tryon 1970; Kramer and Green 1990; Smith et al. 2008; Sharpe and Mehltreter 2010; Kholia et al. 2013). Likewise giant fern *Angiopteris* has near about 30 species globally as per PPG 1 (2016). The tree ferns are believed to be surviving from late Paleozoic (Permian) and mid Mesozoic (Jurassic) (Rothwell and Stockey 2008; Mehltreter 2010) to present Holocene era. Their long history of evolution suggests these plants are silent spectators to witness the origin and evolution of modern seed plants and mammals including the man, hence considered as 'living fossils'. In India these are generally distributed in the Eastern Himalayas, Western Himalayas (Singh et al. 1986) North-East India, Western Ghats, Andaman Nicobar and Central India (Fraser-Jenkins 2008a, b, 2009). Scott (1874) recognized eight species from Sikkim Himalayas, and Clarke (1880) reported nine species from Northern India. Beddome (1883) reported 11 species from different other parts of India. Mehra and Bir (1964) reported three genera and ten species from the Darjeeling and Sikkim Himalayas. Holttum (1965) worked on Asian tree ferns and reported 12 species of tree ferns from India, of which *Cyathea nilgirensis* (Holtt.) Tryon was described as new to science and the two species *Cyathea henryi* (Bak.) Copel and *Cyathea contaminans* (Wall. ex Hook.) Copel were considered as of doubtful occurrence. Later on Rao and Jamir (1985) described *Cyathea holttumiana* Rao & Jamir from Nagaland. Three species have been explored from South India (Manickam and Irudayaraj 1992; Manickam 1995). Dixit and Sinha (2001) reported two species from Andaman and Nicobar Islands, India; Ghosh et al. (2004) reported eight species from the North-East. Dixit (1984) reported

Fig. 3.1 (**a**) *Cyathea albosetacea* (Bedd.) Copel., (**b**) *Cyathea spinulosa* Wall. ex Hook, (**c**) *Cyathea gigantea* (Wall. ex Hook.) Holt., (**d**) *Angiopteris evecta* (G. Forst.) Hoffm.

19 species of *Cyathea*, 1 species of *Cibotium*, 1 species of *Alsophila* and 4 species of *Angiopteris* from India (Fig. 3.1).

The tree fern family Cyatheaceae are well known for their beautiful huge foliage throughout the world. It is the second largest living fern group among the pteridophytes. They always attract researchers and naturalists because of their remarkable morphology, wide geographical distribution and pronounced local endemism. Most of the species of Cyatheaceae are scaly, spore-bearing, caudex massive, erect, thick, unbranched and arborescent. They have huge leaves (to 5 m), bipinnate-tripinnatifid lamina and veins free to margin, mostly simple or forked; sori indusiate or exindusiate, apparently at the apex or the surface of the vein; and spores tetrahedral, trilete, non-perinate, exine smooth or granulose. *Cyathea* is the most widely distributed and most successful tree fern among all along with genus *Angiopteris*, *Sphaeropteris* and *Cibotium*. Tree ferns are rapidly decreasing throughout the world mainly due to overexploitation for socioeconomic uses and habitat destruction.

In India, tree ferns are represented by 12 species, out of which 11 belong to the genus *Cyathea* of Cyatheaceae (Fraser-Jenkins et al. 2017) and 1 belongs to the genus *Cibotium* of Cibotiaceae. Likewise giant ferns are represented by four species belonging to genus *Angiopteris.*

3.2 Description, Distribution, Uses and Status

The description, distribution, uses and status of the tree ferns and giant ferns found in India are described below.

Cyatheaceae

***1. Cyathea albosetacea* (Bedd.) Copel.,** Philipp. J. Sci., C, 4: 55. 1909.
Alsophila albosetacea Bedd., Suppl. Handb. Ferns S. Ind. Brit. India 2. 1876.
Sphaeropteris albosetacea (Bedd.) R.M.Tryon, Contrib. Gray Herb. 200: 21. 1970.

Description

Gregarious tree fern, 5–10 m high; trunk 15–20 cm in diameter. Fronds 2.5–5 m long; stipes stramineous brown, warty to spinulose; spines thick, 1–3 mm long, scattered with scales, glabrous with age. Scales 5–10 × 1–2 mm, setiferous; pinnae up to 1 m long; pinnae-rachis warty to spinulose, clothed with multicellular hairs and narrow shining scales, dark brown. Pinnules sessile, 10–15 × 2–2.5 cm, deeply lobed up to costa; basal segments almost free; costules 5–7 mm apart; veins 9–10 pairs, forked, olive green, crenate at margin. Sori along costules up to 2/3 portion; small bullate scales abundant on costules, multicellular hairs on lower surface of costae (Jain and Sastry 1983).

Distribution: It is also endemic to India which is only found in the Nicobar Islands of the Indian union territory. It is found in the *Pandanus* forest in rocky clay to sandy loam. It is under vulnerable category in the IUCN list.

Uses: Unknown.

Status: Vulnerable.

***2. Cyathea andersonii* (Schott ex Bedd.) Copel.,** Philipp. J. Sci., C, 4: 56. 1909.
Alsophila andersonii J.Scott ex Bedd., Ferns Brit. India t. 310. 1869.
Gymnosphaera andersonii (J.Scott ex Bedd.) Ching & S.K.Wu, in Wu, Fl. Xizang. 1: 54. 1983.

Description

It grows in moist valleys and montane forest at an altitude of 300–1200 m. The trunk is erect and 6–10 m tall. Fronds are bi- or tripinnate, muricate, asperous and 2–3 m long. The entire plant is relatively dark in appearance, main rachis sometimes flushed glabrescent. Pinnae up to 75 cm long, pinna rachis bearing deciduous scales. Mature pinnules 12–15 × 2.5–3.2 cm; basal basioscopic segment almost free, a few adnate to costa; most pinnules deeply lobed 1–1.5 mm from costa; costules 5–6 mm apart; veins 10–12, rarely 14 pairs, simple or forked; lamina segments herbaceous, thin, crenate, subfalcate; apex bluntly pointed or rounded. Sori exindusiate along costule; paraphyses pale, slender, usually longer than sporangia at age; lower surface densely clothed with hairs mixed with smaller scales; hairs also present on the upper surface (Jain and Sastry 1983).

Distribution: It is a tree fern native to India, Bhutan and southern China. It is found in the Indian states of West Bengal (Darjeeling), Sikkim, Arunachal Pradesh, Assam and Meghalaya.

Uses: The core is dried removing the stem bark and ground; the powder thus obtained is used as substitute of wheat flour (Jain and Sastry 1983).

Status: Unknown.

***3. Cyathea brunoniana* (Clarke) Clarke & Baker**, J. Linn. Soc., Bot., 24. 409. 1888.

Alsophila brunoniana Wall. ex Hook.*;*
Sphaeropteris holttumiana (R.R. Rao & Jamir) R.D. Dixit;
Cyathea holttumiana R.R. Rao & Jamir

Description

Trunk erect, up to 10–20 m tall, up to 20 cm in diameter. Stipe and rachis yellowish to purplish, smooth or finely warty at base; scales pale brown or brown, thin, with setiferous edges; lamina 2-pinnate-pinnatifid, 2–3 × to 1.6 m; pinnae 20–30 pairs, ascending, lanceolate; largest pinnae up to 90 × 25 cm; pinnules narrowly lanceolate, 9–14 × 2–3 cm, slightly narrowed at base, apex caudate, pinnatifid to pinnatisect; pinnule segments 16–25 pairs, falcate, 10–16 × 3–5 mm, wider at base, entirely or minutely crenate, rarely with small segments; veins two- or three-forked; abaxial side of pinnules glabrous and adaxial side glabrous or with sparse hairs; lamina glaucous abaxially; adaxial side of pinna rachis with pale antrorse hairs, a few pale hairs and scales along costules abaxially. Sori close to midveins of fertile pinnule segments, often throughout lower lamina; paraphyses pale to brown, filamentous, longer than sporangia or equal in length; indusia absent; lower surface glaucous green; margins entire or undulate. Sori large, pale brown, round, exindusiate; fertile segments narrower than the sterile ones; paraphyses many; narrow scales around sorus (Kholia 2010).

Distribution: It is found in the Indian states of West Bengal (Darjeeling, Kalimpong), Arunachal Pradesh, Assam (Cachar-Barak RF, Inner Line RF, Hailakandi Inner Line RF), Meghalaya (Jaintia Hills-Jowai, Khasi Hills-Cherrapunjee, Garo Hills-Tura Peak), Manipur, Mizoram (Kolasib-Bukpui), Nagaland (Mokokchung), Arunachal Pradesh (Papum Pare, Tirap) and Sikkim. It grows in the moist hill slopes in forests, along forest fringes in open places and along water channels.

Uses: Phytochemical analysis revealed the presence of steroids, flavonoids and saponins in extracts of the caudex and leaves. TLC profiling of plant extracts in different solvent systems confirms the presence of diverse group of phytochemicals (Talukdar et al. 2010) which shows antibacterial activity against both Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*, *Pseudomonas aeruginosa*) multidrug-resistant organisms (Nath et al. 2017).

Population status/cause for RET: Vulnerable.

***4. Cyathea contaminans* (Wall. ex Hook.) Copel**., Philipp. J. Sci., C, 4(1): 60. 1909.
Sphaeropteris glauca (Blume) R.M. Tryon
Alsophila contaminans Wall. ex Hook

Description

Trunks up to 10 m or more tall. Stipes up to 60 cm or more long, stout, strongly thorny, purplish, glaucous, scaly near the base; scales light brown to paler, 4 cm long, 3 mm broad, thin, bearing short darker setae at margin; main rachis spiny, glaucous or brown, glabrescent; pinnae up to 80 cm or more long, 30 cm wide, lower ones lightly reduced in size; pinna rachis light brown or paler, spiny beneath, glabrescent or hairy on upper surface; pinnules about 2.5 cm apart, lanceolate acuminate at apex, subtruncate at base, sessile, patent, almost straight, up to 15 cm long, 2.5 cm wide, deeply lobed almost to costa, a few lowest segments quite free; segments oblique, falcate, round to moderately acute at apex, up to 1.5 cm long, 4.5 mm broad, 5–6 mm apart, crenate at margin; costae and costules glabrous or very sparsely hairy near apices of pinnules, scales rarely residual, small, pale, not bullate; papyraceous, green, glaucous beneath; veins forked, distinct beneath. Sori nearer to costule than to edges of lobes, exindusiate; receptacles large, prominent.

Distribution: Found in a single location Rungbee Valley, below Mongpong, Darjeeling, West Bengal of the Indian state.

Uses: The young fronds are boiled and eaten as vegetable; pounded leaves rubbed on the forehead to use for headaches and used for rheumatic problems. Used for wound healing: the soft apical portion of caudex is cut into small pieces, crushed in a mortar and made into paste and then applied daily to major cuts and wounds until healed. Rhizomes used topically for wounds and ulcers. A study isolated a new acylated flavonol glycoside from the fronds of *Cyathea contaminans* and was chemically characterized as kaempferol-7-(6″-succinyl)-glucoside (Yamane et al. 1985). Charred stem rubbed on the forehead of an afflicted child to protect against evils.

Status: Critically endangered or extinct in the wild (Fraser-Jenkins 2012).

***5. Cyathea crinita* (Hook.) Copel.,** Philipp. J. Sci., C, 4: 40. 1909.
Sphaeropteris crinita (Hook.) R.M. Tryon
Alsophila crinita Hook

Description

It has distinctive, very dense, pale and narrow scales at the growing apex of the trunk. It grows up to 12 m in height and 12–25 cm in diameter. Stipe 40–85 cm long; lamina 100–200 cm long, 50–100 cm wide; petiole 3.5–4 cm long, 2–5 mm wide with scales.

Distribution: *Cyathea crinita* is endemic to the southern Western Ghats and Sri Lanka (Chandra et al. 2008; Ranil et al. 2011). In Kerala, it occurs in Munnar; Devikulam; Umayamala; Rajamalay; Kanthalloor; Mannavan shola (Idukki); Chandanathode, Kannoth (Wayanad); dam site area of Silent Valley; Lower Valakkad (Palakkad); Tamil Nadu in Avalanche (Nilgiris), Palani Hills (Dindigul);

and Anaimalai Hills (Coimbatore) (Manickam and Irudayaraj 1992, 2003). The species is very rare, known only from a few localities. The number of plants are very few, and populations are declining due to harvesting for ornamental purposes and isolation caused by heavy fragmentation (Irudayaraj 2011).

Uses: The species is used as an ornamental by the tribes in Kerala during wedding and other ceremonies. This seems to be a new practice, which has never been recorded before. The trunks are cut at the base, and the entire plant is used to decorate the entrance of the homes. New tribal practices that consist in using the entire tree fern for ornamental purposes have resulted in the loss of some populations in Kerala. Road construction through sholas (forested and shaded areas with high-altitude streams) in Kerala has already resulted in the destruction of a subpopulation of this species and area of suitable habitat. Further, heavy fragmentation due to loss of subpopulations and road construction is isolating subpopulations which causes a decline in the number of plants and habitat quality.

Status: Endangered.

***6. Cyathea gigantea* (Wall. ex Hook.) Holt.,** Gard. Bull. Straights Settlem. 8(4): 318. 1935.

Alsophila gigantea Wall. ex Hook.,
Gymnosphaera gigantea (Wall. ex Hook.) J.Sm.,

Description

Tree fern, 1–3 m tall with a loose crown of leaves; rhizome massive. Fronds herbaceous or submembranaceous, tufted; stipes more than 1 m long, castaneous or reddish purple or black, upper part more or less glabrous; scales black and castaneous on stipe base, 10–12 × 1–2 mm, middle portion dark brown; few deciduous scales on rachis and costae. Pinnules short stalked, 5–12.5 × 1.5–2.5 cm, gradually narrowed towards the apex, distinctly lobed up to 2/3rd of costa; costules 4–7 mm apart; veins 2–6 pairs; basal basioscopic vein usually from costa, herbaceous, dark green on upper surface, light green on lower surface; margins strongly crenate. Sori exindusiate, basal ones away from costules and upper ones close to costule; paraphyses dark brown, shorter than sporangia. Pinna rachis dark purplish, smooth, glabrescent or with a few small residual scales. Sori round, exindusiate, closer at top of pinnulet and wide apart at base. It is grown as an ornamental. It is exploited for starch, and the frond is used for growing epiphytic orchids.

Distribution: It is a tree fern found extensively in moist open areas of North-Eastern to Southern India. It is majorly found in the Indian states of West Bengal (Darjeeling), Sikkim, Arunachal Pradesh, Meghalaya, Odisha, Madhya Pradesh, Tamil Nadu and Kerala.

Uses: The methanolic extract of leaves of *C. gigantea* at doses of 100 mg/kg bw and 200 mg/kg bw has significant effect on the liver with paracetamol-induced hepatotoxicity (Kiran et al. 2012). The leaf powder is used with *Angiopteris helferiana* Presl in case of white discharge. The trunk is useful for the plantation of orchid and used as an ornamental plant. *C. gigantea* along with other combinations of herbs is used in pain from traumatic injury, such as sprains (Xavier-Ravi Baskaran and Antony-Varuvel Geo Vigila).

Status: Least concern.

***7. Cyathea henryi* Copel,** Philipp. J. Sci., C, 4: 38. 1909.
Alsophila henryi Baker
Gymnosphaera henryi (Baker) S.R.Ghosh

Description

The trunk of this plant is erect and may be 5–7 m tall or more. Fronds are bi- or tripinnate and usually 2–3 m in length. The rachis is smooth and dark but occasionally has a few scattered scales. The stipe also has these scales. The scales are either small and pale with irregular fringed edges or large and dark with a paler margin. Sori are borne on minor veins and lack indusia.

Distribution: This tree fern is native to India and China. It grows at submontane and montane forest at an altitude of 600–1200 m.

Uses: Unknown.

Status: Rare.

***8. Cyathea khasyana* (Moore ex Kuhn) Domin**, Pteridophyta, Praha 262. 1929.
Alsophila khasyana T. Moore
Gymnosphaera khasyana (T. Moore) Ching

Description

The trunk of the plant is 1.5–2 m tall, rarely. The crown is spreading with bipinnate, lanceolate fronds. The stipe is dark brown to castaneous with minute murications at the base otherwise with rough sandpaper-like appearance; a yellow short streak also runs on sides of stipe. The rachis is also rough. Pinnules are long, narrow lanceolate with pointed apex. Under surface of rachis, costa and costules bear small bullate lanceolate scales with darker tips. Veins are once forked. Sori are globose, slightly close to midrib, more or less in parallel lines on either side of midrib, exindusiate. Sori globose, slightly close to midrib, more or less parallel lines on either side of midrib, exindusiate near costules.

Distribution: It is found in the Indian states of Meghalaya (Khasi Hills), Assam, West Bengal (Darjeeling) and Sikkim Himalayas and in the border areas of India and Burma.

Uses: The tender leaves of the species are used as fodder, and old leaves are used for cattle beds (Kholia 2010).

Status: Vulnerable.

***9. Cyathea nicobarica* N. P. Balakr.**,
Sphaeropteris nicobarica (N.P. Balakr. ex R.D. Dixit) R.D. Dixit;

Description

It is a tree fern, ca 2.3 m high. Fronds 1–2 m long; stipes dark chestnut coloured, spinulose; spines 1–3 mm long, densely clothed with long spreading hairs and scales; scales 5–15 × 3–5 mm, pale brown; hairs light brown, 5–10 mm long; rachis stramineous to chestnut coloured. Pinnae 20–30 × 10–15 cm; pinnules 4–10 × 1.5–2.5 cm, lowest deeply lobed; costules 4–5 mm apart; bullate scales and simple hairs present on both surfaces; veins 5–6 pairs, forked, rarely simple.

Distribution: It is endemic to the single location and endemic to Indian territory Nicobar Islands (Kamorta) along cliffs in island hill forests on rocky loam. It is a vulnerable species.

Uses: Not known.

Status: Critically endangered (Fraser-Jenkins 2012).

***10. Cyathea nilgirensis* Holttum,** Kew Bull. 19: 468. 1965.
Alsophila nilgiriensis (Holttum) R.M. Tryon
Alsophila latebrosa Wall. ex Hook. var. schmidiana Kunze,

Description

Tree fern ca 5 m tall. Stipes up to 40 cm long, dark purple, spinulose; spines 1–3 m long; scales glossy brown, 10–15 × 1–2 mm; margins fragile; rachis stramineous brown; verrucose with very short spines. Pinnae 50–75 cm long; middle pinnules 10–12 × 2–2.5 cm, deeply lobed near costa; costules 3–5 mm apart, thin, hairy on lower surface; bullate scales abundant on vegetative pinnules on lower surface; veins 10–13 pairs, furcate; margins crenate-serrate. Sori indusiate; indusium membranaceous, persistent at base; paraphyses shorter than sporangia.

Distribution: It is endemic to India (Fraser-Jenkins 2008a, b) and particularly found in south Indian parts (Andhra Pradesh, Tamil Nadu and Kerala). It was listed 'endangered' (Walter and Gillett 1998a, b), 'least concern' (Irudayaraj 2011) but subsequently brought into the category of threatended by (Dudani et al. 2014).

Uses: Plant extracts showed significant antimicrobial activity against *Pseudomonas aureus* and *Klebsiella pneumoniae* and followed by *L. lanceolatus* against *K. pneumoniae* and *Aspergillus niger* (Pradhees et al. 2017). It shows the inhibitory effect on four pathogens, viz. *P. aureus*, *K. pneumoniae*, *A. niger* and *Fusarium* sp. with the maximum inhibition in the highest concentration (100 μg/ml).

Status: Vulnerable.

***11. Cyathea spinulosa* Wall.ex Hook**, Sp. Fil. 1: 25, t. 12 C. 1844.
Alsophila spinulosa (Wall. ex Hook.) R.M.Tryon
Alsophila decipiens J. Scott ex Bedd.
Hemitelia decipiens J. Scott

Description

Trunk 5–15 m, 10–20 cm in diameter, densely covered by adventitious roots. Stipes dark purplish distinctly. Spiny near base; scale shining dark brown, stiff; their bases later develop into spines. Laminae about 3 m long, 1.5 m wide, ca. 23 pairs of pinnae.

Distribution: It is mostly found in the North-Eastern and Eastern and Western Ghats and Central India. Some have also reported of their presence in north Indian states (Goel and Pande 2001).

Uses: The whole part of the plant is used for greying of hair and also used as general hair tonic. Powder of fronds is used as a sudorific and aphrodisiac. The whole plant is used as ornamental. The stem is used for orchid cultivation and pith from the trunks is used as a food product and also the stem as food and in making pots. Trunk fibres are used for orchid tissue culture media. The stem can be used in traditional Chinese medicine for eliminating dampness and strengthening muscles and joints. Roots are used for the preparation of local drink. Mixture of stem powders of *Cyathea spinulosa* and *Angiopteris helferiana* is administered orally with water to the cattles such as cows, buffalos and goats in cases of indigestion and hair loss due to various reasons. Little amount of potion is also applied on the skin for rapid growth of hairs. Powder of fronds is useful as sudorific and aphrodisiac (Singh and Upadhyay 2012; Updhyay et al. 2011).

Cibotiaceae

***Cibotium barometz* (L.) J. Smith.,** London J. Bot. 1: 437. 1842.
Polypodium barometz L.
Aspidium barometz (L.) Willd.

Description

A large tree fern with stem usually creeping and, like the petiole bases, covered with stiff, golden hairs. Caudex (trunk) massive, prostrate to erect, up to 2–3 m long, the young parts at the top very densely covered with shiny golden-brown hairs up to more than 4 cm long, young plants softly hairy throughout. Leaves in a tuft at the apex of the trunk; petiole stout, sometimes attaining 2 cm in diameter, more than 1.5 m long in larger ones, brownish, bases hairy like the caudex, the rest tomentose when young and glabrescent when old; lamina bipinnately compound, ovate to elliptical in outline, up to 2 m × 1 m, under side glaucous, upper side darker green, at underside the veins with pale, entangled, flaccid, appressed hairs (young plants hairy throughout); rachis brown, densely covered with pale to ferruginous hairs; pinnae many, alternating, pinnate-pinnatifid, in outline oblong to lanceolate, the largest ones up to 80 cm × 25 cm, stalk 0.5–1 cm long, apex acuminate; pinnules numerous, often with a few pairs of tertiary leaflets at the base, deeply pinnatifid throughout, very shortly stalked or subsessile at distal parts of pinnae, linear-lanceolate, 10–15 cm × 1.5–2.5 cm, broadly cuneate to subtruncate at base, gradually narrowing towards acuminate apex; ultimate divisions oblong, oblique to subfalcate, 0.8–1.4 cm × about 3 mm, acute at apex, shallowly but distinctly dentate at margin; veins distinct, oblique, once (or twice in larger lobes) forked, sparsely hairy below. Sori protected by two indusia which are alike in texture and different from the green lamina; outer indusium deflexed so that the sorus appears to be on the underside of the lobe, permanently round; inner indusium at maturity bending back towards the costule and elongating, becoming oblong; the two indusia joined together for a short distance at their bases, thus forming a small cup, terminal on usually unbranched lower veins, 2–4 or more pairs on a lobe on the largest leaves, parallel to edge of lobes; paraphyses long and numerous; sporangia gradate, annulus oblique and opening laterally. Spores with equatorial ridge, annulate or annulotrilete; exine with proximal face bearing three rows of short laesural ridges, distal face with a distal ridge.

Distribution: It is mainly found in North-Eastern India specifically in Arunachal Pradesh and Sikkim.

Uses: The plant is sometimes gathered from the wild for local medicinal use. It is sometimes grown as an ornamental. Its young fronds are eaten by local peoples. The plant is an indicator of acid soils. Rhizomes are vermifuge and roots used as tonic and in lumbago; paleae have the property of rapidly coagulating blood and have been used as styptic (Benniamin 2009). The extract of the rhizome is used as antirheumatic, anti-inflammatory and vermifuge; to stimulate the liver and kidneys, to strengthen the spine and to expel wind and dampness; and as a prostatic remedy. The yellow hairs on the rhizomes contain tannins and are astringent. Rhizomes and roots are collected and used for treatment of ulcers, rheumatism and coughs. The yellow hairs of the rhizome are used as a styptic to stop bleeding and in a haemostatic poultice for wounds.

Status: Neither threatened nor vulnerable.

Marattiaceae

***1. Angiopteris crassipes* Wall. ex C.Presl,** Suppl. Tent. Pterid. 23. 1845.
Angiopteris distans C.Presl
Angiopteris huegeliana C.Presl

Description

Habit: Rhizome erect, cylindrical, apex densely covered by dark brown hairs. Lamina deltoid, bipinnate; pinnae up to 16 pairs, sub-opposite, oblong-lanceolate; lamina dark coloured, texture herbaceous, recurrent false veins reaching the soral line. Soral line is close to or at the margin and generally has smaller segments with prominent teeth near their tips.

Distribution: It is common along shaded stream banks. It is native to India found in the south Indian states of Karnataka and Kerala (Rajagopal and Bhat 1998).

Uses: The root extract is used for the treatment of dysentery. It has antihyperglycemic, antinociceptive activity (Dudani et al. 2013).

Status: Near threatened.

***2. Angiopteris evecta* (G.Forst.) Hoffm.,** Commentat. Soc. Regiae Sci. Gott. 12: 29, t. 5. 1794.
Polypodium evectum G.Forst.
Danaea evecta (G.Forst.) Spreng.

Description

Rhizomes form a massive, somewhat spherical trunk to ca. 120 cm high and 100 cm in diameter. On either side of the petiole insertion, the rhizome bears two flat, rounded, dark brown, leathery, stipule-like outgrowths, ca. 10–15 cm long that bear proliferous buds and can grow into new plants when broken off. The petioles are thick and fleshy and can reach ca. 2 m long with a swollen base and bipinnate lamina which are glabrous, very large and spreading, usually to ca. 6 m long and to ca. 2.5–3 m broad. The pinnae are ca. 30 cm wide; ultimate segments (pinnules) are numerous, alternate, shortly stalked, commonly (8−) 10–13 (−20) cm long, (0.8−) 1.5–2.5 (−4) cm wide, linear; the base unequally wedge-shaped to more or less rounded; the margins serrate towards the apical part; the apices acuminate. Sporangia are clustered in short double rows of three to seven with no indusium (Christenhusz and Toivonen 2008).

Distribution: Found in North-Eastern states of India in Assam and in Arunachal Pradesh, Uttar Pradesh, Madhya Pradesh and the Nilgiri hills.

Uses: It is cultivated worldwide as an ornamental fern. Also, its starchy rhizomes are sometimes eaten or used to perfume coconut oil (Christenhusz and Toivonen 2008). The starchy rhizome has been eaten as a starvation food. Young fronds are also eaten in Ambon and the croziers are cooked as a vegetable. In traditional medicine, a decoction of the rhizome is used to stop bleeding during a miscarriage; the pounded stem is used to treat cough; and the young fronds are used as a poultice for swellings. The plant is a popular ornamental in gardens and parks and can live for 50 years or more. Leaf extract is used in the treatment of dysentery and diseases of blood ulcers. Spores are said to be effective in the treatment of leprosy and other skin diseases (Benniamin 2009). The rhizomes of *Angiopteris evecta* are used for scabies and in the treatment of headaches in India.

3. Angiopteris helferiana C.Presl;
Angiopteris latemarginata Ching
Angiopteris subcuneata Ching.

Description

Fronds 2–3 m; stipes smooth. Laminae bipinnate; pinnae 60–80 × 20–30 cm, with 15–20 pairs of pinnules; pinnules 10–20 × 2–6 cm; bases cuneate; margins serrate to sharply serrate; apices acuminate to caudate. Veins sparse, ca. 10 per cm; false veins present, rarely absent. Sori 2–3 mm from margin, 1.5–3 mm, composed of 14–26 sporangia.

Distribution: In India it is found in Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura.

Uses: Mixture of stem powders of *Cyathea spinulosa* and *Angiopteris helferiana* is administered orally with water to the cattles such as cows, buffalos and goats in cases of indigestion and hair loss due to various reasons. Little amount of potion is also applied on the skin for rapid growth of hairs. Powder of fronds is useful as sudorific and aphrodisiac (Singh and Upadhyay 2012).

Status: Near threatened.

3.3 Conservation of Tree and Giant Ferns

These ferns love humid, sultry and shady places to meet their moisture requirement which is essential for their rich growth. They are found along the stream side at 335–2250 m altitude in North-Eastern states (Arunachal Pradesh, Sikkim, Nagaland, Manipur), Eastern Ghats areas [Niyamgiri hill range (Odisha)], West Bengal, Central core Pachmarhi (Madhya Pradesh) (Singh and Upadhyay 2010; Singh and Sahu 2015), Uttar Pradesh and Western Ghats (Kerala, Tamil Nadu, Karnataka). Availability of moisture and light is an indispensable factor for the growth of these ferns during their different developmental stages. Perhaps that is the reason the North-Eastern area provides the most adequate environment for the growth and development of tree and giant fern species (Unwin and Hunt 1997). Intense light exposure or a dark environment will suppress sporophyte and gametophyte growth affecting seedling regeneration.

3.4 Threats to Tree and Giant Ferns

At present the populations of these ferns are in alarming condition as compared to the ancient times. These ferns are confronting serious survival challenges due to increasing pressures of habitat loss by deforestation and development activities and also changing climate. Many tree and giant fern species having ecological and economic significance are facing tremendous pressure and are at risk to become endanger and extinct. Tree ferns are declining rapidly in the wild (Nayar and Sastry 1983; Dixit and Singh 2004; Chandran 2008). The poor regeneration stands as a critical threat because of the less populations of tree fern species in their natural habitats (Paul et al. 2015), although some have a good regeneration potential. Threats for tree fern include both natural and anthropogenic nature.

3.4.1 Natural Threats

Conservation of tree and giant ferns in reserves or ex situ conditions is a very difficult task because of their giant growth habit and cold sensitivity. If we want to protect these plants, it is important to protect their habitat that will guarantee the availability of microclimate requirements for their reproductive success and colonization (Khare et al. 2006), and further, they need to conserve their associate plant species (Paul et al. 2015). But unfortunately human beings can't regulate the natural threats to conserve these beautiful plants. Heavy rainfalls, cloudburst, flood and landslides are major natural devastating factors which pose threats to the species as well as to its habitat. Many times it is found that these plants grow in the areas which are more prone to landslides as in the Himalayas and sometimes found to grow near water channels in the deep ravines as in Central India. Their occurrence to such habitat also makes them prone to threat during heavy rainfalls. Pollution and growing impacts of global climate change are also forcing these species to become extinct (CBD 2008).

3.4.2 Anthropogenic Threats

Various anthropogenic activities like deforestation for agriculture, urbanization and road/trail-building activities have resulted in tremendous pressure on the natural habitat of these fern species. A huge market demand for their multiple socioeconomic uses, viz. ornamental, horticulture, food and medicinal uses (Dixit and Singh 2004; Rout et al. 2009; Chandra et al. 2008; Kholia 2010), is resulting in the rapid decline of the wild population of tree ferns. The unsustainable harvesting of crosier leaf, trunk, rhizome and fronds of tree fern for food and fodder by local people without taking into consideration its own natural viability challenges and its conservation strategies has affected the tree ferns in India. Lack of the knowledge on the importance of tree fern stands as one of the major factors for the declining tree fern populations in that area. Another very important anthropogenic activity is extensive mining by different mining industries for the raw materials and ore which destroys the whole habitat of the tree and giant ferns. The species of *Angiopteris* and *Cyathea* are currently facing the major threat due to the mining activity. One of the threats to Indian tree ferns is exploitation for their use as avenue plants and orchid culture (Kholia 2010). Saplings from the forests are extirpated to use as avenue plants which when grown the adult starts sporulation but the germination percentage is hampered probably on account of unfavourable habitat. The continuous practice of bringing the saplings from natural habitats has greatly affected the populations of these plants.

3.5 Strategies for Conservation

The family Cyatheaceae is listed in the Appendix II of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 1975, in order to protect these tree ferns from being sold randomly and overexploitation. It is also listed in the threatened category of the International Union for Conservation of Nature and Natural Resources (IUCN) Red Data Book in 1998. Despite the fact that this family being listed in CITES and IUCN Red Data Book, no special strategy has been adopted for the protection of the species of this family in India. The family Marattiaceae which includes most of the extinct and some of the living threatened plants is also included as endangered in the IUCN Red list.

Every organism in the planet has its own role in maintaining the stability of its ecosystem. The tree ferns and giant ferns like all living organisms contribute a number of services to the animals including the humans and the ecosystem where they exist. It is very imperative to gather about the ecology, social and economic values and potential threats that have been pushing these plants towards endangerment. They have unique ecological niches and are highly sensitive to changes in microhabitat nearby their vicinity (Harper 1977). The absence of active community participation and awareness has hampered the conservation of tree ferns especially where subsistence livelihood system is highly dependent on forest resources. Now this is high time that efforts should be given both by local communities and government authorities in India for conservation and sustainable utilization of these ferns. Collaborative actions from conservationists, environmentalists, local communities, civil societies and government authorities are very important. Effort should be made to strongly link conservation and community ownership through citizen scientist approach for the conservation of the species. This linkage needs support from the knowledge generated from the scientific researches and the ethno-botanical value of tree ferns and giant ferns and feeding the knowledge into the policies to have concrete achievements for the conservation and management of the tree ferns.

3.6 Conclusion and Future Prospective

Throughout the world all the species of *Cyathea* are under great threat of extinction due to natural and manmade factors and covered under leading conservation umbrellas. They are placed in the Appendix II of CITES, Red listed in IUCN Red Data Books, mentioned as negatively listed plants, etc.

To achieve the goal for the conservation and sustainable management of tree ferns, we need to think on these objectives:

1. To supplement the general scientific understanding and more information regarding the development of database in relation to tree fern
2. To conserve tree fern and their associated species along with their habitats
3. To create a relation of tree ferns with livelihood by their wide and sustainable use
4. To create awareness regarding the conservation and importance of tree fern in our society
5. To emphasize the topic of conservation of tree fern by building the capacity of the concerned stake holders, their associated species and their habitat
6. To identify and validate the microclimate, ecosystem, reproductive behaviour, regeneration potential, ecological modelling and in vitro mass multiplication of tree and giant ferns
7. To promote the research for the concession of tree ferns by establishing research fund in coordination with the government, universities, etc.
8. To conduct the phytosociological behaviour of the tree ferns with the habitat association of other tree and invasive species and their impact on the tree ferns

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4 Status of Medicinal Plants in Context of Arunachal Pradesh

Tonlong Wangpan and Sumpam Tangjang

Abstract

The ethnomedicinal use of plants is one of the most successful criteria used by the pharmaceutical industry in finding new therapeutic agents for the various fields of biomedicine. There are more than one-tenth of plant species used in drugs and health products, with more than 50,000 species being used worldwide. Arunachal Pradesh alone has recorded more than 500 species of medicinal plants used by traditional herbal practitioners. These knowledge are generally passed down orally. About 70% of the herbalists are from old generation, which shows that this wisdom in the young generation is degrading fast due to rapid modernization. Unfortunately, medicinal plant resources are being harvested haphazardly in increasing volumes from its native habitat. Recently, various sets of recommendations relating to the conservation of medicinal plants have been developed, such as providing both in situ and ex situ conservation. Also, the policymaker of the state has come up with several plans with an idea of conservation of these plants, such as Herbal Garden, State CAMPA, Demonstration plot, Demonstration plot cum Nursery and MPCA (Medicinal Plants Conservation Area). The plants used in traditional medicines are potential source of therapeutics aids and have significant role in rural healthcare system all over the world. There is a vast scope for Arunachal Pradesh to emerge as a major player in the global herbal product-based medicine, owing to its rich biological resources. Therefore, it requires urgent systematic investigation using biotechnological tools to authenticate and develop new novel drugs from the rich bio-resources of the region.

Keywords

Bioactive compounds · Ethnobotany · Biodiversity · Northeast India

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_4

4.1 Introduction

The ethnomedicine is a complex multidisciplinary system constituting the use of plants, spirituality and the natural environment which has been the source of healing for ages. Research interest and activities in the area of ethnomedicine have increased tremendously in the last decade. Since the inception of the discipline, scientific research in ethnomedicine has made important contribution to the understanding of traditional subsistence, medical knowledge and practice. However, it is interesting to note that the ethnomedicinal use of plants is one of the most successful criteria used by the pharmaceutical industry in finding new therapeutic agents for the various fields of biomedicine. Today about 80% of the world's population rely predominantly on traditional medicinal plants and plant extracts for healthcare. According to data released by the World Health Organization (WHO 2002), ethnomedicine has maintained its popularity in all regions of the developing world, and its usefulness is rapidly expanding in the industrialized countries. The systematic study of medicinal and aromatic plant has been gaining its importance and momentum after the UN Convention on Biological Diversity (1992) wherein due importance has been given for systematic botanical and ethnomedicobotanical researches which include systematic documentation, conservation and sustainable utilization at global level.

WHO Geneva draft guideline on traditional medicine strategy (2004) revealed that 80% of global population depend on herbal medicine, mostly of botanical origin. The declaration further serves as directives to the member nations for systematic research, collection and harvesting of aromatic and medicinal plant resources. Medicinal plants have played an essential role in the development of present healthcare systems. Since many decades, man has relied on traditional medicinal plants for curing and preventing ailments, including the elevation of both physical and spiritual well-being. The use of herbal medicines to treat disease is almost universal among the many tribal societies, and the integrity and healing properties of these herbs were explored and witnessed by several people as well as many researches since ages. Likewise, herbal drugs were basis of Indian and Chinese medicine for millennia. Being considered as one of the 17 mega biodiversity countries of the world, India is rich in its biological resources. It has rich vegetation of more than 50,000 plant species of which about 20,000 plants have medicinal values. However, the traditional practitioners may be using more than the official statistics in preparation of herbal formulation. According to the report of WHO (World Health Organization), 80% of world population still depends on traditional medicines owing to its efficiency, safety, cost-effectiveness and easy accessibility. In this region, most herbal practitioners formulate and dispense their own recipes which seek attention of researchers for proper documentation and scientific intervention. North-eastern part of India, with richest reservoir of diversity of plants, is one of the biodiversity hotspots. Also, this region is known for diversified culture of inhabiting ethnic tribal communities.

The state of Arunachal Pradesh with total geographical area of 83,743km^2 lies in between latitude 26° 30′ N and 29° 30′ N and longitude 91° 30′ E and 97° 30′ E. The entire East Himalayan region including Arunachal Himalaya has been rated as one of the top 12th global biodiversity hotspots. Due to its unique topography, the forest of

Arunachal Pradesh is a hub centre of medicinal and aromatic plants, and the state comprises of all the characteristic vegetation type of the country. The state is also known for its rich and veritable cultural heritage wherein 26 major tribe and 110 subtribe living in close association with nature. The indigenous medicinal knowledge of Arunachal Pradesh has been found to be very rich and diverse among the tribes (Tag and Das 2006). The tribal population of this region possess treasured traditional knowledge since the time immemorial. This knowledge is completely based on their needs, instinct, observation, trials, errors and long-term personal experiences. Further, the traditional knowledge have always been developed, enhanced and passed on from one generation to the next, playing a vital role in the lives of these rural folks. In recent decade, plant-based medicine has gained its popularity worldwide because of their better cultural acceptability, compatibility and lesser side effect in comparison to its allopathic counterpart. The therapeutic activity of these herbs has made a significant contribution in the advancement of several local herbal therapies, but such folk traditional system is waning fast with the impact of modernity. Also, the increasing pressure from un-systemic harvesting, expansion of agricultural land, urbanization and other anthropogenic activities have further exploited the traditional herbal therapies.

4.2 Literature on Status of Medicinal Plants Research in Arunachal Pradesh

Arunachal Pradesh is known for its rich of medicinal plant heritage in nature. Such vast diversity at species level in medicinal plants sector confers scopes for priorities research in the state. Jain (1987) initiated some ethnobotanical research in Arunachal Himalaya. Subsequent documentation work on medicinal and ethnobotanical line was carried out in state by Hajra et al. (1996), wherein they mentioned 76 medicinal plants used by the Monpa tribe of the state. Tag et al. (2008) and Das (1986) reported ethnobotanical heritage of the Adi tribe of East Siang District wherein he also reported some significant medicinal species used by the tribes. The unexplored traditional knowledge relating to the diverse use of medicinal plant need to be documented with methodological rigour. Murtem (2000) reported some 25 species of wild edible plants of Nyishi tribe from Subansiri and Papum Pare District. Tag and Das (2004) documented 28 species of ethnobotanical plant used by Hill Miri (Nyishi) tribe of middle Subansiri which includes medicinal plants used in curing various ailments. Kala (2005) reported ethnomedicinal botany of the Apatani of Subansiri District wherein he mentioned 158 species of medicinal plant distributed across 73 families and 124 genera. Das and Tag (2005) reported 45 species of ethnomedicinal used by the *Khamti* tribe of Lohit District. They have reported five antimalarial plants four species in bone fracture, three species in anaemia and two species in snakebite, cancer, reproductive health and rabies and one plant each in tuberculosis, diabetes and jaundice, and the rest are used for curing different ailments. Hussain and Hore (2008) have mentioned 64 species of medicinal and aromatics plant distributed over 45 genera and 36 families that were collected from 6 districts of Arunachal Pradesh. Sarmah et al. (2008) reported 63 medicinal plant used by the Chakma community residing in the northwestern periphery of Namdapha National Park in curing various diseases. Kar and Borthakur (2008) dealt with 35 plant species use against dysentery, diarrhoea and cholera from erstwhile undivided Kameng District of Arunachal Pradesh wherein they emphasized on conservation of indigenous plant wealth through commercial cultivation and also for developing new and more efficacious remedies. Tag et al. (2009) highlighted diversity and distribution of ethnomedicinal plant used by the Adi tribe in East Siang District of Arunachal Pradesh, wherein they mentioned 41 species of ethnomedicinal plants belonging to 39 genera clubbed within 28 families that are mostly used in human and animal healthcare system among the rural Adi folk of East Siang District. Sen et al. (2009) reported 37 plant species belonging to 29 families used by Khamptis of Arunachal Pradesh used in traditional healthcare practices. Cut and wound, pain and inflammation caused by the insects and accidental injuries are one of the common ailments faced by the tribes of tropical and subtropical Arunachal Himalaya. In this line, Namsa et al. (2009) reported 34 species of anti-inflammatory plants used by the Khamti tribe of Lohit District. Tag et al. (2009) evaluated anti-inflammatory potential of *Chloranthus* species used by the Khamti tribe through mouse model experiment. Goswami et al. (2009) reported 10 medicinal plant used by Tagin tribe for curing dysentery, while Srivastava (2009) investigated medicinal plants of Adi tribe and reported 108 species of plant used in their day-to-day life. Kato and Gopi (2009) reported 12 species of insect that is used as edible food, but there is no proper documentation of plant species that is used for medicinal purpose in Galo tribe. Kagyung et al. (2010) mentioned 44 plant species belonging to 31 families used in treatment of various gastrointestinal diseases from Arunachal Himalaya. Doley et al. (2010) reported 15 species of lesser known ethnomedicinal plant used by the *Nyishi* community of Papum Pare District, while Shrivastava et al. (2010) appraised various uses of 106 plant species used among the Apatani tribe as food and ethnomedicine and for handicraft, hunting and cultural purposes. Panda and Srivastava (2010) reported new ethnomedicinal uses of seven species of Ericaceae by the people of Aka tribe of Jamiri, Nepalese of Dedza village and Bomdila and Dirang Monpas or Drangangpa of Bomdila in West Kameng District. Tangjang et al. (2011) reported 74 medicinal plants species from Tirap, Lower Dibang Valley and Papum Pare District of Arunachal Pradesh, Eastern Himalayan region. Khongsai et al. (2011) presented their cross-cultural ethnobotanical report on Apatani, Monpa, Sinpho, Nyishi, Tangsa, Padam and Idu tribe of Arunachal Pradesh, but they could quantify the data in quantitative ethnobotanical approach.

4.3 Diversity and Utility of Medicinal Plants in Arunachal Pradesh

More than one-tenth of plant species are used in drugs and health products, with more than 50,000 species being used (Chen et al. 2016). China and India have the highest numbers of medicinal plants used, with 11,146 and 7500 species, respectively (Rafieian-Kopaei 2013). Arunachal Pradesh alone has recorded 5000 species of angiosperms, of which more than 500 species of medicinal plants are reported from the state (Murtem 2000; Haridasan et al. 2003). Table 4.1 contains some of the important medicinal plants commonly used by the tribal community of this region.

4.4 Practitioners Eminence Knowledge

Traditional knowledge of the remedies is passed down orally, without any written records. About 70% of the herbalists are from old generation, strongly bonded with their traditional knowledge. The traditional wisdom in the young generation of most of the tribes is degrading fast due to the wind of modernization. Younger generations are least concerned about their ancestral wisdom. Herbal practitioners among the tribe being mostly marginal farmers, having very little income from their agriculture produce earn their sustenance partly from selling their herbal preparations. They collect the plants used in herbal preparation mostly collected from the forest. However, some expert practitioners have their own herbal garden. Thus, for such practitioners, the degree of dependence on the forest resources becomes partial.

4.5 Conservation Strategies and Sustainable Management of Medicinal Plants

The local communities are chiefly dependent on the traditional healthcare system, while the medicinal plants required in traditional therapy are mostly confined in the core of forest area. Unfortunately, medicinal plant resources are being harvested haphazardly in increasing volumes from its native habitat, which forced the policymaker to come up with an idea of conservation of these plants. Recently, conservation efforts have been initiated by State Medicinal Plants Board on conservation of endangered and endemic medicinal plants (Fig. 4.1). There are several ongoing projects on such plants including *Coptis teeta*, *Taxus baccata* and *Paris polyphylla* in several locations, while several projects were already completed such as Herbal Garden, State CAMPA, Demonstration plot, Demonstration plot cum Nursery and MPCA (Medicinal Plants Conservation Area). So, the in situ conservation approach of these plants in their local habitat is the need of an hour, before it is too late in our endeavour, with the help of local communities. Also, encouraging the local communities ex situ conservation of these medicinal plants would help them in deriving their livelihood, raising their living standard. Therefore, it is apparent that medicinal plants proffer with the low-cost investment and high-value income generation involving local communities in conserving medicinal plants would be a noble initiative of recent developments in researches.

Various sets of recommendations relating to the conservation of medicinal plants have been developed, such as providing both in situ and ex situ conservation. Natural reserves and wild nurseries are typical examples to retain the medical efficacy of plants in situ (or in their natural habitats), while botanic gardens and seed banks are important paradigms for ex situ conservation.

Table 4.1 Common medicinal plants of Arunachal Pradesh used in preparation of herbal formulation of traditional medicines

Sl. no.	Botanical name	Family	Utility
1.	*Abroma augusta* (L.) L.f.	Rubiaceae	Stomach ache, dysentery and vomiting
2.	*Achyranthes aspera* L.	Amarnanthaceae	Malaria
3.	*Achyranthes bidentata* Blume	Amaranthaceae	Plant is diuretic and astringent
4.	*Aconitum ferox* Wall.	Ranunculaceae	Underground roots and tubers are used in arrow poisoning by local hunters
5.	*Acorus calamus* L.	Araceae	Rhizome is used in respiratory disorders
6.	*Adiantum capillus-veneris* Linn.	Adiantaceae	Plant is used in cough
7.	*Aegle marmelos* Correa	Rutaceae	Fruit is used in diarrhoea and dysentery
8.	*Ageratum conyzoides*	Asteraceae	Blood flow, dysentery and diarrhoea, wound healer, veterinary, fish poison
9.	*Ajuga integrifolia* Buch.-Ham.	Lamiaceae	Malaria
10.	*Alangium alpinum* (C.B. Clarke) W.W. Sm. & Cave	Cornaceae	Used in abdomen of child to deworming
11.	*Allium hookeri* Linn.	Liliaceae	Skin diseases, veterinary, bone fracture
12.	*Allium sativum* Linn.	Liliaceae	Bone fracture and malaria
13.	*Alnus nepalensis*	Betulaceae	Disinfectant, diuretic, reduce swelling, prevent excessive sweating, also used for carpentry
14.	*Aloe barbadensis*	Liliaceae	Burns and cut, applied in face for smoother skin, anti-inflammatory, dermatitis
15.	*Aloe vera* (L.) Burm.f.	Xanthorrhoeaceae	Acid reflux
16.	*Alpinia nigra*	Zingiberaceae	Analgesic, appetizer, antifungal, jaundice, gastric ulcer, diuretic, expectorant, anti- inflammatory
17.	*Alstonia scholaris* (L.) R. Br.	Apocynaceae	Snakebite, skin diseases, malaria and inflammation
18.	*Amaranthus spinosus* L.	Amaranthaceae	Stomach ache, constipation
19.	*Amomum subulatum* Roxb.	Zingiberaceae	Fruit is used in cough and stomachic disorders
20.	*Andrographis paniculata* (Burm. f.) Nees.	Acanthaceae	Malaria
21.	*Anthocephalus chinensis* (Lam.) A. Rich. Ex. Wall.	Rubiaceae	Plant is used as tonic in dysentery and spleen disorders
22.	Argyreia nervosa	Convolvulaceae	Malaria

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
23.	Argyreia nervosa (Blume.) Boj.	Convolvulaceae	Rheumatism and as tonic, wounds and malaria
24.	*Arisaema consanguineum*	Araceae	Locally used for arrow poisoning for hunting
25.	*Artemisia nilagirica*	Asteraceae	In headache and stomach pain, used as vegetable, to get relief from asthma
26.	*Artemisia indica* Willd.	Asteraceae	Malaria
27.	*Artemisia nilagirica* (Clarke) Pamp.	Asteraceae	Wounds, cuts, scabies and inflammations
28.	*Artemisia vulgaris* L.	Asteraceae	Root is used as tonic; plant is used as anthelmintic
29.	*Arundina graminifolia* (D.Don) Hochr.	Orchidaceae	Intestinal biliary colic, abdominal pain
30.	*Asplenium phyllitidis*	Aspleniaceae	Antioxidant, antimicrobial, locally used for decoration in local festival
31.	*Azadirachta indica* A. Juss	Meliaceae	Stomach disorder, diarrhoea and malaria
32.	*Baliospermum calycinum*	Euphorbiaceae	Purgative, stimulant, antidote in snakebite, asthma, jaundice, gastric problem, gout and rheumatism, toothache
33.	*Bambusa tulda*	Poaceae	Bamboo shoots are consumed as integral part of diet
34.	*Bauhinia purpuea* L.	Caesalpiniaceae	Stem bark is used in throat disorder, worm infestation
35.	*Bauhinia variegata*	Fabaceae	Asthma, ulcer, digestive problem, antioxidant, locally also used as spies
36.	*Begonia josephii* A. DC.	Begoniaceae	Dysentery
37.	*Berberis aristata* DC	Berberidaceae	Root bark is used in diabetes, jaundice and leucoderma
38.	*Bidens pilosa* Linn.	Asteraceae	Wounds and skin inflammations
39.	*Blumea adamsii* J.-P. Lebrun & Stork	Compositae	Constipation
40.	*Bombax ceiba* L.	Bombaxaceae	Root and stem bark are aphrodisiac, stimulant
41.	*Brassica campestris* Linn.	Brassicaceae	Oil from seed along with ginger, turmeric, garlic used in various ailments
42.	*Brassica rapa* L.	Brassicaceae	Bladder inflammation
43.	*Bryophyllum adelae* (Hamet) A.Berger	Crassulaceae	Dysentery
44.	*Bryophyllum calycinum* Salisb.	Crassulaceae	Leaf juice is used in kidney stone and urinary disorders
45.	*Buddleja asiatica* Lour.	Scrophulariaceae	Diarrhoea, beverages fermentation

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
46.	Calamus inermis	Arecaceae	Malaria
47.	*Callicarpa arborea*	Verbenaceae	Insect repellent, skin diseases, scorpion sting, also used in toothache
48.	*Callicarpa macrophylla* Vahl	Verbenaceae	Fruit is used in blood dysentery and skin diseases
49.	*Calotropis gigantea* (L.) R.Br. ex Ait	Asclepiadaceae	Flowers are used in cough; root as *Rasayana*
50.	*Campylandra aurantiaca Wall*	Liliaceae	Indigestion
51.	*Cannabis sativa* L.	Cannabinaceae	Plant leaf is used in digestion and dysentery
52.	*Cannabis sativa*	Cannabaceae	Stomach disorder, hypnotic, sedative, anti- inflammatory, analgesic, nausea, vomiting, hallucinogenic
53.	*Carica papaya* L.	Caricaceae	Malaria and gastric
54.	*Cassia alata* L.	Caesalpiniaceae	Leaf is used in ring worm; leaf decoction is used in bronchitis and asthma
55.	*Cassia fistula* Linn.	Caesalpiniaceae	Leaves and seeds are laxative. Leaf juice is used in skin diseases
56.	*Cassia tora* Linn.	Caesalpiniaceae	Leaf paste and oil are used in skin diseases
57.	*Centella asiatica* (L.) Urban	Apiaceae	Plant is used in arthritis, diabetes, blood disorders and brain tonic
58.	*Cephalanthus occidentalis* L.	Caesalpiniacae	Plant is digestive and used in skin diseases, fever and cough
59.	Chenopodium album	Chenopodiaceae	Locally used in preparing local wine and also eat as a vegetable
60.	*Chromolaena odoratum*	Asteraceae	Wound healing, relieve pain, anti-gonorrheal, diuretic, skin disease
61.	*Chrysanthemum indicum*	Compositae	Chest pain, prostate cancer, antidiabetic, stomach ache, fever, dysentery, cold, swelling
62.	*Cinnamomum camphora* Nees Eberm.	Lauraceae	Leaf is useful in diarrhoea and skin diseases
63.	*Cinnamomum tamala* Nees Eberm.	Lauraceae	Leaf is used in cough, digestion and diabetes
64.	*Cissampelos pareira* L.	Menispermaceae	Root is bitter, diuretic and useful in fever and dysentery
65.	*Citrus indica* Tanaka.	Rutaceae	Face pimples removal
66.	*Citrus limon* L. *(Linn.) Burm.*	Rutaceae	Dysentery, dehydration and stomachic trouble and liver problem
67.	*Citrus maxima* (Burm.) Merrill.	Rutaceae	Fruit is digestive and cardiotonic

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
68.	*Citrus medica*	Rutaceae	Treatment of scurvy, intestinal ailments, antidote, anticancer, weak eyesight, vomiting, skin diseases, haemorrhoids
69.	*Citrus reticulata* Blanco	Rutaceae	Fruit juice is used in rheumatism, fever, blood disorder and digestion
70.	*Citrus sinensis* (L.) Osbeck	Rutaceae	Kidney stone problem
71.	*Clerodendrum colebrookianum* Walp.	Verbenaceae	High blood pressure, stomach disorder, headache
72.	*Clerodendrum glandulosum* Lin dl.	Lamiaceae	Malaria
73.	*Clerodendrum serratum* (Linn.) Moon	Verbenaceae	Root is useful in malaria
74.	*Colocasia esculenta*	Araceae	Fever and cough, petiole juice is used as styptic and stimulant
75.	*Coptis teeta Wall.*	Ranunculaceae	Malaria, fever, jaundice, stomach ache, liver diseases, hypertension and diabetes
76.	*Costus speciosus (Keon.) Sm.*	Zingberaceae	Rhizome is used as worm repellent and blood purifier
77.	*Crassocephalum crepidioides*	Asteraceae	Antimalarial, analgesic, epileptic, wound bleeding, headache
78.	*Crotolaria juncea* L.	Fabaceae	Seeds, leaves are used in insanity, fever with catarrhal
79.	*Curcuma caesia* Roxb.	Zingibaraceae	Rituals and pimple removal
80.	*Curcuma longa* L.	Zingiberaceae	Stomach ache
81.	*Cyclosorus parasiticus*	Thelypteridaceae	Gout and rheumatism, anthelmintic, antifungal and antibacterial
82.	*Datura stramonium* L.	Solanaceae	Leaves are used as narcotic, sedative and diuretic
83.	*Debregeasia longifolia*	Urticaceae	Antitumours, rheumatism; juice is applied to the areas of the skin affected by scabies
84.	*Dendrocalamus strictus Nees.*	Poaceae	Wound or cut
85.	*Dillenia indica* Linn.	Dilleniaceae	Fruit is used to improve appetite, heart fever, cough and mouth disease
86.	*Dioscorea alata* Linn.	Dioscoreaceae	Gastritis
87.	*Dioscorea bulbifera* L.	Dioscoreaceae	Root is aphrodisiac and tonic
88.	*Dioscorea floribunda*	Dioscoreaceae	Intestine diverticulosis, gall bladder pain, for increasing, energy, rheumatoid arthritis
89.	*Dioscorea pentaphylla* L.	Dioscoreaceae	Root is aphrodisiac and tonic
90.	*Drymaria cordata* (L.) Willd. ex Schult.	Caryophyllaceae	Vomiting

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
91.	*Drymaria diandra* Blume	Caryophyllaceae	Plant juice is laxative and ant febrile
92.	*Elaeocarpus floribundus* Blume	Elaeocarpaceae	Bark and leaf infusion is used as mouth wash for inflamed gums. Fruit is rich source of vitamin C and digestive
93.	*Eleusine coracana*	Poaceae	Cough, cold, congestion, antimicrobial, anti- inflammatory, food preservative
94.	*Elaeocarpus floribundus*	Elaeocarpaceae	Fruits have medicinal properties
95.	*Embelia ribes* Burm. f.	Myrsinaceae	Fruit and root used in worm infestation, liver disorders and as tonic
96.	*Emblica officinalis*	Euphorbiaceae	Liver tonic, antidiabetic, asthma, peptic ulcer, analgesic, heart problems, jaundice
97.	*Erigeron bonariensis*	Asteraceae	Vapour of leaves is inhaled in sinus problem
98.	*Eryngium foetidum* L.	Apiaceae	Dysentery
99.	*Erythrina stricta roxb.*	Fabaceae	Scorpion sting, gout, anti-inflammatory, anxiolytic property
100.	*Euphorbia ligularis roxb*.	Euphorbiaceae	Bone fracture, arrow poisoning, antiarthritis, purgative, asthma, expectorant
101.	*Fagopyrum esculentum* Moench	Polygonaceae	Stomach ache
102.	*Ficus cordata* (Thunb.)	Moraceae	Dysentery
103.	*Ficus glomerata* Roxb.	Moraceae	Diabetes and common fodder
104.	*Garcinia pedunculata* Roxb.	Clusiaceae	Leaves used in dysentery and cough
105.	*Gerbera piloselloides*	Compositae	Treat cold, fever, acute conjunctivitis, rheumatic pain
106.	*Gmelina arborea*	Lamiaceae	Purify blood, stomach trouble, leprosy, diuretic, anaemia, snakebite and scorpion sting, ulcers
107.	*Gnaphalium affine*	Asteraceae	Treatment of common cold, antimicrobial
108.	*Gonostegia hirta* (Blume ex Hassk.) Miq.	Urticaceae	Gastric problem, constipation
109.	*Gymnocladus assamicus* Kanjilal.	Fabaceae	Detergent (soap), religious and veterinary
110.	*Gynocardia odorata* R.Br.	Flocourtiaceae	Fruit is used in tooth ailment
111.	*Gynura crepidioides* (BTH.) Moore.	Asteraceae	Vegetables and stomach disorder
112.	*Hedychium gracile*	Zingiberaceae	Mosquito repellent, antifungal, also used as spies

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
113.	*Hedychium aureum* C.B. Clarke & H. Mann ex Baker	Zingiberaceae	Liver problem
114.	*Hedychium coccineum*	Zingiberaceae	Cure asthma and indigestion, antimicrobial, also used for local ornamental purposes
115.	*Hedyotis scandens* Roxb.	Rubiaceae	Gastritis, beverages fermentation
116.	*Hibiscus fragrans* Roxb.	Malvaceae	Paste of leaves/flowers used in hair fall/ dandruff problem
117.	*Houttuynia cordata* Thunb.	Saururaceae	Stomach ache, diarrhoea and deworming
118.	*Hydrocotyle sibthorpioides* (Lam.)	Apiaceae	Dysentery
119.	*Laggera pterodonta*	Asteraceae	Anthelmintic, treatment in inflammation and swelling
120.	*Leucas aspera* Spreng.	Lamiaceae	Cuts and wounds, earache, inflammation
121.	*Lindera neesiana* (Wallich ex Nees) Kurz.	Lauraceae	Anthelmintic, diarrhoea, scabies, vegetable oils
122.	*Litsea cubeba* (Lour) Pers.	Lauraceae	Condiments, eczema, heart disease and stomach disorder
123.	*Litsea polyantha*	Lauraceae	Antidepressant, bruises, anti-infertility, cytotoxic, antifungal, insecticide, antiseptic
124.	*Macaranga denticulata*	Euphorbiaceae	Skin damage, antibacterial, fungal infection, wound healing, stomach pain
125.	*Mentha arvensis*	Lamiaceae	Stomach disorder, influenza, appetizer, gall bladder problems
126.	*Mikania scandens*	Asteraceae	Blood clotting, insect bites and sting, antifungal, gastric ulcer, locally used as ornamental plant
127.	*Mimosa pudica*	Mimosaceae	Antidepressant, anticonvulsant, antifertility, sinus, dysentery, tumour, insomnia, antidote in snake poison
128.	*Momordica charantia* Linn.	Cucurbitaceae	Anthelmintic, diabetes
129.	*Moringa oleifera*	Moringaceae	In liver disorder, water purification, etc.
130.	*Mucuna pruriens*	Fabaceae	Parkinson's disease, antiepileptic, antidote in snakebite, in the treatment of itching
131.	*Murraya paniculata*	Rutaceae	Analgesic, antidiarrhoea, anti-inflammatory
132.	*Musa acuminate*	Musaceae	In anaemia, diarrhoea, constipation, ulcer, for menstrual cramps
133.	Musa balbisiana	Musaceae	Blood dysentery, diarrhoea

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
134.	*Musa sapientum* L.	Musaceae	Dysentery, urinary problems
135.	*Musa sapientum*	Musaceae	Boiled unripe fruits are given during dysentery, diabetes, anaemia
136.	*Mussaenda glabra* Vahl	Rubiaceae	Constipation
137.	*Mussaenda roxburghii*	Rubiaceae	Detoxify mushroom poison, antipyretic, diuretic, treat blemishes on tongue, acute gastroenteritis
138.	*Mycetia longifolia*	Rubiaceae	Pain relief, ulcer, wound healing, inflammation, antinociceptive
139.	*Ocimum sanctum* Linn.	Lamiaceae	Stomach disorder, inflammations, wounds, cuts
140.	*Ocimum tenuiflorum* L.	Lamiaceae	Gastric problem and malaria
141.	*Opuntia monacantha* (Willd.) Haw.	Cactaceae	Dysentery
142.	*Oroxylum indicum*	Bignonaceae	Cancer, antimalarial, jaundice, anti-arthritic, diarrhoea, fever, ulcer, anti-inflammatory
143.	*Oroxylum indicum* (L.) Kurz.	Bignoniaceae	Malaria and jaundice
144.	*Oxalis corniculata*	Oxalidaceae	Dyspepsia, bowel disorder, anaemia, scurvy, cure opacity of cornea
145.	*Oxalis corniculata* L.	Oxalidaceae	Dysentery
146.	*Oxalis debilis* Kunth	Oxalidaceae	Gastric problem
147.	*Oxyspora paniculata*	Melastomataceae	Treatment of various liver disorder, stomachic, antidote against snake poisoning
148.	*Paederia foetida* L.	Rubiaceae	Stomach ache, gastric, indigestion
149.	*Perilla ocymoides*	Lamiaceae	Locally used as spices or as a curry, in treatment of asthma, also used for nausea, sunstroke, reduce muscle spasms
150.	*Persicaria barbata* (L.) H.Hara	Polygonaceae	Constipation
151.	*Phlogacanthus curviflorn*	Acanthaceae	Boiled leaf juice are used to cure cough and fever
152.	*Phlogacanthus thyrsiflorus*	Acanthaceae	Expectorant, asthma, stomach problems, fever
153.	*Phrynium capitatum*	Marantaceae	Antidiabetic, analgesic, anti-hyperglycaemic, locally used as wrapping and packaging materials
154.	*Physalis minima*	Solanaceae	Gastric trouble, laxative, diuretic, anticancer, in hypertension, anti-inflammatory

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
155.	*Piper betel*	Piperaceae	Leaf after rubbing with mustard oil and warming over burning charcoal is applied to belly during stomach ache of children
156.	*Piper longum* L.	Piperaceae	Malaria
157.	*Piper pedicellatum* C. CD.	Piperaceae	Stomach ache, dysentery
158.	*Plantago erosa*	Plantaginaceae	Constipation, improves digestion, astringent, demulcent, diuretic, expectorant, anti-inflammatory
159.	*Plantago major* Linn.	Plantaginaceae	Wounds, inflammations, veterinary
160.	*Polygonum hydropiper* Linn.	Polygonaceae	Fish poison
161.	*Pouzolzia bennettiana* Wight.	Urticaceae	Stomach disorder
162.	*Pouzolzia hirta* Blume ex Hassk.	Urticaceae	Acidity, gastric, appetizer
163.	*Pouzolzia viminea*	Urticaceae	Bleeding, sore
164.	*Psidium acranthum* Urb.	Myrtaceae	Diarrhoea
165.	*Psidium guajava* Linn.	Myrtaceae	Diarrhoea, cough
166.	*Punica granatum* Linn.	Punicaceae	Stomach ache and diarrhoea
167.	*Rauvolfia serpentine*	Apocynaceae	Antihypertensive, sedative, hypnotic, liver ailments, constipation, epilepsy, schizophrenia
168.	*Rhododendron arboreum* Smith. Gurans	Ericaceae	Dysentery, diarrhoea, throat clearance when fish bones get stuck in the gullet
169.	*Ricinus communis* L.	Euphorbiaceae	Abdominal pain
170.	*Rotheca serratum* (L.) Steane & Mabb.	Verbenaceae	Constipation
171.	*Rubia manjith Roxb.*	Rubiaceae	Used to cure headache, cough, cold, locally used as a textile dye
172.	*Rubus acanthophyllos* Focke	Rosaceae	Liver problem
173.	*Saccharum officinarum* Linn.	Poaceae	Jaundice and malaria
174.	*Sapium baccatum*	Euphorbiaceae	Analgesic, antimicrobial, skin irritant, locally used as fish poison
175.	*Saurauia armata* Kurz. Syn.	Saurauiaceae	Leaves applied on the wounds
176.	*Schima wallichii* (DC.) Korth.	Theaceae	Seeds used in stomach trouble

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
177.	*Scoparia dulcis*	Plantaginaceae	Jaundice, diabetes, antioxidant, diuretic, analgesic, anti-inflammatory
178.	*Senna tora* (L.) Roxb.	Leguminosae	Liver problem
179.	*Sida rhombifolia* (L.) Raf.	Malvaceae	Gastric problem
180.	*Solanum abancayense* Ochoa	Solanaceae	Constipation
181.	Solanum indicum	Solanaceae	Ringworm, gout, asthma, diuretic, stimulant, expectorant, toothache
182.	*Solanum indicum* Linn.	Solanaceae	Anthelmintic, beverages fermentation
183.	*Solanum khasianum*	Solanaceae	Root decoction is used to treat malaria, antifertility property, anti-inflammatory
184.	*Solanum kurzii*	Solanaceae	Appetizer, toothache, roughage, berry is given to patient of stone problem
185.	*Solanum nigrum* L.	Solanaceae	Diarrhoea
186.	*Solanum spirale Roxb.*	Solanaceae	Stomach ache and indigestion
187.	*Solanum torvum* Sw.	Solanaceae	Stomach ache, spleen problem and anthelmintic
188.	*Solanum xanthocarpum* Burm. f.	Solanaceae	Dental problem
189.	*Spilanthes oleracea* Murr.	Asteraceae	Stop bleeding, skin infections and gastritis, fish poison
190.	*Spilanthes paniculata Wall.*	Asteraceae	Toothache
191.	*Spilanthes acmella*	Asteraceae	Antimalarial, antipyretic, analgesic, flowers are chewed during toothache
192.	*Spondias radlkoferi* Donn. Sm	Anacardiaceae	Dysentery
193.	*Stellaria media* (Linn.) Vill.	Caryophyllaceae	Paste of crushed plant used to stop bleeding
194.	*Stephania japonica* Miers.	Menispermaceae	Stem used in dysentery, leaves in malarial fever
195.	*Sterculia hamiltonii* (Kuntze) Adelb. Syn.	Sterculiaceae	Ayurvedic preparations have medicinal uses
196.	*Stevia suaveolens* Lag.	Compositae	Stomach ache
197.	*Swertia chirayita*	Gentianaceae	Plant decoction is taken in fever, anti-hepatitis B
198.	*Syzgium cumini*	Myrtaceae	Astringent, carminative, antidiabetic, stomach disorder, diarrhoea and dysentery
199.	*Tacca integrifolia*	Dioscoreaceae	Skin disease, leprosy, wound healing, stomach pain, dysentery

(continued)

Table 4.1 (continued)

Sl. no.	Botanical name	Family	Utility
200.	*Terminalia bellerica Roxb.*	Combretaceae	Cold, cough, fever
201.	*Terminalia chebula* Retz.	Combretaceae	Malaria
202.	*Terminalia myriocarpa*	Combretaceae	Bark extract is given in chest pain and as cardiac stimulant
203.	*Thalictrum foliolosum* DC.	Ranunculaceae	Decoction of root used in fever and eye diseases
204.	*Thunbergia grandiflora* (Roxb. ex Rottl.) Roxb.	Acanthaceae	Gastric problem
205.	*Tinospora cordifolia* Miers.	Menispermaceae	Stem used in stomach trouble, dysentery and skin diseases
206.	*Zanthoxylum rhetsa DC*	Rutaceae	Jaundice, wart
207.	*Zanthoxylum armatum*	Rutaceae	Seed and bark are used as tonic during fever and cholera, stomach disorder
208.	*Zanthoxylum hamiltonianum Wall.*	Rutaceae	Malaria
209.	*Zanthoxylum nitidum* (Roxb.) DC.	Rutaceae	Gastric problem
210.	*Zanthoxylum oxyphyllum* Edgew.	Rutaceae	Stomach ache
211.	*Zingiber officinale* Rosc.	Zingiberaceae	Cough and stomach ache
212.	*Zingiber zerumbet (L) Smith*	Zingiberacea	Stomach ache, vomiting, diarrhoea, cough

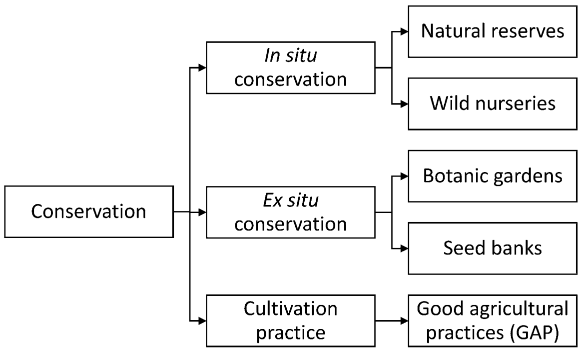

Fig. 4.1 Methodological systems involved in the conservation of medicinal plant

In situ conservation of whole communities allows us to protect indigenous plants and maintain natural communities, along with their intricate network of relationships. It also increases the amount of diversity that can be conserved and strengthens the link between resource conservation and sustainable use. However, the successful in situ conservation depends on rules, regulations and potential compliance of medicinal plants within growth habitats. Some of the best examples of in situ conservations are natural reserves and wild nurseries. Natural reserves are protected areas of important wild resources created to preserve and restore biodiversity. On the other hand, a wild nursery is established for species-oriented cultivating and domesticating of endangered medicinal plants in a protected area, natural habitat or a place that is only a short distance from where the plants naturally grow.

Ex situ conservation is not always sharply separated from in situ conservation, but it is an effective complement to it, especially for those overexploited and endangered medicinal plants with slow growth, low abundance, and high susceptibility to replanting diseases. It aims to cultivate and naturalize threatened species to ensure their continued survival and sometimes to produce large quantities of planting material used in the creation of drugs, and it is often an immediate action taken to sustain medicinal plant. Some of the good examples of ex situ conservation includes botanic gardens and seed bank. Botany garden maintains the ecosystems to enhance the survival of rare and endangered plant species. It involves a wide variety of plant species grown together under common conditions and often contain taxonomically and ecologically diverse flora. On the other hand, seed banks offer a better way of storing the genetic diversity of many medicinal plants ex situ than through botanic gardens and are recommended to help preserve the biological and genetic diversity of wild plant species.

Apart from in situ and ex situ, cultivation of medicinal plants will provide the opportunity to use new techniques to solve problems encountered in the production, such as toxic components, pesticide contamination, identification error, etc. It can improve the yields of active compounds and ensures the stability of production.

4.6 Conclusion

The plants used in traditional medicines are potential source of therapeutics aids and have significant role in rural healthcare system all over the world. There is a vast scope for Arunachal Pradesh to emerge as a major player in the global herbal product-based medicine, owing to its rich biological resources. The medicinal plants sector provides employment and income opportunities for a large number of indigenous folk in this region. The rich traditional knowledge spawning in this region should be given priority for better utilization of the available resources. However, there is a need of detail study of the medicinal plants used by the community with possible phytochemical investigation. Such investigation may further highlight the true value of these plant species so that they can be managed and conserved for the benefit of the local community in particular and for the welfare of mankind in general. Therefore, it requires urgent systematic investigation using biotechnological tools to authenticate and develop new novel drugs from the rich bio-resources of the region. Scientific approach for their exploration, utilization, conservation and value addition may be the key points for entrepreneurship development by exploiting the indigenous knowledge on medicines.

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5 Nutrient Enrichment in Lake Ecosystem and Its Effects on Algae and Macrophytes

Divya Dubey and Venkatesh Dutta

Abstract

Freshwater lakes constitute a significant part of the hydrological cycle of the earth as they maintain ecological balance and support diverse aquatic biodiversity. Increasing urbanization, land use modifications, pollution, and various other anthropogenic activities including catchment land use change around lakes cause stress on lake ecosystem which include eutrophication, acidification, siltation, introduction of exotic macrophytic species, and toxic contamination. Eutrophication is considered as a major stress for lake ecosystem as increasing nutrients mainly nitrogen and phosphorous result in greater density of macrophytes that leads to change in trophic states of lakes. Unhealthy anthropogenic activities leading to eutrophication and excessive growth nuisance of macrophytes result in disturbed ecological balance within the lakes. As reported by many limnologists, macrophytes in freshwater lakes are highly sensitive to slight change in climatic conditions, along with changes in nutrient concentration, because of which macrophytes are considered as bioindicators for assessing the trophic states of lakes. This review paper presents an overview of the problem of nutrient enrichment leading to eutrophication, characteristics of different trophic states, and effects of nutrient enrichment on macrophytes and algal species present in lakes. Eutrophication causes changes in physical and chemical quality of water and sediments which affects the whole ecohydrology of lakes along with changes in composition, diversity and richness, and species succession of algae and macrophytes along with change in trophic state. Eutrophication results in growth of undesirable and harmful algal species and flourishing growth of exotic invasive macrophytes resulting in altered species composition and habitat structure which affects overall ecological functioning of lakes and results in extinction

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_5

of many sensitive species of algae and macrophytes. This may disturbs the overall lacustrine food web irreversibly affecting our aquatic biodiversity adversely.

Keywords
Lakes · Eutrophication · Algae · Macrophytes · Species succession

5.1 Introduction

5.1.1 Lakes

Lakes are treasured water resource that serve various ecological and economic functions in an ecosystem. Lakes support a large section of human population by providing various direct and indirect ecological and economic benefits. The water quality and ecological integrity of several lakes around the world and particularly in India are getting deteriorated, often with unrecoverable impacts by natural means. Anthropogenic activities have a major influence on lake ecosystem affecting the quantity and quality of water which affect aquatic biodiversity, nutrient dynamics and habitat suitability. The increasing anthropogenic pressure on the lakes which include encroachments near shoreline area and pollution from domestic, industrial and agricultural sectors are the main cause of increasing pressure and deterioration of lake ecosystem (Brucet et al. 2013).

The growth of aquatic algae and macrophytes within the lakes is primarily regulated by various climatic, geographic, physical, and chemical factors which directly or indirectly affect the natural process (Reynolds and Reynolds 1985). The concentration and nature of nutrients, turbulent mixing, and food web are the main factors which affect the biomass trends and the composition of macrophytes and algae in lakes (Rhew et al. 1999). Composition of aquatic plant and animal is influenced by the nutrients present in the lakes; many algal species exploit both inorganic and organic nutrient sources with changeable capabilities. Different nitrogen sources encourage and contribute the growth of different dominant algal species in the lake ecosystem (Berman and Chava 1999).

Lakes support primary producers (algae and macrophytes) that form the base of aquatic food chain and the proper function of ecological services, but due to negligence of human beings, conditions of lakes are deteriorating day by day. Pollution and degradation cause variation in water quality and sediment characteristics of lakes that disturb the community structure of aquatic biota affecting the proper functioning of lakes as well as reducing the native biodiversity (Bolpagni and Piotti 2015; Bolpagni and Piotti 2016).

The main motivation for this review is that, nowadays lake ecosystems are exposed to severe ecological degradation, nutrient enrichment, and anthropogenic encroachment leading to degraded condition, and that’s why there is an urgent need to understand the main causes and effects of nutrient enrichment and eutrophication which causes ecological, economic, and environmental impacts on lake ecosystem at national and global scale (Leonhard 2013). Lakes in urban areas mainly serve as an abandoning ground of solid waste, sewage and construction waste. Therefore, proper monitoring of lake ecosystem along with checking the consequence of nutrient enrichment on various algal and macrophyte species is required to evolve management and conservation of the aquatic ecosystem and biodiversity present in it.

5.1.2 Major Stressors in Lake Ecosystem

Presently lakes are getting fewer in number due to increasing human pressure and encroachment, and the ones which exist are in fragile condition with deteriorated water quality and depressed catchment areas. Due to increasing population and irrational human activities, lake ecosystems are subjected to various types of stresses which include eutrophication, siltation, acidification, occurrence of exotic species and toxic contamination by heavy metals and pesticides both in the sediments and water. Major stressors and their causative agents having long-term impact along with its case study and restoration are elaborated in Table 5.1. As shown in the table, lakes are subjected to various stresses, but eutrophication is considered as a major problem as nutrient enrichment from human activities has increased resulting in adverse effect on aquatic biodiversity and most probably leading to extinction of native sensitive species of flora and fauna present in the lakes.

5.2 Nutrient Enrichment Leading to Eutrophication in Lakes

5.2.1 Major Nutrients Responsible for Nutrient Enrichment in Lakes

Within the lake, nutrient of shortest supply is phosphorous as compared to nitrogen (Novotny 1994). Phosphorous does not have any atmospheric reservoir as nitrogen has, and that is the reason of its limited availability as compared to nitrogen. Phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth and they are usually not soluble in water. Phosphorous strongly absorbs to soil particles which makes dry deposition and erosion as one of the chief sources of phosphorous in water. Although phosphorous is a naturally scarce nutrient, anthropogenic activities like industrialization, urbanization, sewage discharge, agricultural runoff and detergents used for domestic purposes are major sources for the rise in phosphorous concentration in lakes (Chapra 1997; Stednick and Hall 2001).

Nitrogen is most plentiful in the environment as compared to phosphorous, and therefore it is not a limiting nutrient in lacustrine ecosystem influencing primary productivity of lake ecosystem (Chapra 1997). However, both forms of nitrogen, that is bioavailable and total concentrations are still used for predicting eutrophication. Inorganic nitrogen or bioavailable nitrogen constitutes ammonium, nitrate, and nitrite. Total nitrogen constitutes total Kjeldahl nitrogen, nitrate, and nitrite. Nitrogen

Table 5.1 Major stress and their causative agents having their long-term impact on the lake ecosystem with case studies and restoration measures (Compiled from National Research Council 1992)

Type of stress	Major drivers or causative agents	Impact on lake ecosystems	Case study	Restoration measure
Eutrophication	*Nitrogen and phosphorous* input from various point and nonpoint sources	Nutrient enrichment of nitrogen and phosphorous causes excessive growth of *algal blooms* and macrophytes, which causes decrease in dissolved oxygen concentration in lakes resulting in *choked and anoxic condition*	Large, deep and eutrophic medical lake in Eastern Washington. Eutrophic condition arises due to wastewater diversion and high rate of internal nutrient enrichment resulting in dense blue-green algal bloom causing anoxic condition and decrease in fish population. To overcome nutrient enrichment, aluminum sulfate was added in the lake to remove the excess phosphate. This treatment reduces the phosphorous concentration and algal blooms and helps in restoration and rejuvenation of lake	Nutrient source reduction and diversion, land disposal
				Wastewater treatment
				Interception of nonpoint sources of pollution, dilution, aeration, dredging, biomanipulation
				Artificial circulation, flushing, sediment skimming, sediment oxidation, sediment desiccation, alum treatment
Siltation	*Suspended particulate matter, earthly clastic material*, dominated by *silt and clay*. Soil erosion and sediment spill and agricultural practices in lakes catchment area	It *reduces the transparency* and *increases the turbidity* of lakes. It affects the photosynthetic process of aquatic flora as suspended particles do not allow the sunlight into the pelagic and benthic region of lake ecosystem	Siltation problem is usually found in the central and southeastern part of the United States, agricultural practice of row crop farming and existence of erosive soils are the main causes of siltation. Excessive sediment buildup makes large area of lakes unsuitable for recreational purpose, it	Reduction of nutrient source and its diversion, interception of non-point sources, sediment skimming, sediment desiccation, dredging

			adversely affects the habitat and diversity and spawning of fishes. These suspended particles inhibit the submerged plant productivity	
Acidification	Its causes are natural as well as anthropogenic including *acid rain and global warming caused* due to increase in atmospheric carbon dioxide concentration	Acidification causes *decrease in pH*, leading to extinction *of acid-sensitive species of aquatic plant and animals*. It increases water clarity and *affects biodiversity* by increasing abundance of acid-tolerant species	Some lakes in Florida having an acidic pH of 4.5 have vigorous and healthy fish communities, although fish production is low because acidic lakes mainly incline to be oligotrophic in nature. Fish productivity mainly depends on nutritional status than its pH. Mature fish species are more tolerant than the immature forms	Nutrient source reduction
			Several researches had revealed that acidification is a major factor causing loss of game fish (trout) in lake Adirondack over the past 50–60 years. Various species of fishes suffer from mortality or reproductive failure due to change in pH of lake water. Acidic condition is not favorable for fishes	Dilution, flushing, in-lakes methods, liming of lakes.
Exotic species	It is assumed that exotic species are introduced accidently and sometimes intentionally in lakes. Dispersal through ballast water are the common modes of	Exotic species invasion leads to *extinction of native species* effecting native biodiversity. Exotic sp. with low nutritive value like purple loosestrife and	Great Lakes were invaded by zebra mussel (*Dreissena polymorpha*) which was first reported in 1988 in Lake St. Clair, these species were	In-lakes methods, biomanipulation, biocides (algicides/herbicides/pesticides) control, biocontrol agent, bioharvesting

(continued)

Table 5.1 (continued)

Type of stress	Major drivers or causative agents	Impact on lake ecosystems	Case study	Restoration measure
	transport. Exotic invasive species threatened the survival of native species. Nutrient discharge in Lakes provides *favorable condition for the growth and reproduction exotic species*	water hyacinth provide a *poor base for the aquatic food chain effecting the overall ecological process*	found throughout the Lake Erie in western basin during 1989. They were introduced in Great Lakes by the discharge of ballast water from ocean-going vessels. It caused hindrance with water intake from power plant and municipal and industrial wastewater treatment. They further disturb the food web affecting the overall aquatic biota directly or indirectly.	
Toxic contaminants	*Pesticides and heavy metals*, released by anthropogenic activities from point sources, runoff from non-point sources, and atmospheric deposition	*Bioaccumulation* and *biomagnification* in aquatic ecosystem which adversely affect the aquatic food chain and food web	In Lake Superior, high amount of PCBs are found in some trout above the permissible limit. In spite of the minor point and nonpoint sources of PCBs, atmospheric transport is the main source. Hence it adversely affects the lake aquatic biota and disturbs their whole aquatic ecological balance	Nutrient source reduction Product modification, wastewater treatment, nonpoint sources interception, dilution Flushing, in-lakes methods, sediment skimming, deepwater discharge

is not readily absorbed by soil particle as phosphorous does, it exists in the atmosphere and may be removed through the process of denitrification (Chapra 1997).

Nitrogen and phosphorous ratio is useful in finding out the nutrient in shortest supply that will limit the growth of primary producer (algae and macrophytes) in lakes (Chapra 1997). Majority of lakes are found to be nitrogen or phosphorous limited; however, some lakes are also reported to be carbon limited (Novotny 1994). The ratio of nitrogen and phosphorous helps in monitoring the nutrient limitation in lakes. It is predicted that primary producers are directly proportional to the amount of either nitrogen or phosphorous in the lake ecosystem. The total and bioavailable ratio of nitrogen and phosphorous provide useful information regarding nutrient limitation in lakes. Variation in the nutrient ratio is a reason for regional differences and an interval where both nutrients may be limiting (Rast and Ryding 1989).

5.2.2 Nutrient Enrichment

Nutrient enrichment in lakes from point and nonpoint sources of pollution produces physicochemical and biological changes leading to proliferation of excessive algal blooms and macrophytes leading to the anoxic condition as a consequence of which bacterial respiration takes place causing breakdown of dead aquatic biota. This creats a choking and degrading condition in the lake ecosystem as shown in Figure 5.1. Human activities result in excessive discharge of nitrogen, phosphorous, and heavy metal loadings in water bodies causeing negative ecological consequences of the aquatic ecosystem which changes the structure, function and composition of biotic communities (Western 2001). Nutrient enrichment also enhances competition between macrophytes and algae (epiphytic/phytoplankton) in lake ecosystem (Hilton et al. 2006).

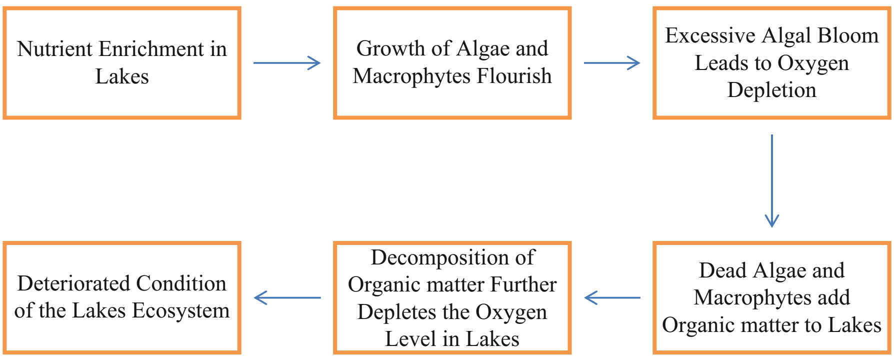

Fig. 5.1 Shows the nutrient enrichment and its effects on lake ecosystem

5.2.3 Eutrophication

Eutrophication in lakes is not a new problem as it is a natural ageing process of the lake, but it came into prominence during the middle of the last century. Its impacts have become globally widespread as it occurs in water bodies where catchment areas are involved in intensive agriculture practices and are under severe anthropogenic influence (Smith 2003). Eutrophication in lakes is mainly caused by nitrogen and phosphorous which accumulates in water column in pelagic region and benthic sediments. It is a natural process which occurs slowly during ecological succession as organic matter builds up. However nowadays human activities have accelerated this process which are detrimental to aquatic ecosystem (Oertli et al. 2005). Major nonpoint sources of nutrient in lakes are runoff from agricultural field and point sources include discharge from septic tanks, domestic wastewater, and construction debris (Carpenter et al. 1998; Velinsky 2004). It is difficult to identify and control nonpoint sources in comparison to point sources of the pollution as the main step to control nutrients discharge is to stop the nutrient flow from point and nonpoint sources (Carpenter et al. 1998).

At a global level, eutrophication in lakes is considered as an utmost challenging ecological problem. Increasing severities of eutrophication in lakes have been taken up as a resource management challenge by both the public and government organizations. The main factor leading to eutrophication in lakes is excessive nutrient loading from internal and external sources (Fang et al. 2004). The major hazard for lake ecosystem is the input of nitrogen and phosphorous from different sources of domestic and industrial pollution (Andersen et al. 2004). Eutrophicated lakes mainly lose its primary functions influencing the sustainable development of society both ecologically and economically. Figure 5.2 shows the schematic representation of eutrophication in lake ecosystem.

5.2.4 Trophic State of Lakes

Trophic state of lake ecosystem is demarcated as the total biomass of living biological matter present at a specific time and location. Trophic state is a biological response of nutrient addition in lake ecosystem (Naumann 1929), but the effects of nutrient addition are influenced by many parameters such as climatic conditions, geographical locations, grazing, and mixing depth. Trophic state index of lakes mostly relies upon total nitrogen and phosphorous and chlorophyll concentrations and Secchi disk depth as it controls the primary production of lakes (Novotny 1994; Stednick and Hall 2001). Trophic classification of lakes is currently the most widely used and accepted concept for judging the condition of lakes (Leach and Herron 1992). Few sample pictures, showing the different trophic states of lakes are shown in Fig. 5.3.

On the basis of the amount of nutrients and primary productivity, lakes are mainly classified into three trophic states which are as follows:

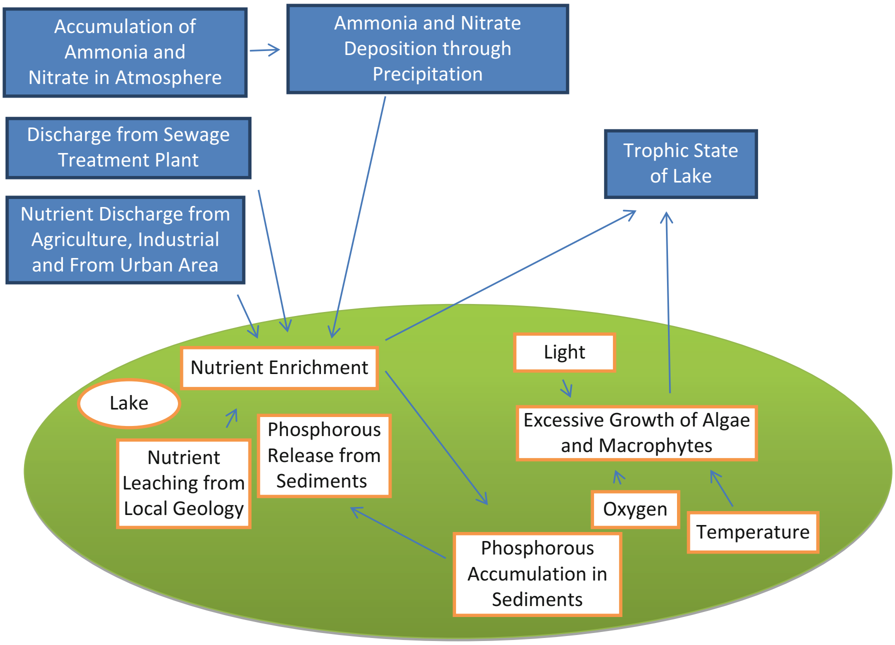

Fig. 5.2 Shows the schematic representation of eutrophication in lake ecosystem

(a) Oligotrophic
(b) Mesotrophic
(c) Eutrophic

5.2.4.1 Description of Different Trophic States of the Lake Ecosystem

Classification of lakes in different trophic state terminology viz. oligotrophic, mesotrophic and eutrophic states is shown in Table 5.2.

5.2.4.2 Association of Eutrophication in Lakes with Climatic and Geographic Factors

Eutrophication is the most severe environmental threat in lake ecosystem (Table 5.2). Climatic condition and geographical location of lakes also affect the mechanism of eutrophication as it is caused by anthropogenic as well as natural factors (Liu et al. 2010). Eutrophication parameters help us to understand the trophic state of lakes (Fraterrigo and Downing 2008). Lake morphometry and geographic factors including latitude, altitude, sunlight, temperature, salinity, humidity, and precipitation affect the process of eutrophication in the lakes (Nõges 2009).

Fig. 5.3 Pictures showing the different trophic conditions of lake ecosystem with increasing nutrient concentration. (**a**) Shows oligotrophic condition. (**b**) Mesotrophic condition showing macrophytic growth. (**c**) The eutrophic condition showing excessive algal and macrophytic growth

5.3 Effects of Nutrient Enrichment on the Algae Present in Lake Ecosystem

Algae are abundant community of the aquatic component which comprise of phytoplanktons and are mainly involved in the exchange of energy and matter inside the lake ecosystem. They can directly utilize sunlight, consume carbon dioxide and produce oxygen. As a single-celled organisms having a short regeneration time algae react more rapidly in terms of change in their community structure and density to physical, biological, and chemical changes occuring in the lake ecosystem. Algae community is mainly associated with a high nutrient level or eutrophic condition of lakes (Table 5.3).

Table 5.2 Classification of lakes in different trophic states

Eutrophication	Classification of trophic state	Nutrients Inputs	Characteristics of the lake ecosystem
Process over time ↓	Oligotrophic lakes as shown in Fig. 5.3a	Limited supply of nutrients	Lakes have good water clarity, low productivity, low sediment volume; dissolved oxygen is present in sufficient amount
	Mesotrophic lakes as shown in Fig. 5.3b	Increased input of nutrients	Decrease in water clarity of lakes, productivity increases, higher sediment accumulation and amount of decaying matter increase. Dissolved oxygen decreases
	Eutrophic lakes as shown in Fig. 5.3c	Surplus availability of nutrients	High productivity makes water clarity of lakes disagreeable; lakes become oxygen deficient, with the high buildup of sediment and decaying matter. Algal bloom is dominant

Table 5.3 The table shows the geographical and climatic effect on lake trophic states

S. no.	Geographical and climatic factors	Effect on lake trophic state	References
1.	Latitude	At different latitudes trophic status of lake varies due to difference in temperature, duration of sunlight, precipitation, atmospheric pressure. All these factors directly or indirectly affect the trophic condition of lakes	Tibby and Tiller (2007)
2.	Altitude	Change in altitude also leads to variation in climate variables like temperature, duration of sunlight, precipitation, atmospheric pressure affecting the trophic status of lakes	Tibby and Tiller (2007)
3.	Temperature	Increase in temperature directly affects the aquatic biodiversity leading to proliferation of algal blooms in lakes as they commonly occur between 23 °C and 28 °C. Variation in temperature leads to drastic change in algal community	Telesh (2004)
4.	Salinity	Salinity also affects the trophic states of lakes. Variation in salinity has direct effect on the aquatic biotic diversity. Algal blooms always occur at salinity 5 between 23% and 28%. Salinity gradient in Vistula Lagoon was determined as an important factor to define the dynamics of zooplankton biomass and abundance in the estuary	Telesh (2004)

(continued)

Table 5.3 (continued)

S. no.	Geographical and climatic factors	Effect on lake trophic state	References
5.	Precipitation	Precipitation during monsoon seasons serves as flushing mechanism by reducing seasonal eutrophication and secondly they prevent long-term annual accumulation of organic matter in the sediment	Yin (2002)
6.	Duration of sunlight	It plays an important role in the growth and distribution of aquatic flora. Optimum light intensity and duration are considered important factors for proper growth of aquatic flora	Shen (2002)
7.	Seasonal changes	Different seasons like summer, monsoons and winter affect the process of eutrophication in lakes as nutrient concentration in water quality vary due to change in seasons. Seasons also effect the aquatic biota of aquatic ecosystem as in summer algae and macrophytes coverage area is slightly larger as compared to winter seasons	Yin (2002)
8.	Increased level of carbon dioxide or effect of climate change	Due to global warming carbon dioxide concentration is increasing in atmosphere which directly affects the pH of lake water leading to acidification in lake ecosystem	Nõges (2009) and Liu et al. (2010)

5.3.1 Climate and Seasonal Changes of Algal Species, Algal Coverage Area, and Algal Biomass

Global warming which results in increase in concentration of carbon dioxide in atmosphere, speeds up the occurrence of algal blooms. Incident of toxic algal blooms in lakes is increasing now a days mainly because of changing climatic condition. Toxic algal species *Microcystis*, *Nodularia*, *Coelosphaerium*, *Gloeotrichia*, *Anabaena*, *and Aphanizomenon* are reported in various eutrophic lakes (Cole and Weihe 2015).

Algae the main primary producer of lake ecosystem is directly affected by seasonal and geographic factors. In summer season, the coverage area of algae increases whereas total coverage area during winter lessens. Any change in algae community have a direct consequence on the bio-integrity of the lakes as a whole. Seasonal succession in the different trophic state of lakes are shown in Table 5.4. High reproduction rate of algae which is characterized by small life cycles make them an important indicator of any short-term effect in lake ecosystem. Algae are good indicators of lake's trophic state as it is measurable by estimating the chlorophyll a concentration and they respond quickly and predictably to changes in nutrient status of lakes (Netherland et al. 2009).

Table 5.4 Phytoplankton seasonal succession in trophic state of lakes (Bellinger and Sigee 2015)

Seasons	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Spring	Diatoms (*Cyclotella*) ↓	Diatoms (*Asterionella*) ↓	Diatoms (*Asterionella*) ↓	Small diatoms (*Stephanodiscus*) ↓
		Chrysophytes (*Mallomonas*) ↓	Green algae (*Eudorina*) ↓	Green algae (*Scenedesmus*) ↓
Summer		Dinoflagellates (*Ceratium*) ↓	Blue-green algae (*Anabaena*, *Aphanizomenon*) ↓	Green algae (*Pediastrum*) ↓
	Dinoflagellates (*Ceratium*) Blue-green algae (*Gomphosphaeria*)	Diatoms (*Ceratium*)	Dinoflagellates (*Ceratium*) ↓	Blue-green algae (*Aphanocapsa*)
Autumn			Diatoms (*Stephanodiscus*)	
Example of lakes	Carinthian Lakes, Austria Wastewater Ennerdale, UK	Lunzer Untersee, Austria Bodensee, UK Erken, Sweden Windermere Grasmere, UK	Prairie Lakes, USA Norfolk Broad, UK Rostherne Mere UK	Fertilized waters, e.g., Třeboň fishponds, Czech Republic

5.3.2 The Relationship Between Nutrient Concentration and Growth of Algal Blooms in Lake Ecosystem

Algal diversity is extensively used for monitoring of lake water quality and the efficiency of restoration measures because of their unique position in aquatic food webs (Rakocevic-Nedovic and Hollert 2005). Unfortunately, occurrence and intensity of blue-green algae increased at a disturbing rate and this is mainly due to increased anthropogenic pressure in lakes leading to eutrophic condition (Conley et al. 2009).

Carvalho et al. (2012) studied the unlikelihood and power of algal metrics for assessing the eutrophication impacts on the lakes. Algae are diverse short-lived organisms which derive their nutrients from water column of lakes. These features of algae make them the direct and easiest indicator for assessing the effect of changing nutrient concentration on lake ecosystems. Algae are particularly suitable for use as a bioindicator for calculating the success of restoration measure which is done by reducing the nutrient inflow in the lakes.

Carvalho et al. (2012) integrated a large number of work on methods established for assessing the environmental status of European lakes by using algae as a bioindicator as required for the water framework directive and by using three strongest metrics that is phytoplankton trophic index, chlorophyll a and cyanobacteria biovolume. These are suggested for evaluating the ecological quality of lakes in relation to nutrient loading pressures. High species sensitivity of algae to various environmental factors is widely used as an important indicator of water quality due to changing nutrient (Murphy et al. 2002).

Colijn et al. (2002) in his study stated that greater nutrient concentrations and loading in numerous coastal areas of the North Sea, resulted in increased production and changes in composition of algal species. Eutrophication is related to a range of factors but the mechanisms which influence the algal blooms are not clearly defined. In moderately eutrophicated lakes, algal blooms occur in some seasons, when favorable environmental conditions prevail. Algal blooms caused by an increase in phosphorous input also depend on several abiotic factors which govern the diversity, growth and density of biotic components in lakes (Yang et al. 2008). Table 5.5 shows different algal species found in different trophic states of freshwater lakes globally.

5.4 Algae as a Bioindicator of Lake Ecological Condition

Cellamare et al. (2012) used biological elements including phytoplanktons, phytobenthos, benthic invertebrate and fish employed by the European Union water framework directive as an ecological indicator for assessing the trophic state of lakes. Use of primary producers, that is, phytoplanktons and phytobenthos, for assessment of lake water quality has a long account globally. In their work, flora communities were used for estimating the ecological trophic status of five natural lakes located in Aquitaine region of southwest France. Primary producer provides and indicates the ecological trophic status of lakes including the invasion of exotic taxa. Phytoplankton analysis integrated and reflected the condition of water quality in lakes. This study concludes that strong relationship exists between the phytoplankton index and lake trophic states.

Monitoring efforts should always be directed toward worldwide perennial species as there exists strong relationship between algal assemblages and diversity with various environmental factors (Eriksson and Bergström 2005). Studies had shown that some brown perennial macroalgae species are very fragile to sewage discharge and pollution (Soltan et al. 2001). Waste discharge from municipal sewage and industrial sectors in lakes from many years often produce a drastic change in community of benthic algae resulting in extinction of sensitive native species which leads to evolution of more stress-tolerant algal species in aquatic ecosystem (Middelboe and Sand-Jensen 2000).

Table 5.5 Different algal species found in different trophic states of freshwater lakes

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Algae species present in lakes	References
1.	Lake Taşkısığı, North Turkey	Shallow Mediterranean lake	Surface area, 0.9 km^2; length, 1.2 km; maximum depth, 5 m; mean depth, 1.5 m	Chl a – 0.005 mg L^{-1} TP – 0.036 mg L^{-1} Secchi disk depth is 68.91 cm	Shallow eutrophic freshwater lake	Bacillariophyta, Chlorophyta, Cryptophyta, *Cyanobacteria*, Euglenozoa, Charophyta, Dinophyta	Sevindik et al. (2017)
2.	Lake Little Akgöl (LLA) North Turkey	Shallow Mediterranean lake	Surface area, 0.16 km^2; length, 0.58 km; maximum depth, 1.3 m; mean depth, 0.5 m	Chl a – 0.011 mg L^{-1} TP – 0.167 mg L^{-1} Secchi disk depth is 55.3 cm	Shallow eutrophic freshwater lake	Bacillariophyta, Chlorophyta, Cryptophyta, *Cyanobacteria*, Charophyta	Sevindik et al. (2017)
3.	Lake Balaton, Europe	Large shallow lake	Surface area, 593 km^2; average depth, 3.2 m	–	Eutrophic condition up to 1994; due to management measures, it changes into mesotrophic condition in 2000	*Cylindrospermopsis raciborski*, Nostocales, Oscillatoriales, species like *Attheya zachariasii*, *Urosolenia eriensis*, *Diplopsalis acuta* can scarcely be reported, or if so only at the level of presence	Padisák et al. (2006)

(continued)

Table 5.5 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Algae species present in lakes	References
4.	Lake Ferto (Neusiedlersee), Austrian-Hungarian border	Large shallow lake	Surface area, 300 km^2; mean depth, 1.3 m	Conductivity ranges (2000–3500 μS cm)1; pH is 7.5–10. Secchi, 0.2 m; TN, 297μG/l; TP, 15 μg/l	Mesotrophic lake with high salt content	Blue-green algae (*Aphanocapsa*, *Aphanothece*), *Meroplanktonic* species (*Surirella peisonis*, *Campylodiscus clypeus*, and *Fragilaria construens*), green algal species (*Oocystis* spp.; *Planktosphaeria gelatinosa*, *Coenochlorys* sp., *Lobocystis planktonica*), Chloroccalean species (*Monoraphidium* and *Koliella* spp.)	Padisák et al. (2006)
6.	Lake Syczyńskie, Eastern Poland	Small shallow lake	Surface area, 5.6 hectare; max. depth, 2.9 m; mean depth, 0.9 m	**Winter parameter** Conductivity, 537 μS cm^{-1}, phosphate, 0.30 mg/l; ammonia, 1.35 mg/l; Secchi disk depth, 64 m; chlorophyll= 77.7 μg/l **Summer parameter** Conductivity,	Eutrophic/ hypertrophic lake	**Algae present in winter season**: *Stephanodiscus minutulus*, *Limnothrix redekei* (*Cyanobacteria*), *Koliella longiseta* (Chlorophyceae), *Mallomonas* sp. (Chrysophyceae) and *Monoraphidium komarkovae*	Toporowska et al. (2010)

				536 μS cm^{-1}, phosphate, 0.052 mg/l; ammonia, 0.418 mg/l; Secchi disk depth, 0.28 m; chlorophyll = 145.0 μG/L		(Chlorophyceae), *Planktothrix agardhii* (dinoflagellate) *Peridinium aciculiferum f. inerme* Dominants during winter seasons were cryptophytes, chrysophytes, microchlorophytes, or diatoms **Algae present in summer season** *P. agardhii*, and ten other taxa of *Cyanobacteria*, Bacillariophyceae, Chlorophyceae and *Cryptophyceae* *L. redekei*, *Planktolyngbya limnetica*, the diatoms (*Fragilaria ulna*, *Navicula* sp.), the cryptophyte (*Cryptomonas* sp.), as well as the green algae (*Actinastrum raphidioides*, *Dictyosphaerium tetrachotomum*, *Monoraphidium contortum*, *Monoraphidium minutum*	

(continued)

Table 5.5 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Algae species present in lakes	References
7.	Upper Lake, Bhopal, Madhya Pradesh	Man-made lake	Catchment area, 361 km^2; submergence area, 36.54 km^2; storage capacity, 117.05 M.cum; maximum depth, 11.7 m; maximum water level, 508.65 m	Secchi depth, 0.63 m; BOD, 7.7 mg/l; TN, 2.49 mg/l; TP, 1.8 mg/l; chlorophyll a, 11.2 μg/l	Threshold level of eutrophication	*Microcystis*, *Ankistrodesmus*, *Chlorella*, *Closterium*, *Cyclotella*, *Euglena*, *Gomphonema*, *Melosira*, *Navicula*, *Nitzschia*, *Oscillatoria*, *Phormidium*	Rahul et al. (2013)
8.	Lake Kovada, Turkey	Deep tectonic lake	The deepest point of lake is about 7 m; average width is about 2–3 km; channel, length 22 m, provides a link between Eğirdir and Lake Kovada	Ammonia, 0.07 mg/l; nitrite, 0.020 mg/l; nitrate, 0.26 mg/l; phosphate, 0.20 mg/l	Hypereutrophic	Total 51 taxa were found which include Bacillariophyta (37), Chlorophyta (8), Charophyta (4), Bacillariophyta (*Cymbella* and *Navicula*). *Diatoma vulgaris*, *Encyonema minutum*, *Epithemia sorex*, *Ulnaria ulna*. *Epithemia sorex*, *Navicula capitatoradiata*, *Nitzschia palea*, *Diatoma vulgaris Bory*, *Gomphonema parvulum*, *Diatoma tenuis*	Çiçek and Yamuç (2017)

9.	Lake Vortsjarv, Central Estonia	Large shallow lake	Area, 270 km^2; mean depth, 2.8 m; retention time, 1 year	pH, 7.5–8.5; transparency, less than 1 m; TN, 1.6 mg l^{-1}; TP, 53 mg $^{-1}$	Eutrophic lake	*Aulacoseira ambigua*, *A. granulate*, *A. subarctica*, *Tetraedron*, *Monoraphidium*, *Ankistrodesmus*, *Lagerheimia* and *Crucigenia*, *Mallomonas*, *Dinobryon*, *Oocystis*, *Dictyosphaerium*, *Kirchneriella*, *Staurastrum*, *Cosmarium*, *Tabellaria*, *Scenedesmus*, *Pediastrum* and *Coelastrum*, *Limnothrix*, *Planktolyngbya*, *Aphanizomenon*, *Planktolyngbya limnetica*, *Limnothrix redekei*, *Limnothrix planktonica*, *Aphanizomenon skujae*	Noges et al. (2010)
10.	Lake Monate, located in Varese province, Lombardy region, Italy	Small, warm monomictic, lake. Its deep relative depth helps in development of stable thermal stratification	Lake area , 2.51 km^2; catchment area including lake, 6.3 km^2; maximum depth, 34 m; mean depth, 18 m; theoretical retention time, 7.9 years	DO, 0.0–18.0 mg/l; DIN, 0.0–0.28 mgNl^{-1}; nitrate, 0.0–0.2628 mgNl^{-}; phosphate, 0.0–19.6 mgPl^{-}; silica, 0.0–1.84 mg/l; chlorophyll a, 0.8–10.0 mg/l	Oligo-mesotrophic lake	*Mallomonas caudata*, *M. aeromonas*, *Dinobryon divergens*, *Planctosphaeria gelatinosa*, *Ceratium hirundinella*, *Cyclotella* sp., *Oocystis* spp., *Chlamydocapsa planktonica*, *Aphanothece* sp., *Asterionella formosa*, *Radiocystis* sp.	Noges et al. (2011)

(continued)

Table 5.5 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Algae species present in lakes	References
11.	Lake Varese, located in Varese province, Lombardy region, Italy	Medium size, warm monomictic, lake	Lake area, 14.8 km^2; catchment area including lake, 112 km^2; maximum depth, 26 m; mean depth, 11 m; theoretical retention time, 1.7 years	DO, 0.0–15.5 mg/l; DIN, 0.0–2.2 $mgNl^{-1}$; nitrate, 0.0–0.83 $mgNl^{-}$; phosphate, 0.0–392 $mgPl^{-}$; silica, 0.01–2.65 mg/l; chlorophyll a, 0.2–48.6 mg/l	Eutrophic	*Chlamydocapsa planktonica*, *Cyclotella* sp., *Ceratium hirundinella*, *C. furcoides*, *Fragilaria crotonensis*, *Woronichinia naegeliana*, *W. compacta*, *Aulacoseira granulate*, *Anabaena* sp., *A. planktonica*, *Cryptomonas* sp., *Aphanizomenon* sp.	Nõges et al. (2011)
12.	Lake Hourtin, situated along Atlantic coastline, southwest of France	Aquitaine, polymictic lake with sandy substrate	Surface area, 62 km^2; catchment area, 360 km^2; maximum width, 4 km; length, 18 km; maximum depth, 11 m; mean depth, 3.4 m; residence time, 1.8 years	pH, 8.2; Secchi transparency, 0.7 m; conductivity, 320 µS cm^{-1}; total P, 33.6 µg L^{-1}; total N, 1554 µg L^{-1}; N/P, 51; DOC, 23.9 mg L^{-1}; chlorophyll a, 19.6 µg L^{-1}; algal biomass, 6.2 mg L^{-1}	Eutrophic	*Puncticulata radiosa*, *Tetraedron caudatum*, *Aphanothece nidulans*, *Aphanothece stagnina*, *Cyanodictyon tropicale*, *Synechocystis* sp., *Chroococcus minutus*, *Brachysira neoexilis*, *Navicula radiosa*, *Spondylosium papillosum*, *Spondylosium tetragonum*, *Staurastrum excavatum*, *Tabellaria*	Cellamare et al. (2012)

						flocculosa, *Teilingia excavate*, *Planktolyngbya circumcreta*, *Planktolyngbya limnetica*, *Planktolyngbya microspira*	
13.	Lake Lacanau, situated along Atlantic coastline, southwest of France	Aquitaine, polymictic lake with sandy substrate	Surface area, 20 km^2; catchment area, 285 km^2; maximum width, 3 km; length, 7.7 km; maximum depth, 8 m; mean depth, 2.6 m; residence time, 0.4 years	pH, 7.6; Secchi transparency, 1.2 m; conductivity, 249 μS cm^{-1}; total P, 25.9 μg L^{-1}; total N, 826 μg L^{-1}; N/P, 37; DOC, 16.8 mg L^{-1}; chlorophyll a, 9.6 μg L^{-1}; algal biomass, 4.2 mg L^{-1}	Meso-eutrophic	*Urosolenia longiseta*, *Puncticulata radiosa*, *Aulacoseira ambigua*, *Dinobryon bavaricum*, *Oocystis lacustris*, *Pediastrum tetras*, *Tetraedron caudatum*, *Aphanothece nidulans*, *Cyanodictyon tropicale*, *Chroococcus minutus*, *Radiocystis aphanothecoidea*, *Spondylosium papillosum*, *Spondylosium planum*, *Staurastrum* cf. *longipes*, *Staurastrum excavatum*, *Staurastrum tetracerum*, *Staurodesmus cuspidatus*, *Tabellaria flocculosa*, *Planktolyngbya circumcreta*, *Planktolyngbya limnetica*, *Planktolyngbya microspira*	Cellamare et al. (2012)

(continued)

Table 5.5 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Algae species present in lakes	References
14.	Lake Cazaux, situated along Atlantic coastline, southwest of France	Aquitaine, monomictic lake with sandy substrate	Surface area, 58 km^2; catchment area, 200 km^2; maximum width, 10 km; length, 11 km; maximum depth, 23 m; mean depth, 8.6 m; residence time, 4 years	pH, 7.6; Secchi transparency, 4.2 m; conductivity, 171 µS cm^{-1}; total P, 13.3 µg L^{-1}; total N, 686 µg L^{-1}; N/P, 59; DOC, 6.3 mg L^{-1}; chlorophyll a, 3.8 µg L^{-1}; algal biomass, 0.8 mg L^{-1}	Oligo-mesotrophic	*Cyclotella comensis*, *Cyclotella cyclopuncta*, *Aulacoseira italic*, *Puncticulata radiosa*, *Aulacoseira ambigua*, cf. *Erkenia*, *Chrysophyte non-identified*, *Dinobryon bavaricum*, *Tetraedron caudatum*, *Peridiniales 2*, *Peridinium* sp., *Peridinium umbonatum*, *Radiocystis aphanothecoidea*, *Cymbella helvetica*, *Encyonopsis cesatii*, *Fragilaria virescens*, *Navicula radiosa*, *Spondylosium papillosum*, *Spondylosium planum*, *Tabellaria flocculosa*, *Fragilaria nanana*, *Planktolyngbya limnetica*, *Cryptomonas* sp.	Cellamare et al. (2012)
15.	Lake Parentis, situated along Atlantic coastline,	Aquitaine, monomictic lake with sandy substrate	Surface area, 36 km^2; catchment area, 252 km^2; maximum	pH, 7.7; Secchi transparency, 2.3 m; conductivity, 161 µS cm^{-1}; total P, 31.9 µg L^{-1}; total N,	Meso-eutrophic	*Aulacoseira italic*, *Aulacoseira ambigua*, *Actinocyclus normanii*, *Flagellates non-identified*, *Anabaena circinalis*,	Cellamare et al. (2012)

	southwest of France		width, 8.4 km; length, 9 km; maximum depth, 20.5 m; mean depth, 6.7 m; residence time, 1 year	658 μg L^{-1}; N/P, 20; DOC, 5.8 mg L^{-1}; chlorophyll a, 12.2 μg L^{-1}; algal biomass, 2.7 mg L^{-1}		*Anabaena flos-aquae*, *Aphanizomenon flos-aquae*, *Aphanothece clathrata*, *Pediastrum boryanum*, *Tabellaria flocculosa*, *Fragilaria crotonensis*, *Staurastrum pingue*, *Xanthidium antilopaeum*, *Planktolyngbya limnetica*, *Monoraphidium contortum*, *Plagioselmis nannoplanctica*, *Chromulina* cf. *magnifica*, *Cryptomonas* spp.	
16.	Lake Soustons, situated along Atlantic coastline, southwest of France	Aquitaine, polymictic lake with sandy substrate	Surface area, 3.8 km^2; catchment area, 350 km^2; maximum width, 2 km; length, 4.6 km; maximum depth, 1.9 m; mean depth, 0.6 m; residence time, 0.02 year	pH, 8.8; Secchi transparency, 0.7 m; conductivity,159 μS cm^{-1}; total P, 119.2 μg L^{-1}; total N, 1226 μg L^{-1}; N/P, 13; DOC, 5 mg L^{-1}; chlorophyll a, 73.9 μg L^{-1}; algal biomass, 19.1 mg L^{-1}	Hypereutrophic	*Aulacoseira italic*, *Aulacoseira ambigua*, *Cyclotella meneghiniana*, *Nitzschia gessneri*, *Nitzschia intermedia*, *Nitzschia palea*, *Staurosira berolinensis*, *Dinobryon bavaricum*, *Mallomonas lefevriana*, *Aphanizomenon gracile*, *Scenedesmus acuminatus*, *Scenedesmus longispina*, *Scenedesmus magnus*, *Scenedesmus opoliensis*, *Scenedesmus quadricauda*, *Cyanonephron styloides*,	Cellamare et al. (2012)

(continued)

Table 5.5 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Algae species present in lakes	References
						Peridiniales 1, *Microcystis wessenbergii*, *Staurosira construens*, *Ulnaria biceps*, *Ulnaria ulna*, *Fragilaria nanana*, *Staurastrum chaetoceras*, *Pseudanabaena recta*, *Pseudanabaena* sp., *Romeria elegans*, *Cylindrospermopsis raciborskii*, *Monoraphidium contortum*, *Cryptomonas* spp.	

The connection between algal biomass and nutrient concentration has long been recognized and is the basis for many commonly used eutrophication models (Brown et al. 2000). The general supposition for these equations is that with increase in total phosphorous concentration in lakes chlorophyll a concentration also increases because main nutrient which control algal growth is phosphorous. In some lakes, limiting nutrient is nitrogen, and several models incorporate both total nitrogen and phosphorous as a limiting nutrient (Hoyer 1981; Smith 1982; Canfield 1983; Brown et al. 2000). Over the past 30 years, many popular classification systems had evolved to compare the trophic state of the lake along with algal blooms in the aquatic ecosystem.

According to Smith and Bennett (1999) algal species from the Euglenophyta, Cryptophyta, or Chrysophyta divisions were identified in the reservoirs and it is found that several of them lack chlorophyll. It can be assumed that these groups contribute minimally to the chlorophyll *a*, *b*, and *c* measurements. Chlorophyll *a* is found in all of the three divisions of algae that is Chlorophyta, Cyanophyta and Bacillariophyta. However, chlorophyll *b* is only present in the Chlorophyta (green algae) and chlorophyll-*c* is only found in Bacillariophyta (diatoms). Thus, we can relate that increases in these chlorophyll concentrations with increases in algal species in the lake.

Algae species of genus *Cystoseira* are sensitive to anthropogenic and natural stress that dominated in Mediterranean communities of upper sublittoral regions and therefore they suffer intense changes and decline in number over extensive areas along the northwestern Mediterranean coasts. The highly productive and structured species of *Cystoseira mediterranea* community was observed in non-polluted water. With the increase in concentration of organic matter and nutrients drives *Cystoseira*-dominated communities was replaced by the red alga *Corallina elongata* and the mussel *Mytilus galloprovincialis*. Chlorophyta that are short-lived such as *Ulva*, *Cladophora*, and *Enteromorpha* are mainly dominated in highly distressed environments. Presence of blue-green algae such as *Oscillatoria*, *Lyngbya* and *Phormidium* indicates a very degraded condition of lake ecosystem (Pinedo et al. 2007).

Changes in algae community composition help in finer-scale evaluation of changes in environmental condition. German phytoplankton taxa index of lakes was prepared by Mischke and Böhmer 2008, as part of national assessment system that classified trophic states of lakes from oligotrophic to eutrophic based on the assessment of composition of phytoplankton species. For some phytoplankton species, the climate change trends are well recognized and these can be used for future estimation. Climate change is the potential catalyst for the proliferation of harmful cyanobacteria blooms or cyanotoxins predominantly in eutrophic lakes because the increased level of carbon dioxide enhances the process of acidification and eutrophication which promote the growth of toxic algal blooms in the lake ecosystem (Paerl and Huisman 2008).

Paul et al. (2012) in their study find the relationship between trophic states of lakes with catchment land use. But direct relationship between land use and algal taxa is inadequate in the literature. Phyla cell abundance represents the algal composition which was monitored in 11 lakes in Rotorua region in New Zealand over a period of 4 years. In the research done by Paul et al. (2012), it was found that lake differed in their trophic state on the basis of morphometry, land use and catchment land use. They verified proportion of land use which indirectly or directly represent relative nutrient loading which was the main factor affecting algal composition. The trophic state was negatively correlated with native forest pasture and urban areas are positively correlated. Cyanoprokaryota species were correlated negatively with native forest and positively with trophic state and pasture. Chlorophyta was positively correlated with urban land use area and native forest and negatively with trophic state and pasture. Dissolved inorganic nitrogen and dissolved silica are positively correlated with Bacillariophyta (mainly diatoms) present in lakes. Lakes with the higher trophic state have high nutrients concentration resulting in Cyanoprokaryota dominance. Chlorophyta was negatively interrelated with Bacillariophyta and Cyanoprokaryota. This study suggests strong competition among algal species. This shows that lakes are possibly subject to changes in algal composition along with change in trophic states which arises due to changes in catchment land use.

5.5 Macrophytes and Its Type Present in Freshwater Lakes

5.5.1 Macrophytes

Macrophytes are found in lentic and lotic water bodies. They include angiosperm, mosses, liverwort, fern and some freshwater microalgae constituting aquatic macrophytes (Sculthorpe 1967; Cronk and Fennessy 2001). Macrophytes play a diverse role in the structuring and functioning of lake ecosystem. Macrophytes are extremely flexible in relation to changing environmental condition in comparison to algae. They are the most important component of lake littoral zone helping in remediation of heavy metal and pollutants through the natural process from the water and sediments that's why they help in the cleaning process and maintaining homeoststis in lacustrine ecosystem (Lacoul and Freedman 2006). Macrophytes are broadly categorized into three major categories which are as follows:

5.5.2 Emergent Macrophytes

They are mostly found in shallow water as they are rooted in bottom sediments but the main body of plant extends above the water surface. Emergent macrophytes derive their nutrient requirement from the bottom substrate that is from sediments. Nutrients in pelagic region are of less use to these macrophytes as they are mainly depend on sediments and bottom substrate for acquiring nutrients. These group of macrophytes include Poaceae (grasses), Typhaceae (cattails), Cyperaceae (bulrush) and Junceae (rushes) (Lacoul and Freedman 2006).

5.5.3 Floating Rooted Macrophytes

They are mostly found at moderate depth in lakes and may be prominent in low-visibility water. Leaves of these macrophytes float on the surface of water and roots are rooted in the sediment. It includes Nelumbonaceae (lotus) and Nymphaeaceae (water lily).

5.5.4 Submerged Macrophytes

They occur at various depths in lakes and are usually rooted in bottom sediments. They may be free floating and their main body is mainly underwater. It includes Callitrichaceae (starwort), Haloragaceae (water milfoil), Hydrocharitaceae (elodea, frogbit, and wild celery) and Potamogetonaceae (pondweed).

5.5.5 Free-Floating Macrophytes

These macrophytes freely move on to the surface of the lake by the action of wind and water current. Their roots are not embedded on bottom sediments. They totally depend on nutrients in water of lakes for their survival as they do not take any nutrients from the sediments. It includes Azollaceae (mosquito fern), Araceae (water lettuce), Pontederiaceae (water hyacinth) and Lemnaceae (duckweed and watermeal) (Lacoul and Freedman 2006).

5.6 Ecological and Economic Benefits of Lake Macrophytes

Freshwater macrophytes of lakes serve numerous functions as they form critical habitat for lacustrine fauna by providing substrate for attachment of algae, spawning and nursery area for young fish, turtles and other fauna present in lakes and habitat for adult life stages. Most importantly, they form the base of food chain in aquatic food web by providing food sources to aquatic fauna in early phase of macrophytes' life. Aquatic macrophytes form detrital matter after death and help in the growth and development of benthic fauna which includes microorganism, invertebrate's, insects and large crustaceans. Macrophytes directly or indirectly support whole nutrient dynamics, absorb waves, and produce oxygen for lake ecosystem. Macrophytes provide many ecological and economic benefits in promoting aquatic diversity and maintaining natural functioning of lacustrine ecosystem that is why lake and wetland ecosystem are considered as one of the productive aquatic areas worldwide (Carpenter and Lodge 1986). The importance of macrophytes in littoral zone of lakes are numerous as they help in nutrient cycling and provide food and habitat to aquatic flora along with maintaining the diversity, structure, and function of lake ecosystem. Many aquatic macrophytes found in lakes have been used in food, livestock fodder, medicine, compost, mulch, fertilizer, and building material and for bioremediation.

Some species of macrophytes like Indian lotus (*Nelumbo nucifera*) also have religious significance (Wersal and Madsen 2012).

5.7 Interaction of Macrophytes with Various Components of Lake Ecosystem

5.7.1 Macrophytes Interaction with Environmental Factors

Macrophytes are an important component of lacustrine ecosystem. Distribution and composition of macrophytes are influenced by various environmental factors. This is the main reason why macrophytes respond quickly to sudden changes in nutrient concentration in lakes. Macrophytes are reliable indicators of any change in lake ecosystem (Fennessy 1998; Aznar et al. 2002). The usefulness of macrophytes is related to their sensitivity to both short-term and long-term changes or any change in synergetic manner that may be beneficial or damaging in lacustrine ecosystem (Seddon 1972; Carbiener et al. 1990; Seele et al. 2000; Thiebaut et al. 2002; Schneider and Melzer 2003; Stelzer et al. 2005). Macrophytes integrate physical, chemical, biological, temporal and spatial factors of lake ecosystem. Previous researches in various climatic regions have demonstrated the influence of interacting environmental factors on composition, distribution and abundance of macrophytes (Suren and Ormerod 1998; Heegaard et al. 2001; Barendregt and Bio 2003; Bernez et al. 2004). Hutchinson (1975) gave importance to the comparative studies of aquatic macrophytes in lakes differing in limnological characteristics. This helps in understanding the effect of environmental and anthropogenic impacts on macrophytes species and communities. Availability of light, turbidity, dissolved organic carbon, Secchi depth, chlorophyll a, sediment characteristics and trophic status are related to nutrient chemistry of lakes. Physical factors like wind, wave, and hydrologic variation and biological factors which include selective grazing, allelopathy and shading by algae also affect the distribution of macrophytes in lakes (Lacoul and Freedman 2006).

5.7.2 Macrophytic Dominance and Its Effect on Other Components of Lakes

In eutrophicated lake, macrophytes grow continuously throughout the whole year differently from seasonal die-off process (Ferreira et al. 2008). This affects the lake ecosystem slowly but permanently by enhancing macrophytic dominant community (Ferreira et al. 2008). Higher density of macrophytes along with dominance of fish omnivore results in the trophic interaction which proceeds in different ways (Meerhoff et al. 2006). The high productivity of floating and emergent macrophytes contributes a large amount of soluble organic matter in lakes that can be transported to benthic and pelagic region of lakes and it affects overall lacustrine metabolism (Wetzel 1992). In eutrophic lakes, excessive macrophytes growth and their metabolism and decomposition within littoral region generate recalcitrant organic compounds affecting overall mechanism of lakes by severely affecting the whole lake biodiversity (Stewart et al. 1982). Lakes with dense macrophyte coverage area would have strong effect on the distribution, structure and dynamics of algal community along with the gradient of macrophyte community (Søndergaard and Moss 1998). In shallow lakes, this interaction is found to be more intrinsic because it is influenced by intense wind-driven hydrodynamics regimes, which end up dominating spatial heterogeneity of biotic components present in lakes (De Souza Cardoso and Da Motta Marques 2009). Wind direction, intensity and lake mixing are main factors which determine the hydrodynamics distribution of physical, chemical and biological components along the littoral pelagic gradients. Allelopathic substances released by some macrophytes species affect the distribution of other species of macrophytes and algae present in lakes. Nutrient competition is also one of the important factors which effect the distribution of macrophytes and other biotic components in lakes (Ferreira et al. 2018).

5.7.3 Interaction of Macrophytes with Water and Sediments of the Lakes

Macrophytes including submerged species present in freshwater lakes influence various limnological variables and nutrients (orthophosphate, bicarbonate and total phosphorous) in pelagic water zone and benthic region of lakes. The nutrients trigger the increase in macrophytic beds, resulting in decrease of dissolved organic carbon and humic substances in pelagic region of lakes. In shallow lakes macrophytes affect the nutrient cycling by acting as nutrient sinks inside the lakes (Carpenter 1981). Labile tissue present in submerged macrophytes helps in easy uptake of water from lakes (Duarte 1992). Macrophytes species ability for uptaking nutrients is measured by the amount of nutrient trapped into biomass of macrophytes. Species of macrophytes with diminutive root system are capable of better absorbing power of nutrients present in lakes (Kufel and Kufel 2002). Under controlled condition in Lake Mangueira, species of macrophytes *Ceratophyllum* and *Egeria* were able to efficiently reduce the concentration of phosphate from the lakes (Ferreira 2009). Interaction between roots of macrophytes and sediments are regarded as a sink of phosphorous as sediments are oxidized by macrophytes which enhance the binding of phosphorous by iron (Jensen and Andersen 1992). This contributes to internal nutrient enrichments in lake ecosystem which enhances eutrophication. Eutrophic freshwater lakes having dense macrophytes coverage, high algal density attached to macrophytes and additional activities of bacterioplanktons stimulate the release of large amount of organic carbon by macrophytes present in lakes. (Søndergaard and Moss 1998).

5.8 Submerged Macrophytes as an Indicator of Eutrophication in Lakes

Submerged macrophytes in freshwater lakes promote various physical, chemical and biological changes (Wetzel 1992). Submerged macrophytes population and diversity are used as bioindicators of eutrophication in lakes as in oligotrophic lakes density of submerged macrophytes is high in comparison to eutrophic lakes. Submerged macrophytes anchor sediments, remove suspended particles in water which result in increase in transparency, stabilize slopes present underwater in lakes and remove additional nutrients from water in pelagic region of lakes (Doyle 2000; Madsen et al. 2001). It is reported that various submerged macrophytes provide positive feedback effects that improve the water transparency, further stabilizing the clear-water state in shallow temperate lakes. But it is not clear how the structuring effect of macrophytes impact on the food web of subtropical and tropical ecosystems (Ferreira et al. 2018). The lack of submerged macrophytes in eutrophicated lakes results in frequent resuspension of bottom sediments which result in low-light environment in deeper layer of lakes affecting the growth and productivity of aquatic flora and fauna found in deeper lakes (Scheffer 1998). Spatial distribution of submerged macrophytes in lakes is regulated by suspended particulate matter present and availability of sunlight, these two factors are mostly seen in eutrophicated lakes (Madsen et al. 2006). Large fraction of submerged macrophytes communities comprises of food items consumed by waterfowl in lake ecosystem (Havera 1999). That is the main reason why oligotrophic lakes are considered as diverse as they support diverse aquatic flora and fauna and stable aquatic ecosystem whereas eutrophic lakes are considered to be unstable due to less or negligible submerged macrophytes, lesser aquatic diversity and dominance of invasive exotic species. Submerged macrophytes provide suitable environment and supports aquatic micro- and macroinvertebrates as they are the major source of protein for breeding and migrating aquatic flora in benthic region of lakes (Baldassarre and Bolen 1994). Submerged macrophytes are known to prevent the growth of excessive phytoplanktons in lakes (Van den Berg et al. 1998) which helps in reducing the problem of eutrophication.

5.9 Macrophytes as a Bioindicator of Nutrient Status of Lakes

Macrophytes are good indicators of trophic state of lakes. Macrophytes mainly flourish in moderately nutrient-enriched lakes. Sensitive and tolerant macrophytes species show different adaptation mechanisms. Sensitive macrophytes species sometimes are incapable to survive in disturbed environmental conditions whereas tolerant species of macrophytes cope up with the aquatic disturbances leading to their successful survival and these species act as a bioindicator species in the aquatic ecosystem. Macrophytes are used for bioassessment of lake's ecological variations as they are characterized by low mobility as compared to algae, fishes and invertebrates. They are commonly used for lake ecosystem assessment integrating the nutrient change, environmental change, phonological rhythm, dynamical tendencies and vegetational series. Macrophytes indices are usually associated with frequency, composition, presence and abundance of specific taxa (Sender et al. 2017).

Mikulyuk et al. (2017) researched in north temperate lakes on macrophytes bioassessment approach linking taxon-specific abundance and tolerance in north temperate lakes. Biological assessments of lakes are mainly needed to monitor lake's ecological condition as they are bioindicators of trophic state. In 462 north temperate lakes the bioassessment method was developed and tested. This approach links abundance of macrophytes with lake's ecological condition through estimates of taxon-specific abundance which get affected due to man-made disturbances. They calculated abundance-weighted tolerance ranges for 59 macrophytes species and grouped them according to their tolerance level to man-made disturbances. Aquatic macrophytes react gradually to change in nutrient condition, and that is the main reason why macrophytes are used as long-term indicator with high spatial resolution (Melzer 1999).

Sender et al. (2017) proposed a new method for assessment of biological status of lakes which is based on analysis of macrophytes along with landscape, geomorphological and catchment source of the threat. In the transboundary biosphere reserve of Poland, 22 lakes were explored along trophic state and anthropogenic pressure gradients. The indexation includes 22 criteria that include catchment land use, richness of plant species found and phytolittoral area concerning three different evaluating zones that is, littoral, lake shore and surrounding area and provided a five-class ecological classification.

5.10 Effect of Eutrophication on Macrophytes

5.10.1 Effect on Biomass and Propagation and Regeneration Efficiency of Macrophytes

Eutrophication affects macrophyte diversity and its associated services in lake ecosystem. Eutrophication adversely affects the tolerance of macrophytes by increasing the biomass of floating and emergent macrophytes and by decreasing the biomass of submerged species and their regeneration efficiency (Xie et al. 2015). In eutrophicated lakes, anoxia, low light and high nutrients concentration in water and sediments have a major influence on propagation and regeneration capacity of submerged macrophytes (Wu et al. 2009; Xie et al. 2010). Eutrophication affects the vegetative parts of the macrophytes as asexual propagule of macrophytes has a capacity to propagate new shoot formation to sustain its race (Klimes 2007). Therefore eutrophication affects the life history of aquatic macrophytes by effecting its growth, n lakes vegetative reproduction results in biodiversity loss due to eutrophication. Problem of eutrophication needs to be properly managed for conserving the aquatic biodiversity and integrity. (Xie et al. 2015).

5.10.2 Changes in Species Composition of Macrophytes in Lakes

In lakes, readily usable form of nutrients by macrophytes are nitrogen and phosphorous, although various physical and biotic factors also influence the macrophytic productivity (Novotny 1994; Stednick and Hall 2001). The major cause of the change in composition, abundance, evenness, richness and loss of native species are the dominant, exotic, invasive and efficient species in the lake ecosystem. High nutrient turnover results in decrease in primary producer of lakes (Liu and Qiu 2007). Nutrient enrichment results in proliferation of macrophytes which utilizes sunlight and inorganic substances present in lakes through the process of photosynthesis. The composition of macrophytes species changes along with change in trophic state of lakes. The native and sensitive species which are adapted to low nutrient concentration are replaced by tolerant, invasive and exotic species that are adapted to nutrient-enriched condition.

5.10.3 Example of Change in Macrophytic Composition along with Change in Nutrients in Lakes

A comparison of diversity of aquatic macrophytes of various water bodies found in different catchment settings can be used to reflect the human-induced disturbances such as those from fish farm, domestic wastewater and sewage discharge. High nutrient loadings which disturbed lakes sites were featured by low richness of vascular plant and absence of macrophytes (Thiébaut and Muller 1998). Distinct changes were detected in the species composition of macrophytes species in response to phosphorous and nitrogen enrichment (Yang et al. 2008). Nutrient-enriched marshy areas were dominated by *Cladium jamaicense* and *Typha domingensis* respectively. Open-water oligotrophic lakes reported the presence of *Eleocharis* species, *Utricularia* species, *Nymphaea odorata* and *Chara zeylanica* and the floating plant *Polygonum* species in eutrophic areas. Change in primary producer due to increased nutrient loading from eelgrass to macroalgae alters the ecology of aquatic habitat, food webs and physicochemical characteristics of water and sediments (Deegan et al. 2002). Table 5.6 elaborates common macrophytes species found in different trophic states of freshwater lakes.

5.11 Growth of Exotic Invasive Species in Eutrophic Lakes

Intensified land use affects the freshwater by increased sedimentation, nearshore habitat destruction, altered hydrology and pollution (Allan 2004). Altering lake habitat reduces species richness which otherwise offer biotic resistance against invasions. Increased anthropogenic influence resulted in decrease in richness of sensitive native species of macrophytes and increase in invasive exotic species (Riley et al. 2005). Invasive exotic macrophytes are directly related to turbidity and nutrient enrichment. Decreased dissolved oxygen and increase in turbidity and

Table 5.6 Common macrophytes species found in different trophic states of freshwater lakes

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Macrophytes species present in lakes	References
1.	Lake Taşkısığı, North Turkey	Shallow Mediterranean lake	Surface area, 0.9 km^2; length, 1.2 km; maximum depth, 5 m; mean depth, 1.5 m	Chl a – 0.005 mg L^{-1} TP – 0.036 mg L^{-1} Secchi disk depth – 68.91 cm	Shallow eutrophic	*Phragmites* sp., *Nymphaea alba* L., and *Ceratophyllum demersum* L.	Sevindik et al. (2017)
2.	Lake little Akgöl (LLA)	Shallow Mediterranean lake	Surface area, 0.16 km^2; length, 0.58 km; maximum depth, 1.3 m; mean depth, 0.5 m	Chl a – 0.011 mg L^{-1} TP – 0.167 mg L^{-1} Secchi disk depth is 55.3 cm	Shallow eutrophic	*Phragmites* sp., *Nymphaea alba* L., and *Ceratophyllum demersum* L.	Sevindik et al. (2017)
3.	Lakes Osterseen, south of Lake Starnberg, Germany	Bavarian lake comprises of 20 individual lakes	-	Mean TP – 52 μg/l, Secchi disk transparency (annual mean > 10 m)	Eutrophic	*Chara hispida*, *C. aspera*, *C. tomentosa*, *C. intermedia*, *C. contraria*, *Potomageton coloratus*, *Utricularia ochroleuca*, *U. minor* and *U. australis*, *Elodea canadensis*, *Potomageton crispus*, *Ceratophyllum demersum*, *Zannichellia palustris*, and *Lemna minor*	Melzer (1999)
4.	Lake Starnberg, Germany	Bavarian lake	Area, 5636 ha; shoreline length, 49.2 km; max depth, 128 m; average depth, 73 m	NA	Meso-eutrophic	*Potomageton pusillus*, *Potomageton pectinatus*, *Ranunculus circinatus*, *Zannichellia palustris*	Melzer (1999)
5.	Lake Chiemsee, Germany	Largest Bavarian lake	Area, 7990 ha; length of shoreline, 63.9 km; max. depth, 73.4 m; average depth, 25.6 m	NA	Eutrophic	*Zannichellia palustris*	Melzer (1999)

(continued)

Table 5.6 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Macrophytes species present in lakes	References
6.	Lake Nagin, Kashmir	Shallow tropical lake	NA	Ammonia, 199.6 μg/L; nitrate, 399.94 μg/L; TP, 492.12 μg/L; transparency, 1.93 m; chlorophyll a, 13.43 μg/L	Eutrophic	*Ceratophyllum demersum*, *Nymphaea alba*, *Nymphoides peltatum*, *Nelumbo nucifera*, *Potomageton natans*, *P. crispus*, *Hydrilla* sp., *Potomageton natans*, *Hydrilla verticillata*, *Ceratophyllum demersum*	Malik et al. (2017)
7.	Lake Scharmutzelsee, southeast of Berlin (Germany)	**Northern basin of lake** – shallow, stratified, dimictic lake with polymictic basin **Southern basin of lake** – larger, deeper, and dimectic basin	Surface area, 12.1 km^2; shore length, 30.3 km; volume, 108.2 × 106 m^3; mean depth, 9.0 m; max depth, 29.5 m; mean residence time, 16 years; and catchment area, 112 km^2 **Northern region of lake –** area, 1.4 km^2; maximum mean depth, 6.5 m **Southern region of lake –** area, 10.6 km^2; mean depth, 29.5 m	Summer Secchi disk transparencies, 3 m **Northern basin of lake –** TP only recorded from 2004 27 μg TP L^{-1} and were significantly higher **Southern basin of lake** – TP concentrations decreased from 44 μg TP L^{-1} in 1994 to 18 μg TP L^{-1} in 2006. TP concentrations were between 33 and 57 μg L^{-1}	Eutrophic condition in 1994 trophic state changes to mesotrophic in 2003	**Northern basin of lake** *Myriophyllum spicatum* L., *Ceratophyllum demersum* L., *Potomageton perfoliatus* L. *N. obtuse*, *Ranunculus circinatus*, *P. pusillus*, *Chara globulis*, *Najas marina*, *Elodea canadensis*, *Najas marina*, *Potomageton lucens* **Southern basin of lake-** *C. demersum*, *M. spicatum*, *P. perfoliatus*, *Najas marina* L.), *C. demersum*, *R. circinatus, M. spicatum*, *P. pectinatus*, *N. obtuse*, *Ranunculus circinatus*, *P. pusillus*, *Chara globulis*, *Utricularia vulgaris*, *Najas marina*, *Elodea canadensis*, *Stratiotes aloides*, *Potomageton lucens*, *Eleocharis acicularis*	Hilt et al. (2010)

8.	Lake Hourtin, situated along Atlantic coastline, southwest of France	Aquitaine, polymictic lake with sandy substrate	Surface area, 62 km^2; catchment area, 360 km^2; maximum width, 4 km; length, 18 km; maximum depth, 11 m; mean depth, 3.4 m; residence time, 1.8 years	pH, 8.2; Secchi transparency, 0.7 m; conductivity, 320 µS cm^{-1}; total P, 33.6 µg L^{-1}; total N, 1554 µg L^{-1}; N/P, 51; DOC, 23.9 mg L^{-1}; chlorophyll a, 19.6 µg L^{-1}; algal biomass, 6.2 mg L^{-1}	Eutrophic	*Caropsis verticillatinundata*, *lobelia Dortmanna*, *Nitella Confervacea*, *Chara Fragifera*, *Juncus Bulbosus*	Cellamare et al. (2012)
9.	Lake Lacanau, situated along Atlantic coastline, southwest of France	Aquitaine, polymictic lake with sandy substrate	Surface area, 20 km^2; catchment area, 285 km^2; maximum width, 3 km; length, 7.7 km; maximum depth, 8 m; mean depth, 2.6 m; residence time, 0.4 years	pH, 7.6; Secchi transparency, 1.2 m; conductivity, 249 µS cm^{-1}; total P, 25.9 µg L^{-1}; total N, 826 µg L^{-1}; N/P, 37; DOC, 16.8 mg L^{-1}; chlorophyll a, 9.6 µg L^{-1}; algal biomass, 4.2 mg L^{-1}	Meso-eutrophic	*Littorella uniflora*, *Nitella confervacea*, *Chara fragifera*, *Egeria densa*, *Lagarosiphon major*	Cellamare et al. (2012)

(continued)

Table 5.6 (continued)

S. no.	Name and location of lake	Type of lake	Morphological characteristics	Nutrient status of lakes	Trophic state of lake	Macrophytes species present in lakes	References
10.	Lake Cazaux, situated along Atlantic coastline, southwest of France	Aquitaine, monomictic lake with sandy substrate	Surface area, 58 km^2; catchment area, 200 km^2; maximum width, 10 km; length, 11 km; maximum depth, 23 m; mean depth, 8.6 m; residence time, 4 years	pH, 7.6; Secchi transparency, 4.2 m; conductivity, 171 µS cm^{-1}; total P, 13.3 µg L^{-1}; total N, 686 µg L^{-1}; N/P, 59; DOC, 6.3 mg L^{-1}; chlorophyll a, 3.8 µg L^{-1}; algal biomass, 0.8 mg L^{-1}	Oligo-mesotrophic	*Elatine hexandra*, *Lobelia dortmanna*, *Littorella uniflora*, *Myriophyllum alterniflorum*, *Nitella confervacea*, *Chara fragifera*, *Juncus bulbosus*	Cellamare et al. (2012)
11.	Lake parentis, situated along Atlantic coastline, southwest of France	Aquitaine, monomictic lake with sandy substrate	Surface area, 36 km^2; catchment area, 252 km^2; maximum width, 8.4 km; length, 9 km; maximum depth, 20.5 m; mean depth, 6.7 m; residence time, 1 years	pH, 7.7; Secchi transparency, 2.3 m; conductivity, 161 µS cm^{-1}; total P, 31.9 µg L^{-1}; total N, 658 µg L^{-1}; N/P, 20; DOC, 5.8 mg L^{-1}; chlorophyll a, 12.2 µg L^{-1}; algal biomass, 2.7 mg L^{-1}	Meso-eutrophic	**Ecological status-inconclusive**	Cellamare et al. (2012)

12.	Lake Soustons, situated along Atlantic coastline, southwest of France	Aquitaine, polymictic lake with sandy substrate	Surface area, 3.8 km^2; catchment area, 350 km^2; maximum width, 2 km; length, 4.6 km; maximum depth, 1.9 m; mean depth, 0.6 m; residence time, 0.02 years	pH, 8.8, Secchi transparency, 0.7 m; conductivity, 159 $\mu S\ cm^{-1}$; total P, 119.2 $\mu g\ L^{-1}$; total N, 1226 $\mu g\ L^{-1}$; N/P, 13; DOC, 5 $mg\ L^{-1}$; chlorophyll a, 73.9 $\mu g\ L^{-1}$; algal biomass, 19.1 $mg\ L^{-1}$	Hypereutrophic	**Ecological status – inconclusive**	Cellamare et al. (2012)

presence of inorganic ion in lake water are important predictor of the presence of exotic invasive species (Früh et al. 2012). Invasive species mostly complicate the management action which are taken for the other problems faced by freshwater lakes (Strayer 2010).

Eutrophic lakes are highly susceptible to invasion of exotic invasive species which affect the overall lake ecosystem adversely. Increased biomass and litter production results in drastic change in water quality and sediments which affect the overall nutrients chemistry of the lakes, severely disturbing the flora and fauna of lakes. It changes the overall carbon and nutrient dynamics. Exotic invasive plants grow very rapidly which threatens the existence of native species. The biochemical composition of exotic invasive macrophytes is totally different from those of indigenous native species of macrophytes (Stewart and Davies 1990). This dramatically alters the nutrient cycle in the lakes. Increase in biomass of exotic invasive species increases the amount of nutrients which escalates the natural eutrophication process (Kalff 2002). Eutrophication leads to gradual change in aquatic flora and fauna populations which result in slow decline of habitat quality (Kalff 2002).The level of impact of exotic invasive macrophytes on nutrient cycle of lakes is determined by the macrophytic structure, vegetative spread, phenology, efficiency of macrophytes in nutrient uptake, type of photosynthesis, tissue chemistry, phosphorous content, allelopathy, presence of symbionts and mechanism of nitrogen fixation (Ehrenfeld 2003).

Exotic invasive macrophytes species that are important invaders of lakes include *Eichhornia crassipes* (water hyacinth), *Pistia stratiotes* (water lettuce), *Salvinia molesta* (kariba weed), *Myriophyllum aquaticum* (parrot's feather) and *Azolla filiculoides* (red water fern). They have become pretty prevalent by forming dense mats in eutrophic lakes either as floating weeds or rooted to shallow sediments.

5.11.1 Effect of Exotic Invasive Species on Native Species and Biodiversity of Lakes

Invasive exotic macrophytes reduce the growth of native sensitive macrophytes growth by forming dense surface canopies that shade out lower-growing native plants and interfere with water quality and change in fish habitat structure. Invasive exotic plants also reduce water quality of lakes. Increased biomass of invasive plant increases the organic sedimentation in lakes. This results in change in lake morphometry as additional organic sedimentation reduces the depth of lake. It results in transition of lakes into wetlands and finally to marshes. Aquatic exotic invasive plants are more productive than native species which increase the rate of nutrient loading in the lakes because plants utilize nutrient from the sediment and water and grow throughout spring and summer and then during senescence period, die and release those taken-up nutrient back to lakes resulting in internal nutrient enrichment. Dense aquatic macrophyte coverage in lakes makes water stagnant and prevents the oxygen circulation from the atmosphere which results in an anoxic condition and fish kills in lakes. Thus it affects the overall aquatic biodiversity in lakes. Native plant communities provide habitat to many aquatic fauna, whereas invasive plants which destroy the native species will result in reduced diversity of aquatic fauna like fishes and aquatic insects. Therefore exotic invasive species of macrophytes are harmful as they disturb proper functioning of lakes and result in loss of aquatic biodiversity with significant impacts on overall biodiversity of lake (Gettys et al. 2014).

5.11.2 Ecological Effect of Exotic Invasive Species on Freshwater Lakes

Exotic invasive species affect the ecological function of lake ecosystem. Some of the ecological impacts are as follows:

1. Reduce species diversity and richness in lakes.
2. Degrade water quality.
3. Suppress growth of desirable native plants.
4. Increase extinction rate of rare, threatened and endangered species of aquatic flora and fauna.
5. Alter animal community interaction in lakes.
6. Increase detritus buildup in lakes.
7. Change overall sediment chemistry of lakes.

5.12 Eutrophication Result in Damage and Loss of Aquatic Biodiversity

Eutrophication hampers the normal structure and function of aquatic ecosystem causeing major damage to aquatic biodiversity leading to extinction of many aquatic species of flora and fauna affecting the overall functioning of the Lake ecosystem. Loss and damage to aquatic biodiversity due to eutrophication are listed below:

1. Changes in macrophytic species composition, diversity and richness.
2. Increased biomass and number of aquatic macrophytes in eutrophicated lakes.
3. Change in macrophytic species composition.
4. Due to high turbidity, submerged macrophytes decreased in number.
5. Exotic invasive species of macrophytes dominate the lake causing extinction of native, sensitive and fragile species.
6. Increase incidents of fish kills.
7. Eutrophication leads to loss of desired fish species and reduction in the number of harvestable fish and shellfish which result in habitat shift of fishes from desired to less desired species.
8. Severely affect other aquatic flora like crustaceans, turtles, and beneficial benthic microorganism.

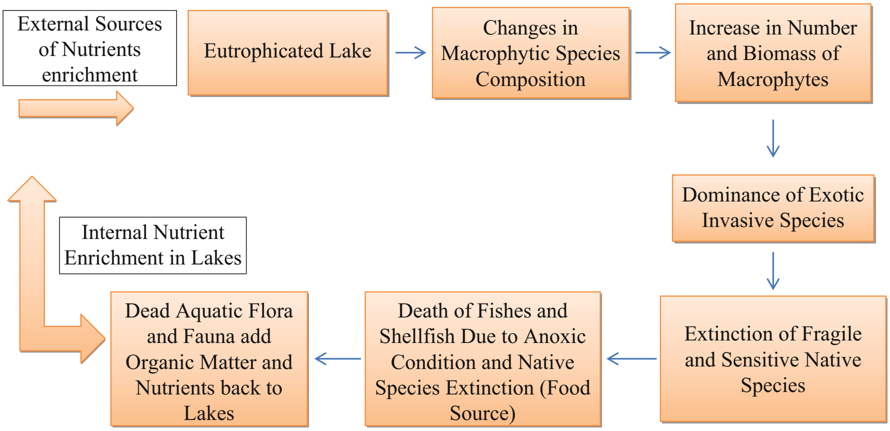

Fig. 5.4 Eutrophicated lake dominated by macrophytes results in loss of aquatic flora and fauna

Eutrophication which starts with nutrient enrichment in lakes results in excessive macrophytes growth ends up with biodiversity loss. It has major ecological impact on flora and fauna and on aquatic community structure (Fig. 5.4).

5.13 Conclusive Remarks

Lakes are subjected to various anthropogenic pressures resulting in eutrophication which disturb the overall ecological balance, nutrient dynamics, species succession along with change in trophic state, and habitat suitability of lake ecosystem. The gradual deterioration of lakes in the temperate climate zone is associated mainly with shallowing and overgrowth caused mostly by excessive nutrients enrichment and eutrophication.

This review focuses on persistent problem in lake ecosystem, that is eutrophication, which results in various problems including changes in water and sediment quality. Due to excessive growth of emerged macrophytes, the trophic states increase limiting the flow water transparency and development of submerged macrophytes. Excessive anthropogenic pressure is intensifying the process of nutrient enrichment which is the main factor affecting overgrowing of lakes as well as the development of phytoplanktons and accompanying biogeochemical processes. Changes in algae and macrophytes species composition and species richness result in gradual shift in biotic and habitat structure, which result in extinction of many sensitive native species of aquatic flora and fauna which depend on algae and macrophytes for food requirements and habitat. The change in trophic states as well as subsequent overgrowth rate of lakes vary from one site to another, however, it is mostly dependent upon the morphometric parameters of the lakes, their size and depth, and the availability of nutrients. It has been observed that the succession of macrophytes occurs faster in shallow lakes as compared to deep lakes, as they are controlled by higher availability of areas of low depth. The increasing rate of nutrient enrichments poses great threat on aquatic biodiversity. So there is critical need to focus fresh water management and conservation strategies on problems related to ecological condition of lakes, and additional research is needed for understanding the mechanism of eutrophication and its effect on algae and macrophytes. Sustainable management, conservation, and restoration of lakes are therefore a serious national and global issue. Finally, we see a great challenge in assessment of the lake overgrowth process and the related management of eutrophication. But with scientific advances in understanding aquatic systems better and enactment of strong legislation for conservation of aquatic ecosystem, major loopholes in the management as well as restoration measures can be addressed.

Acknowledgments We are grateful to UGC and the Department of Environmental Science, Babasaheb Bhimrao Ambedkar University, Lucknow, for providing us infrastructure and facilities for doing this review work.

Declaration of Conflicting Interests The author(s) declared no potential conflicts of interest with respect to authorship, research, and publication of this article.

Funding No financial support or funding is provided for the publication of this review paper.

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Land-Use Change as a Disturbance Regime

6

Ekta Purswani, Bhawana Pathak, Dhananjay Kumar, and Satyam Verma

Abstract

Land is an essential resource providing a variety of ecosystem services. Though it is a finite resource, it is suffering decay and degradation due to human population growth and its excessive resource consumption. Rapid changes in land use and land cover caused by human activities, fast urbanization, and agricultural expansion have led to ecological instability, disruption in many ecosystem services, and loss of biodiversity. It is also greatly interlinked with climate change, energy sources, and anthropogenic resource management. In this chapter, we try to review the mechanisms driving land-use change and research priorities in land-change science. Furthermore, we infer that landscape ecology must be incorporated in urban planning.

Keywords

Land-change science · Climate change · Ecosystem services · Biodiversity · Anthropogenic activities

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_6

6.1 Introduction

6.1.1 Land as a Resource

Land is a key resource inclusive of soil, rocks, underlying surface deposits, hydrological sources, and all living beings (FAO & UNEP 1999). Various ecosystem services such as water and biogeochemical cycles, water filtration, absorption of greenhouse gases, provision of food and habitat to all living organisms, regulation of climate by forests, storage of minerals in deep geological reserves, buffering and filtering chemical pollutants, biodegradation, preservation of past records in the form of fossils, ice cores, archaeological remains, etc. function through land. But, land is a limited as well as a dwindling resource at least in human lifetime (European Commission 2014). Human population explosion has triggered extensive and rapid land-use change worldwide by increase in demand for land for building habitats and food production (Ramankutty et al. 2002). This has also instigated rapid land degradation. Currently, 16% of total arable land area is degraded and is only increasing due to the increasing demand on land, water, and biological resources (FAO & UNEP 1999).

6.1.2 Land Cover, Land Use, and Land-Use Change

Land cover is the natural biophysical cover on Earth's surface, while the utilization of land for a certain purpose is land use (FAO & UNEP 1999). The previous and current land uses in turn determine the present land-cover pattern. The topographical, biological, and geological factors of an area determine the fitness of land for a certain use (The Environmental Literacy Council 2006). These are generally a reflection of the local climate and landforms, though they too can be altered by human actions. Land-cover categories on large scale can include biomes, viz., taiga, tundra, tropical rainforests, dry forests, grasslands, and deserts, while on small scale land covers can be specific plant communities (e.g., monoculture plantations, pine forests, mangroves, crop fields, etc.). Land-use change involves changes in land-cover and land-use patterns by natural or anthropogenic drivers.

6.1.3 Significance of Land-Change Science

Land-use and land-cover changes (LULCC) consist of changes in topographic, biotic, and atmospheric characteristics in the area of land parcel. These changes may include alterations in biodiversity, gross and net primary productivity, soil characteristics, rate of soil erosion, and sedimentation (Turner et al. 2007). Land covers and changes in them are sources and sinks for most of the material and energy flows that sustain the biosphere and geosphere, including trace gas emissions and the hydrological cycle. Land-use changes, both directly and indirectly, hold major implications for sustainable development and livelihood systems and also contribute to changes in the biogeochemical cycles of the earth, affecting the atmospheric levels of greenhouse and other trace gases.

LULCC information is a prerequisite for proper planning and management of land inventory and other natural resources (Dominati et al. 2010; Lange et al. 2015). Thus, it pointedly affects viable and effective management of natural resources and environment (Lange et al. 2015). The LULC changes have been defined as the most important anthropogenic disturbance to the environment at local level (Mayer et al. 2016).

Knowledge of the past and present land-use scenarios helps to predict future land-use configuration and plan development accordingly (Sinha and Kumar 2013). Most of the land-use changes like expansion of agriculture, urban areas, and industries grow from geographical centers of the same class, and many models utilize this phenomenon as a feature to simulate future scenarios (Agarwal et al. 2002; De Sherbinin 2002; Guan et al. 2011).

LULCC are driven by changes in multi-scale interacting driving factors such as biophysical conditions of the land, demography, technology, affluence, political structures, economy, and people's attitudes and values. These driving factors vary with geography and time; therefore, LULCC is also heterogeneous both spatially and temporally. Therefore, improved representation of both spatial and temporal dimensions of LULCC is crucial for better understanding of human influence on the natural environment.

A major reason for researching historical land-use and land-cover change is that by understanding the past, we can better understand future trajectories. Urban areas show decreasing growth from city center toward remote places, and thus, one area gives rise to another area of the same land-use class. Most of the models rely on this distinctive feature to predict future change. One of the first steps toward this goal is to accurately quantify contemporary and historical LULCC, in a spatially explicit way.

6.2 Factors Causing Land-Use Change

Land-use change science digs deep to recognize and apprehend the drivers and factors of change to make plans for sustainable land use. The various forces of change are diverse from physical like climatic, natural disasters, biological-like succession, and evolution to demographic and socioeconomic factor. Among the many different factors, anthropogenic causes are major drivers for increasing the pace of land-use change (De Sherbinin 2002).

6.2.1 Population Rise

Human population ("population" here onward) has risen on an unprecedented scale, and human species has outnumbered all other life-forms. Man has encroached upon habitats and niches of many other species reducing their numbers to the brink of extinction. The struggle has risen even among the humans themselves. The ever-increasing population competes for all resources of food, fiber, and shelter from the same amount of land. However, rapid and unplanned urban growth does not go in accordance with sustainable development without proper development of the necessary infrastructure. The conversion of land from wild and agricultural uses to urban and suburban occupancy is growing at a faster rate than populations in urban complexes (Pickett et al. 2011). And to feed the growing population, more and more land is brought under cultivation, and agriculture is being intensified to obtain maximum yield in limited space. Such human modification of the earth's surface disrupts ecosystems by causing land degradation affecting microclimatic conditions, biogeochemical cycles, biodiversity, and water resources of the region (Bowyer et al. 2009; Mishra and Rai 2016). Therefore, it becomes vital to understand the interactions and relationship of humans with land (The Environmental Literacy Council 2006).

6.2.2 Deforestation

Forests, being the most vulnerable, are key indicators of changes in land-use intensity and pattern (Foley et al. 2005; MacDicken 2015). Transition of forests depends upon the population growth, subsequent increase in demand for agricultural produce, timber, and non-timber forest products (NTFPs), as well as technological development (Köhl et al. 2015). This is more often the case of the present-day developing countries experiencing deforestation. Fire dynamics or natural disasters may also drive changes in forest lands.

Deforestation drives two main changes, viz., loss of biodiversity and global climatic change. These changes in turn disturb the food chains and biogeochemical cycles which act as feedbacks to land-cover change. Land-use change like expansion of agriculture (Maitima et al. 2009; Paterson and Bryan 2012) and urban areas (Nowak 1993) on wild and forested lands is directly linked with global climate change through its impacts like higher soil erosion and soil degradation, loss of biodiversity by adverse effects on habitat and various species important in food chain, alterations in hydrological cycle by impact on runoff and evapotranspiration, and increased carbon emissions (Lambin et al. 2003; Nagendra et al. 2013b).

6.2.3 Urbanization

In the increasingly global and interconnected world, urbanization is a central demographic phenomenon. The world is seeing a slow rise in rural population and rapid increase in urban population. Unrelenting increase in population growth will feed 2.5 billion people to urban areas by 2050 (UNDESA 2014). Currently, most of the rural population (about 90%) resides in Asia and Africa. However, these continents would make up 90% of the global urban population by 2050. Moreover, urbanization is diverse in terms of its characteristics in different regions (UNDESA 2014). This is more visible and significant phenomenon in fast-growing, unplanned urban outgrowths and extensions in developing countries (Schulz 2002). As per the 2014 report on world urbanization prospects by the United Nations, 54% of the world population resides in urban areas, and this figure is projected to rise to 66% by 2050. India is going to be among the top contributors to urban population by adding about 404 million urban dwellers by 2050 (UNDESA 2014).

An uneven pattern of urbanization is observed in the world with most of the urban agglomerations rising in southern countries on the globe. Asia contains most of the developing nations in the world (UNDESA 2014). In the late twentieth century, the urban population of the developing countries in megacities rose from 22% to 36% (UNDP 1996). Such cities called megacities face too many constraints caused by larger population competing for resources in smaller spaces such as but not limited to habitation, sanitation, pollution, water scarcity, and other infrastructure and services.

The current pace of technological advancement in every field supports urbanization but may prove to be very prosperous and positive on one hand while an inadvertent misfortune on the other (UNDP 1996). In the absence of appropriate policies and essential infrastructure, sustainable urban growth becomes a farsighted imagination. Past and present conditions of natural resources should be analyzed to account the changes in them and to develop a framework for their equitable distribution and sustainable use in future (Lambin and Meyfroidt 2011; Schulz 2002).

Instead of providing comfortable and luxury lifestyles, many urban agglomerations in the world have become bigger occupancies of slums. Unplanned growth and expansion causes pollution, environmental degradation, and inefficient management of resources. For a sustainable urban development, the three essentials of economy, society, and environment must be taken care of. In the Rio+20 United Nations Conference, "the future we want," sustainable development goals have included poverty and preserving nature as keystones of the 2030 agenda for sustainable development (FAO 2016; United Nations 2015).

6.2.4 Agricultural Expansion and Intensification

Expansion of agricultural lands has been the principal driver of deforestation and land-use change (De Sherbinin 2002; Morton et al. 2006; Scales 2014). Agricultural lands have shown a net growth of 50% in the twentieth century, while pastures also doubled in expanses from 1700 till 1990 (Lambin et al. 2003). Since the invention of agriculture, the growth has been slow, but over the last three centuries, it has grown very fast to feed the growing population (De Sherbinin 2002; Houghton 1994). After the early 1700s, Europe, North America, and the Soviet Union showed rapid cropland expansion, and it has maintained steady till recent times, while Asian and African countries showed gradual expansion earlier and depict rapid growth after the 1900s. Since the early nineteenth century, 6 million km^2 of forest cover and about 4.5 million km^2 of grasslands have been converted for agricultural produce. However, with doubling of the world population between 1900 and 1990, cropland area per capital decline by 50%. Nevertheless, this decline in per capita land resource also contrasts between developed and developing countries. Asian and African nations containing more than half the world's population saw a per capita decline in cropland area by about 65% during the twentieth century (Ramankutty et al. 2002; Ramankutty and Foley 1999).

With rise in world population by one-third till 2050, there would be higher demand for food production. And to meet the sustainable development goal of zero hunger, there would be higher necessity for agricultural intensification which means growing higher yields in lesser space. With major economies of China and India in Asia contributing about little less than half of the global population, they have intense repercussions for overall resource demand and environment. With a paradigm shift from agricultural to industrial economies, these nations have and will have increasing demands for food, space, and energy resources with rise in per capita income. Agriculture has to play dual role of meeting growing resource demands for food and fiber as well as provide the essential ecosystem services. Altogether, these factors will play cumulative role as drivers of agricultural intensification (Wu and Li 2013).

During the last 100 years, LULCC in India has been manifested in terms of agricultural expansion at the expense of forests. This process continued until the 1960s, when "Green Revolution," for the first time, focused on enhancing agricultural production by means of new high-yielding varieties, extension of irrigation facilities, and use of fertilizers and pesticides. Since the 1960s, modern economic development plans, and their implementation, nonetheless, set new trajectories and pace in the LULCC processes.

6.2.5 Climate Change

Climate change and land-use change both cause and effect each other as they have two-way interaction. Both of them are two prongs of global change effected by anthropogenic actions. Climate change affects land use by means of sea level rise, melting glaciers flooding rivers, irregularity in weather patterns causing drought in dry areas and floods in others, and such other events. These changes induce migrations, biodiversity losses, and tree line shift to higher altitudes, altering the productivity of land for agricultural use. The crops or trees to be grown on a particular expanse of land depend on climate change. Also, the decline in agricultural produce is largely affected by weather patterns which are increasingly becoming unpredictable due to global change (Dale et al. 2011).

6.3 Research Primacies in Land-Change Science

From biogeochemical cycles to water resources to biodiversity, land-use change directly and indirectly influences every aspect of global change and, hence, has been given prime importance in research and in sustainable development frameworks (Agarwal et al. 2002; Canadell 2002; Lange et al. 2015; Turner et al. 2007). In recent years, special attention has been given to land-use changes and dry land degradation (Bowyer et al. 2009; Lal 2015; Lambin 1997; Schulz et al. 2010; Tian et al. 2016). Land-use and land-cover changes result in a variety of consequences and disruption of ecosystem services which are essential for survival of mankind as well as other forms of life (Agarwal et al. 2002; Canadell 2002; Houghton 1994; Lange et al. 2015; Ramankutty et al. 2006).

6.3.1 Loss of Biodiversity

Biodiversity is broadly defined as the "totality of genes, species, and ecosystems of a region." Policies related to land use, conservation, agriculture, and production of goods from timber to non-timber have to take into account biodiversity effects (Croezen et al. 2011; Mayer et al. 2016).

Landscape alterations have significantly impacted biosphere by deforestation, habitat degradation, and habitat fragmentation supplemented by other anthropogenic activities like pollution, agriculture and urban expansion, and global climate change. This has adversely affected food webs; nutrient cycles, resulting in alterations in diurnal and seasonal cycles of organisms; scarcity of food; and habitat loss leading to species extinction and decline in population sizes (Croezen et al. 2011; Maitima et al. 2009; Nagendra et al. 2013b; Newbold et al. 2015). Agricultural expansion is the dominant driver of deforestation and, thereby, land-use change, and conversely, it is also important for feeding the current global population of over 7 billion (FAO 2016). Though the rate of global deforestation has reduced by half, the forests are declining at 13 million hectares per year, and 85% of all the species on earth will get eliminated with 50% reduction in world's remaining forests (Pimm and Raven 2000). Tropical countries, particularly, have shown significantly dwindling forest cover with a decline of 195 Mha that was seen between 1990 and 2015 (Keenan et al. 2015). Therefore, biodiversity and habitat conservation has caught attention of conservationists all over the world since the past few decades (Sundarapandian and Karoor 2013) which led to the need to discover and identify prime in situ conservation areas (biodiversity hotspots), species-specific conservation areas (tiger reserves), and protected areas (national parks and biosphere reserves). Globally, scientists have stated through their studies that land-use changes and associated pressures strongly diminish local terrestrial biodiversity and have estimated global average reductions to date of 13.6% in within-sample species richness, 10.7% in total abundance, and 8.1% in rarefaction-based species richness (Newbold et al. 2015). Spatial comparisons depict and verify the nature of anthropogenic influence on biodiversity in areas which are spatially and geographically similar (Dayamba et al. 2016; Newbold et al. 2015). Studies published on spatial comparisons have made possible to prepare global, taxonomic representative models. Besides, many scientists come together to work collaboratively and share their raw data which makes it conceivable to consider multiple aspects of biodiversity, rather than the single, simple metrics of most existing models, which cannot capture all key aspects of diversity (Pereira et al. 2013). Several reviewers infer that reduced biodiversity losses at local level caused by habitat conversion benefitted people; agricultural expansion and intensification reinforced development across many countries. However, there is inequality in benefit distribution across nations and states. Greater than 20% losses in local species richness would likely markedly weaken ecosystem function and services. In a longer term, local losses cumulatively would invite widespread losses as per the projections of many studies. Transformation of people's attitudes and values with rigorous and focused efforts can help achieve global sustainability of local biodiversity (Newbold et al. 2015).

6.3.2 Rise in Carbon Emissions

Land-use change emissions form 10–15% of the total carbon emissions and 40% of radiative forcing of other greenhouse gases (Mahowald et al. 2017). By greatly influencing energy and mass fluxes, and being the second largest source of carbon emissions (IPCC 2000), land-use change is a major causal factor of climate change. Land inclusive with vegetation and soil is an important source as well as sink of C storage, and modification and alteration of land-use patterns is accountable for large fluxes of carbon (C) (Canadell 2002). In the tropics, C cycle is affected primarily by the trees (Singh and Chand 2012). This has brought attention of the scientists worldwide to conservation of trees both in natural wooded lands like forests as well as managed ecosystems like the urban. Though forest areas are considered as the basic ecosystems for tree resources, a large number of trees also exist outside the continuous forested areas across the continents (Singh and Chand 2012). Management of forests and tree cover outside forests affects the source and sink dynamics of carbon dioxide as trees grow, die, and decay.

The nexus between land-use change and climate change has been cited by many studies since the last decade (Chuluun and Ojima 2002; Li et al. 2017; Mahowald et al. 2017). Several works have analyzed terrestrial ecosystems as sources and sinks of C has been highlighted, underscoring the impact of land-cover changes on the global climate (Houghton 1994; Houghton and Goodale 2004). Based on various potential scenarios, it has been predicted that atmospheric temperature in 2100 will be increased in 1.8–4.0 °C, on average, considering the best estimate (IPCC 2000). However, in its sixth assessment report, IPCC has set the goal of maximum 1.5 °C. In addition, the Earth Systems Research Laboratory/National Oceanic and Atmospheric Administration (ESRL/NOAA) estimated that annual increase in atmospheric concentration of CO_2 is around 3 ppm per year since 2015 with uncertainty of 0.11 ppm per year and the trend seems to continue with an increasing rate of rise on a year-over-year basis because CO_2 emissions from anthropogenic sources currently exceed the capacity of absorption of the terrestrial ecosystems and oceans.

6.3.3 Decrease in Soil Health

Soil quality or soil health is indicated by its physical features like soil aggregates, texture, bulk density, water holding capacity, chemical properties like soil organic carbon (SOC), amount of macro- and micronutrients, and microbial communities in the soil (Koch et al. 2013; Lal 2009, 2015). It is proven by many studies that SOC concentration influences soil quality, and they have termed it as key indicator of soil quality (Batjes 1996; Bhattacharyya et al. 2008; Lal 2015; Manlay et al. 2007). Carbon sequestered in soils is the carbon captured and stored for a long time not bound to escape unless by microbial degradation and respiration (Lal 2003). SOC is critical indicator of soil health as it is the first to be affected by degradation. In recent times, changes in SOC stocks have become commonly incorporated in developing mechanisms and policies for soil security and sustainable development (Lal 2003, 2009).

Land-use change by natural causes or anthropogenic activities like deforestation for conversion to agricultural and pastoral lands, intensive cropping, and urbanization cause degradation of soil by altering physical, chemical, and biological properties, thereby affecting associated ecosystem services. The magnitude and pace of soil decay vary according to the nature and intensity of change. Forest clearing and tree felling aggravate soil erosion by direct exposure to wind and rainfall and decrease litter fall and humidity. These changes deplete soil nutrients and organic matter, negatively affect the soil flora and soil enzymes, and thereby decrease the rate of biogeochemical reactions. Such changes also result in reduction in bulk density; porosity, soil fertility, and infiltration rate are also observed. Consequently, associated services like biodiversity, carbon storage, agricultural productivity, and provision of water are also adversely affected. A reverse change like agriculture or pastures to forest or restoration of degraded lands enhances soil quality and fertility. Naturally, degradation is a slow process, but human interference has both directly and indirectly exacerbated the process causing soil infertility and desertification worldwide.

Anthropogenic land-use change is a result of multiple stakeholders and institutions playing their roles in response to the economic development (Lambin et al. 2001). A speedier loss of soil health has reportedly affected as much as 500 million hectares (Mha) in the tropics (Lamb 2005) and 33% of the total land surface on earth (Koch et al. 2013; Lal 2015). Hence, various initiatives have been taken on global level like declaring 2015 as year of soils, international symposium on soils in 2017 by FAO (FAO, 2017), a special report by IPCC on soils (IPCC 2000). This also gave origin to the concept of soil security (Koch et al. 2013; McBratney et al. 2014).

6.3.4 Nexus Between Land-Use Change, Climate Change, and Biodiversity Loss

The nexus between land-use change and climate change have been observed and proved since the second half of the nineteenth century and got more pronounced in

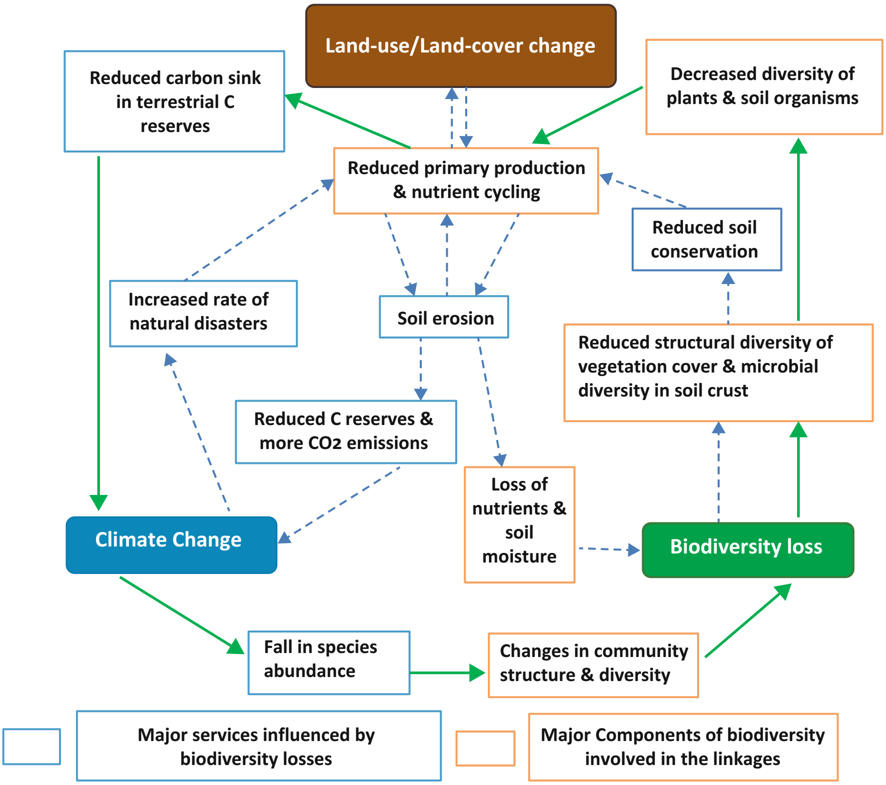

Fig. 6.1 Nexus between land-use/land-cover change, global climate change, and biodiversity. (Source: Millenium Ecosystem Assessment 2005)

the early twentieth century (Fig. 6.1) (Dayamba et al. 2016; Hoover 2011; Mahowald et al. 2017). Land-use change emissions form 10–15% of the total carbon emissions and 40% of radiative forcing of other greenhouse gases (Mahowald et al. 2017). As land is a resource for multiple services from housing to energy and ecosystem services, the carbon markets are on an upward trend and are creating price indicators for the conversion of agricultural land to wild lands (Bryan et al. 2015; Paterson and Bryan 2012; Renwick et al. 2014). Supply of one of the ecosystem services by land-use change rises on compensation of other ecosystem services (Foley et al. 2011; Nagendra et al. 2013a; Poppy et al. 2014; Singh and Singh 2017). A balancing act for utilizing the multiple ecosystem services from land requires its sufficient allocation and judicious usage as we need to achieve food security and biodiversity and prevent global climate change simultaneously (Johnson et al. 2014; Laliberté et al. 2010; Singh and Singh 2017). Hence, an in-depth understanding of ecological economics and the other ecosystem services provided by a particular parcel of land needs to be understood to achieve a balance between minimizing emissions and provision of other ecosystem services (Bryan et al. 2015; Renwick et al. 2014; Smith et al. 2013). Though most studies have dealt with one component of land use and have not included the interrelation of the multiple services of land (Smith et al. 2013). A comprehensive and computable scrutiny of land composition, structure, and the impacts on its services would be required to develop an effective market policy for optimizing the benefits of land resources (Johnson et al. 2014; Mahowald et al. 2017; The Environmental Literacy Council 2006).

LULCC and global environmental change form a complex and interactive system with human actions. Further complicating this system is the fact that the linkages occur at different spatial and temporal scales. The outflow of soil nutrients, for example, has immediate impacts on land productivity, vegetation changes, and soil erosion, midterm impacts on landscape fragmentation and land productivity, and possible long-term impacts on climate change (Chen et al. 2013; Guo and Gifford 2002; Richter et al. 2000).

6.3.5 Use of Geoinformatics in Land-Change Science

It is widely accepted that LULC has an important effect on both the functioning of the Earth's systems as a whole (DeFries et al. 2007; Lambin et al. 2001; Verma et al. 2017) and the majority of ecosystems (Jyoti Nath et al. 2009; Pettorelli et al. 2016; Turner et al. 1995). Remote sensing and GIS approach and growing advances in this area provide tools to study surface changes at different scales. Understanding the dynamics of these changes provides information for better decision-making with respect to management of natural resources.

Over the last three decades, a variety of methods have been available for change detection using RS data. Change detection is defined as the method of analyzing and obtaining changes in landscape features and characteristics on the basis of the multitemporal satellite data of the same geographic unit. Statistical and rule-based techniques are available for change detection. Advancements in fields have made data of high temporal, spatial, and spectral resolution available for every land parcel on earth (Mishra and Rai 2016). Remote sensing and GIS technologies have made possible to obtain cost- and time-efficient data with much less labor required. Thus, updated LULC information can be obtained at any time for any region, and past and current trends can be compared, and future scenarios can be predicted. However, due to a number of sensors offering images of varying resolutions, standard land-use land-cover (LULC) data at decadal intervals or less is not available for the entire earth. As well, there is no temporally continuous LULC data of medium to high spatial resolution for India (Roy et al. 2015). Coarse resolution data like that of MODIS and Landsat MSS is available covering the entire earth. But medium- to high-resolution mapping is required for a variety of purposes with greater than 85% accuracies for local governance and for delineation of different land-cover types.

Regional and national level programs of agricultural planning, river basin and watershed development, biodiversity conservation, urban planning, etc. require medium to fine-scale resolution mapping (Roy et al. 2015).

Quite a many studies have covered land-use and land-cover change analysis using Landsat and IRS images of different cities and regions of India, yet a lot many are yet to be studied (Aithal and Ramachandra 2016; Goswami and Khire 2016; Moghadam and Helbich 2013; Mondal et al. 2016; Paul and Nagendra 2015; Ramachandra et al. 2013). Various agencies carried out LULC mapping and monitoring specific for their objectives at various regional levels like agroclimatic zones, meteorological subdivisions by meteorological centers, watershed and ground zonation potential by groundwater boards, and other maps by survey of India (Central Ground Water Board 2014; Directorate of Census Operations 2001; Roy et al. 2015). The initiation and advancement of remote sensing technology in India brought a paradigm shift in large-scale and national level LULCC mapping by the disposal and accessibility of multispectral and multi-resolution remote sensing data having synoptic and temporal coverage (Navalgund 2014).Various projects requiring mapping received support and fulfilled the then national needs such as natural resource management, afforestation and restoration programs, development of watershed and catchment areas for irrigation, agricultural expansion, and eco-development (Roy et al. 2015). Hitherto, most of the national projects involving land-use mapping and modeling were target specific. Hence, they varied in terms of satellite data utilized, classification schemes, and mapping techniques.

In the present times, landscape dynamics and climate studies need information on phenology and leaf area index of forest; differentiation of cropland, fallow, barren, and wasteland; mapping of non-permeable surface like built-up areas; and features like, dams, mining, aquaculture, and wetlands. Delineation of the classes with acceptable accuracy requires satellite images of medium to high spatial resolution (Majumdar 2008; Rizvi et al. 2016). Besides, consistency between time-series maps and internationally accepted land-cover classification scheme is required for placing proxy to climate variables (Roy et al. 2015; Sinha and Kumar 2013; Taubenböck et al. 2009).

6.4 Gandhinagar as the Case Study

6.4.1 Gandhinagar: The Green City

Gandhinagar is the second planned city in India after Chandigarh and one of the greenest capital cities of India with 54% tree cover. Currently, it is in the 100 smart cities' list of India. According to its architects, the city was designed in a manner that no tree was cut during its planning and building (Apte 2012). We conducted a land-use study to analyze the plant diversity and soil properties in rural and urban land-use classes of Gandhinagar district. The main land-use change pattern observed was 200% increase in rural and urban built-ups and decrease in agricultural area.

6.4.2 Plant Diversity

Patterns in variation in biodiversity in different land-use classes were observed. Biodiversity was analyzed in three different land-use classes, viz., *vegetation*, *rural*, and *urban* (Table 6.1). The areas under *urban* land-use categories showed lower plant diversity than rural and vegetation areas. The urban areas had lowest species richness (12) and Shannon-Weiner's index value (1.45). In rural landscapes, the Shannon-Weiner's index (2.41) and species richness (22) were little lower than that of vegetation areas (Shannon-Weiner's index, 2.72; species richness, 25). Although urban areas have more basal area and stand density than the rural classes, there are quite a number of monoculture plantations. Therefore, the contribution to diversity has been less. A greater number of species should be included in urban plantations to maintain the biodiversity of the area.

6.4.3 Soil Health

Purswani and Pathak (2018) analyzed soil properties in various land-use classes and compared them (Table 6.2). They propose the decline in soil quality in proportion to the decline in number of trees in a landscape. Their study shows vegetation class having the most fertile soil. The stem density and basal area were found to be higher in urban areas than rural areas and so were the macronutrients.

Table 6.1 Species diversity, richness, and stem density in different land uses of Gandhinagar

Diversity index	Vegetation	Rural	Urban
Species	25	22	12
Stem density/ha	665	220	412.22
Basal area/ha	3.97	1.40	2.25
Shannon-Weiner's Index	2.72	2.41	1.45
Simpson's Index	0.91	0.85	0.62

Table 6.2 Soil properties in different land uses of Gandhinagar

Parameters/land-use class		Vegetation	Urban	Rural
Total Nitrogen (%)	0–10	0.14 ± 0.03	0.15 ± 0.01	0.11 ± 0.02
	10–20	0.12 ± 0.04	0.12 ± 0.03	0.10 ± 0.01
	20–30	0.10 ± 0.04	0.11 ± 0.01	0.08 ± 0.01
P (μg/g)	0–10	97.33 ± 1.15	124.33 ± 60.01	67.33 ± 19.50
	10–20	175.67 ± 141.46	103.33 ± 30.92	73.00 ± 5.57
	20–30	325.00 ± 226.32	73.00 ± 20.22	154.00 ± 70.79
Extractable K (μg/g)	0–10	6.00 ± 0.00	4.33 ± 0.58	5.00 ± 1.00
	10–20	6.00 ± 0.00	5.00 ± 0.00	5.37 ± 0.36
	20–30	5.67 ± 0.58	4.67 ± 0.58	6.47 ± 0.49

This study thus showed the effects of land-use change caused by population growth and urbanization to be negative for ecosystem services. They also restate that inclusion of management of ecological features in development can minimize the harmful effects of land-use change.

6.5 Conclusion

Land-use change results in loss of biodiversity, carbon stocks, and soil health. Biodiversity loss disrupts ecosystem properties (Nagendra et al. 2013a, b) thereby leading to decline in carbon stocks and soil health. Decline in tree cover reduces soil quality as well as decline in plant diversity affects soil properties. The degraded soil in turn supports less number of species, and weeds and invasive species dominate. Thus, land degradation affects all the different ecosystem services which when disrupted further feed land-use change, thus forming a vicious cycle. Hence, land-change science needs to be dealt with an integrated approach and must be included in every aspect of development, whether agriculture or urban areas.

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Floristic Diversity, Distribution and Conservation Status in the Vicinity of Coal Mines of Kachchh District in Gujarat, India

7

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Abstract

A study of floristic composition in various kinds of land use and habitat types plays a significant role in the environmental planning as plants are the primary producer of any ecosystem. The study of plant community structure and dynamics is an important aspect of forest ecology where various species contribute in determination of specific type of habitat. Such knowledge is very crucial to draw strategies for conservation and management of natural resources. The study area comprises tropical thorn forest, grassland, savannah, mangrove, saline desert and freshwater wetland as important habitats. During the study, we identified the various landcover and habitat types of western Kachchh and proposed some regional planning attributes for sustainable development in region. We surveyed the Panandhro, Matanamadh and Jadva mining complexes of region, for vegetation. We laid the sampling plot of specific dimension for various plant species in various landcovers and habitats to evaluate them for vegetation characters. During the survey a total of 326 plant species were recorded in which 14 were of conservation significance. To assess the impact of mining activities on floristic diversity, a circular zone of 2 km width was made around all the three sites. During the present study, it was observed that the species diversity decreases towards the mining site. The unfavourable habitat condition leads to reduce the regeneration capacity of various plant species. Furthermore, the dumping of contaminated soil leads to alter natural habitat and leads to growth of invasive alien species, i.e. *Prosopis juliflora*. The native tree species like *Acacia senegal*,

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_7

A. nilotica and *Salvadora oleoides* face immense threats to extinction due to anthropogenic activities associated with mining. To minimize the impact on the vegetation, proper biodiversity conservation plan should be prepared to promote the plantation of native species. Along with that plant, some plant species which can improve the degraded habitat should be preferred.

Keywords
Floral diversity · Land degradation · Coal mines · Soil conservation · Natural resources · Forest ecology

7.1 Introduction

The study of floristic diversity plays very crucial role to understand plant community structure and function (Patel and Dabgar 2012). Further to that, such study also provides vital scientific information for various kinds of environmental planning because plants provide basic amenities that help to sustain life on earth. The study of plant community dynamics and species diversity is an important aspect of forest ecology, which entails the contribution of various species in determining structure of specific habitat type (Patel et al. 2012). To generate the information on diversity and distribution on tree and shrub species is of primary importance for developing the conservation and management strategies (Kumar et al. 2006).

Due to geographical situation and prevailing physio-climatic condition, this region supports the distinctive gene pool distributed in various habitats such as tropical thorn forest, grassland, savannah, mangrove, saline desert and freshwater wetland in the region of our interest, i.e. western Kachchh (Patel 2012). These forests are scattered throughout the district but predominantly recorded from the western part of Kachchh, i.e. Lakhpat and part of Nakhatrana talukas. Noticeably, a large portion of such forests, i.e. about 1185 km^2 area constituting 84% of thorn forest in western Kachchh, remains unprotected and thus not brought under management for maintaining vegetation cover or habitat improvement. Only 228 km^2 area of these forests is confined within the Narayan Sarovar Sanctuary and has got the legal protection.

In general, due to poor canopy formation, these forests form open canopy cover that is mainly constituted by *Acacia senegal* and *A. nilotica*. The occurrence and distribution of codominant species varied greatly within the study area due to high variability within soil taxonomy, moisture regimes and site-specific geological formations. Such species include *Euphorbia caducifolia*, *Grewia tenax*, *Cordia perrottetii*, *Salvadora oleoides*, *S. persica* and *Capparis decidua*. The invasion of *Prosopis juliflora* is very common in these forests, which has changed the floral composition and vegetation structure. Several species of conservation significance are also reported from this area (Patel and Dabgar 2018).

Mining is a major developmental activity in western Kachchh, which promotes several other economic activities and contributes substantially in local and regional economies. Such vigorous developmental activities are causing land and ecosystem damage, which leads to the loss of vegetation cover and loss of species diversity (Huang et al. 2015). Additionally, the overburdens of coal mines when dumped in unmined areas create mine spoils, which also affect the surrounding vegetation cover and plant species diversity (Alekseenko et al. 2018).

In the past very few studies have been conducted on floristic diversity of the region, and limited information is available about the plant community structure. The studies are mainly focused to fulfil legal requirement in the form of Environmental Impact Assessment studies. Gujarat Mineral Development Corporation (GMDC) (1995a, b, c) conducted rapid EIA/EMP studies for proposed Mata-no-Madh, Akrimota and Umarsar lignite mining complex and conducted surveys around these mining complexes to assess the status of biological (flora and fauna) components. Identification afforded recognition of 9 species of trees, 15 species of shrubs and 22 species of herbs from core zone, while 34 trees, 28 shrubs, 51 herbs, 12 climber species and 9 crop species were recorded from buffer zone. From the Umarsar mining site, 9 species of trees, 12 species of shrubs, 31 species of herbs and 8 species of climbers were recorded from core zone, while 26 species of trees, 20 species of shrubs, 41 species of herbs, 9 species of climbers and 11 crop varieties were recorded from buffer zone. In *Akrimota* mining site, 8 tree species, 12 shrubs, 36 herb species and 6 climber species were recorded from core zone, while 26 tree species, 18 shrubs, 43 herbs, 11 climber species and 11 crop varieties were recorded from buffer zone. Also, 10 species of plants that possess medicinal value have also been recorded from this site. Further to that, in 2006 GMDC conducted a Rapid Environmental Impact Assessment for Umarsar Lignite Mine and reported 81 floral species. In the past very few studies have been conducted on the correlation of vegetation and coal mining (Cornwell 1971; Fyles et al. 1985; Prasad and Pandey 1985; Singh and Jha 1987). Hence, present work deals with the community structure and diversity pattern in different zones around the three major mining complexes to assess the impact of mining on floristic diversity.

7.2 Methodology

Floristic diversity assessment methods for various plant life forms such as trees, shrubs, climber, herbs and grasses varied greatly in terms of data collection, characterization, classification and identification (Bhatt 1993; Patel et al. 2012). Specific methods of sampling and data analysis used for evaluating different life forms of interest in the present chapter are as follows:

7.2.1 Sampling Design and Field Sampling

To understand the impact of mining on floral diversity, the diversity and distribution pattern of plant species was recorded in nine mine zones (referred to as Z1 to Z9 in present study) that represent the area under zones at the regular interval of 2 km from centre of the mining centres. After stratification, the entire area was divided into 5 × 5 km grids using Survey of India's geo-referenced co-ordinate system. Those grid cells were further subdivided into 1 × 1 km smaller grids, and a total of 180 transects (Fig. 7.1) were laid down in select grids chosen randomly using random number table (Table 7.1). Stratified random sampling was employed to lay down samples of 1.1 km ($n = 180$ transects) different habitats. All transects were laid diagonally to randomly picked 1 × 1 km grid. Care was taken to have adequate sampling in each of the topographical features across lateral and vertical gradients like altitudinal range and terrain and spatially within each habitat type.

7.2.2 Sampling and Data Collection

To carry out enumeration of the vegetation of the study area, a simple, systematic and predetermined technique was employed. Various habitats were surveyed using transect and quadrate methods as suggested by Misra (1968) and Mueller-Dombois and Ellenberg (1974) to record the various characteristics of tree, shrub and climber species. We used 1.1-km-long transect (180 no.) for vegetation survey (Table 7.1).

Flora of Gujarat State (Shah 1978), flora of the Indian Desert (Bhandari 1990) and the Bombay grasses (Blatter and McCann 1934) were used to identify various plant species collected from study area. Collected plant specimens were deposited in the herbarium section of Gujarat Institute of Desert Ecology, Bhuj. Secondary sources including published literature such as WCMC (1994) and *Red Data Book of Indian Plants* (Nayar and Sastry 1990) were used to identify the rare, endangered and threatened plant species.

7.3 Data Analysis

7.3.1 Species Composition, Distribution and Diversity

Quantitative community characteristics such as density, abundance, % frequency, basal area and important value index (IVI) of each species were determined by following the methods as outlined by Misra (1968) and Mueller-Dombois and Ellenberg (1974). Distribution pattern was analysed using the value of abundance and % frequency. High frequency and low abundance of a species indicate the regular distribution; however, low frequency and high abundance indicate the contagious distribution of species (Misra 1968).

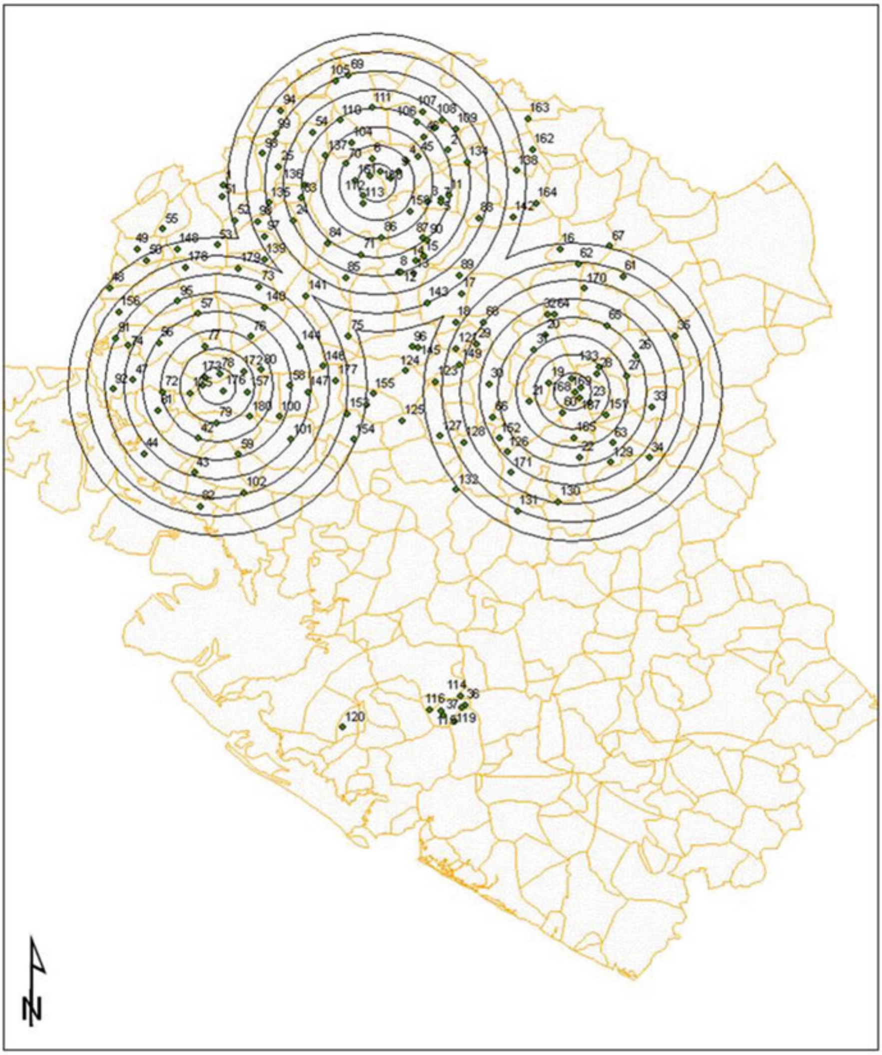

Fig. 7.1 Sampling point location in and around coal mines of Kachchh, Gujrat

The % frequency of each species was calculated and placed into their respective frequency classes as suggested by Raunkiaer (1934). Further, species diversity and similarity indices were calculated using the following formulae:

(A) *Shannon-Wiener diversity index* (H') $H' = \sum pi \times \ln(pi)$

Where:

H = index of species diversity

pi = proportion of total sample belonging to the ith species

ln = natural log1

Table 7.1 Distribution of samples in study area

Mining zone	# of transects
Z1	12
Z2	16
Z3	15
Z4	26
Z5	29
Z6	22
Z7	19
Z8	18
Z9	23
Total	**180**

(B) *Simpson diversity index* (D):
$D = 1-$Dominance. Measure 'evenness' of the community from 0 to 1
(C) *Menhinick richness index* – the ratio of the number of taxa to the square root of sample size
(D) *Margalef's richness index* (*Rl*)

$$Rl = S - 1/\ln(n)$$

(E) *Dominance*:
1 – Simpson index. Ranges from 0 (all taxa are equally present) to 1 species dominant to the community.
D = sum $((ni/n)^2)$ where *ni* is number of individuals of species *i*.
(F) *Equitability* (El or J'): Shannon diversity divided by the logarithm of number of taxa.
This measures the evenness with which individuals are divided among the taxa present. $J' = H'/\text{In}(S)$
where n = total number of individuals and S = total number of species
(G) Buzas and Gibson's evenness: e^H/S

The rarefaction analysis was performed using Biodiversity Pro software (Biodiversity 1997 NHM and SAMS, http://www.nhm.ac.uk/zoology/bdpro) to cope up with the problem in comparing diversity among various zones evaluated during the present study.

7.3.2 Community Characteristics

Similarity indices: Jaccard's similarity coefficient (*Sj*) is used to assess similarity of sites and uses presence/absence data. As it, Sorenson's similarity index (SI), also looks at the similarity of pairs of habitats in terms of presence of species but gives greater preference to the species, those are common to the sites compared to those found on unique sites. Formula for calculating both of these indices are as below:

$$Sj = a/(a + b + c) \text{ and } Ss = 2a/(2a + b + c).$$

Where Sj = Jaccard's similarity coefficient and Ss = Sorenson's similarity coefficient, a = number of species common to (shared by) sites, b = number of species unique to the first site and c = number of species unique to the second site.

Further, cluster analysis, which is a hierarchical, agglomerative and polythetic technique of clustering, was used to quantify the resemblance among plant communities inhabiting various mine zones. Cluster analysis was performed on plant species abundance data obtained from transect survey using minimum variance technique, also known as Ward's method, which has been recognized as best way to classify the ecological communities and to identify community structure (Ludwig and Reynolds 1988). The cluster analysis generated a dendrogram providing hierarchically nested groups or clusters representing distinct plant communities, which were represented by subclusters.

7.3.3 Floristic Diversity and Distribution

Results are presented in the form of the impact of mining on vegetation communities. In order to achieve the objective, the entire study area was stratified into 2 km circular zones around each mining site.

7.3.4 Overall Floristic Composition

Kachchh district falls under arid to semiarid climate which demarcated by the xerophytes or majority of annual plant species. During the present study, a total of 326 plant species (including 1 Gymnosperm, i.e. *Ephedra foliata*) belonging to 63 families and 210 genera were recorded (Table 7.2). Out of them 14 species are of conservation significance that include above-mentioned gymnosperm species (Table 7.3). Poaceae family was the most dominant with 45 species followed by Fabaceae and Convolvulaceae with 24 and 20 species. Twenty-four families were recorded with 24 species while 27 families for single species. Dicotyledonous plants were represented with 81% (n = 264 species) with 7% of tree/small tree, 15% of shrub/under shrub and 12% of climber/twiner/parasite and 50% of herbs, whereas monocotyledonous group was represented by 19% of species of grasses and sedges. Abundance and % frequency ratio reveal that all species were contagiously distributed, while overall plant community was heterogeneous in nature, which was revealed from the frequency diagram. *Acacia senegal* and *Salvadora oleoides* were the most dominant species with high IVI value (76.60). The mean ± SD numbers of tree, shrub and climber species were 4.18 ± 0.14, 9.12 ± 0.30 and 3.37 ± 0.17, respectively. Mean density ± SD for tree, shrub and climber were

Table 7.2 List of plant species reported from study area

S. no.	Plant species	Local name	Habit
	Acanthaceae		
1.	*Barleria acanthoides* Vahl	Kandhari, Kasedo	Herb
2.	*Barleria prionitis* L. var. Prionitis	Kanta Aserio	Herb
3.	*Blepharis linariaefolia* Pers.	Kandhero Gokharu,	Herb
4.	*Blepharis maderaspatensis* (L.) Roth	Uti Gan, Vado Kandho	Herb
5.	*Blepharis repens* (Vahl) Roth	Nadho Chopad kandho,	Herb
6.	*Blepharis sindica* T. Anders.	Kandhero Gokharu	Herb
7.	*Dipteracanthus patulus* (Jacq.) Nees	–	Herb
8.	*Dipteracanthus prostratus* Hassk.	–	Herb
9.	*Ipomoea batatas* (L.) Lam.	Shakkariyu	Herb
10.	*Justicia gendarussa* Burm. f.	Tui, Que, Tue	Herb
11.	*Justicia procumbens* L.	Kari Andhedi	Herb
12.	*Justicia simplex* Don	Kari Andhedi	Herb
13.	*Lepidagathis trinervis* Wall.	Tran Kantho, Tran Ga	Herb
14.	*Peristrophe bicalyculata* (Retz.) Nees	Lasi Adhedi, Kari Adhedi	Herb
	Aizoaceae		
15.	*Corbichonia decumbens* (Forsk.) Jack. ex Exell	–	Herb
16.	*Trianthema triquetra* Rottl. & Willd.	Satodi	Herb
	Amaranthaceae		
17.	*Achyranthes aspera* L. var. *argentea* Hook. f.	Agado, Kandhero	Herb
18.	*Achyranthes aspera* L. var. *porphyristachya* Hk. f.	Vado Andhado	Herb
19.	*Aerva lanata* (L.) Juss.	Sani Buu, Gorkhadi	Shrub
20.	*Aerva persica* (Burm. f.) Merrill	Bou, Bour	Shrub
21.	*Aerva pseudotomentosa* Blatt. & Hallb.	Sane Panjo Bur, Bur	Herb
22.	*Alternanthera sessilis* (L.) DC.	Jar Bhaji, Jar Bhangaro	Herb
23.	*Amaranthus spinosus* L.	Jangali tandaljo	Herb
24.	*Amaranthus viridis* L.	Adbau Rajgaro, Rajgaro	Herb
25.	*Celosia argentea* L.	Lampadi	Herb
26.	*Dicoma tomentosa* Cass	Ashi Kandheri	Herb
27.	*Digera muricata* (L.) Mart.	Lolar	Herb
28.	*Gomphrena globosa* L.	–	Herb
29.	*Pupalia lappacea* (L.) Juss.	Gadar Bhurat	Shrub
	Anacardiaceae		
30.	*Rhus mysurensis* Heyne ex W. & A.	Dasarni, Dasan	Tree
	Apocynaceae		
31.	*Catharanthus roseus* (L.) G. Don	Asi Sada Suvagan	Herb
	Aristolochiaceae		
32.	*Aristolochia bracteolata* Lamk.	Kida Mari	Herb
	Asclepiadaceae		
33.	*Calotropis procera* (Ait.) R. Br.	Akado,Aak	Shrub

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
34.	*Ceropegia bulbosa* Roxb.	–	Climber
35.	*Leptadenia pyrotechnica* (Forsk.) Decne.	Khip	Shrub
36.	*Oxystelma secamone (O. esculentum) Linn.*	Jal- dudhi	Climber
37.	*Pentatropis capensis* (L. f.) Bullock	Dhodhiyal, Dhodheji Val	Climber
38.	*Pentatropis spiralis* (Forsk.) Decne	Dhodhiyal, Dhodheji Val	Climber
39.	*Pergularia daemia* (Forsk.) Chiov.	Dudhariyal, Dudhar Val	Climber
40.	*Sarcostemma acidum* (Roxb.) Voigt	Chhirval, Chirval	Shrub
41.	*Calotropis gigantea* (L.) R. Br.	Vado Akad, Dholo Akad	Shrub
	Asteraceae		
42.	*Blainvillea acmella* (L.) Philip.	Aso Bhangaro,	Herb
43.	*Blumea bovei* (DC.)Vatke	–	Herb
44.	*Eclipta prostrata* (L.) L. Mant.	Bhangaro, Kakrodha	Herb
45.	*Helichrysum cutchicum* (C.B.CI.) Rolla Rao et Des.	Dholu Fuladu	Herb
46.	*Launaea procumbens* (Roxb.) Ram. & Raj.	Vadi Gurval, Vadi Gemar	Herb
47.	*Launaea resedifolia* (L.) Druce	Dhariyai Gurval	Herb
48.	*Oligochaeta ramosa* (Roxb.) Wagenitz	Kandhari, Nandhi Uth Kandhari	Herb
49.	*Pluchea arguta* Boiss.	–	Herb
50.	*Pulicaria angustifolia* DC.	–	Herb
51.	*Pulicaria wightiana* (DC.) Cl.	Son Fuladi	Herb
52.	*Sonchus asper* Hill.	–	Herb
53.	*Spergula fallax* (Lowe) Krause	Vekar	Herb
54.	*Sphaeranthus senegalensis* DC.	Gorakhval	Herb
55.	*Tridax procumbensi* L.	Vilayati Bhangro	Herb
56.	*Vernonia cinerascens* Sch.Bip.	Tatadio, Gandhi Ghenradi	Shrub
57.	*Xanthium strumarium* L.	Kantaru Zadvu, Gokhru	Herb
	Aizoaceae		
58.	*Trianthema portulacastrum* L.	Satodo	Herb
	Balanitaceae		
59.	*Balanites aegyptiaca (L.) Del.*	Hingor, Hingod	Tree
	Bombacaceae		
60.	*Bombax malabaricum* DC.	Rato Shamaro	Tree
	Boraginaceae		
61.	*Arnebia hispidissima* DC.	–	Herb
62.	*Coldenia procumbens* L.	Ukharad	Herb
63.	*Heliotropium bacciferum* Forsk. var. *bacciferum*	–	Herb
64.	*Heliotropium bacciferum* Forsk. var. *suberosum* (Clarke) Bhandari	–	Herb
65.	*Heliotropium curassavicum* L.	–	Herb
66.	*Heliotropium indicum* L.	Agio Kharsan, Morandhi	Herb

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
67.	*Heliotropium marifolium* Koen. ex Retz. var. *marifolium*	Dungario Agio, Zinko Okharad	Herb
68.	*Heliotropium ovalifolium* Forsk.	Ogiar	Herb
69.	*Heliotropium rariflorum* Stocks	Jakhau	Herb
70.	*Heliotropium strigosum* Willd.	–	Herb
71.	*Heliotropium subulatum* Hochst.	Piro Kharsan	Herb
72.	*Heliotropium supinum* L.	Ghedio Kharsan	Herb
73.	*Trichodesma amplexicaule* Roth	Undh Fuli	Herb
	Brassicaceae		
74.	*Farsetia hamiltonii* Royle	Sedha Asario, Adbau Rai	Herb
	Burseraceae		
75.	*Commiphora wightii* (Arn.) Bhandari	Gugar, Gugariya, Gugar Jo Zadvo	Tree
	Cactaceae		
76.	*Opuntia elatior Mill.*	Nag Phan	Herb
	Caesalpiniaceae		
77.	*Bauhinia racemosa* Lam.	Zinj, Zanj, Zinji	Tree
78.	*Cassia pumila* Lam.	Rato Chon, Choniyo, Nidhechor	Herb
79.	*Cassia tora* L.	Punvar, Povario, Dadhar Jo Zad	Herb
80.	*Tamarindus indica* L.	Ambali Jo Zad, Ambali, Emali	Tree
81.	*Cassia auriculata* L.	Avar	Shrub
	Capparaceae		
82.	*Cadaba fruticosa* (L.) Flem.	Karo Pijaro	Shrub
83.	*Capparis cartilaginea* Decne.	Kawari, Karpatrai, Karpatirai, Parvati Rai	Shrub
84.	*Capparis decidua* (Forsk.) Edgew.	Kerado, Dora Kera, Kar Jo Zad	Shrub
85.	*Capparis grandis* L. f.	Dumaro, Dumar Jo Zad	Tree
86.	*Cleome gynandra* L. var. *gynandra*	Bidhro, Asso Bidharo, Vado bidharo	Herb
87.	*Cleome vahliana* Fresen.	–	Herb
88.	*Cleome viscosa* L.	Beddhro, Prlobidhro, Badhod	Herb
89.	*Crateva nurvala* Buch-Ham. var. *nurvala*	Tarapan, Tripan Jo Zad	Tree
90.	*Maerua oblongifolia* (Foeak.) A. Rich.	Pinjolo, Accho Pinjolo	Shrub
	Chenopodiaceae		
91.	*Atriplex hortensis* L.	Palakh Ni Bhaji	Herb
92.	*Chenopodium album* L.	Chir, Chir Ji Bhaji	Herb
93.	*Suaeda fruticosa* (L.) Forsk. ex Gmel.	Khario Luno, Lano, Luno	Shrub
	Commelinaceae		
94.	*Commelina benghalensis* L.	Sis Muriyu	Herb
95.	*Commelina diffusa* Burm. f.	–	Herb

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
	Convolvulaceae		
96.	*Argyreia nervosa* (Burm. f.) Boj.	Samandharsos Ji Val, Vardharo	Climber
97.	*Convolvulus arvensis* L.	Neri Val, Neri	Herb
98.	*Convolvulus auricomus* (A. Rich.) Bhandari var. *auricomus*	Rushad Neri Val	Herb
99.	*Convolvulus microphyllus* (Roth) Sieb. ex Spr.	Mankhani, Makhan Val, Ashi/ Bethi Sankh Val	Herb
100.	*Convolvulus stocksii* Boiss.	–	Herb
101.	*Cressa cretica* L.	Oin, Bukan, Gun, Lun, Un Bakano	Herb
102.	*Evolvulus alsinoides* (L.) L. var. *alsinoides*	Kari Sankhval, Sani Buti, Kari Buti	Herb
103.	*Ipomoea aquatica* Forsk.	Nari Val, Pani Ji Val	Herb
104.	*Convolvulus auricomus* (A. Rich.) Bhandari var. *auricomus*	Rushad Neri Val	Climber
105.	*Ipomoea kotschyana* Hoc. ex Choisy	Bhoyan Fotiyargi Val	Herb
106.	*Ipomoea nil* (L.) Roth	Trikhuni Potiyar, Kari Potiyar	Climber
107.	*Ipomoea obscura* (L.) Ker-Gawl	Gumadiyar, Satari Val, Gumdiyal	Climber
108.	*Ipomoea pes-caprae* (L.) Sw.	Dhariya Val, Ravar patri	Herb
109.	*Ipomoea pes-tigridis* L.	Fotiyal, Fotiyar	Climber
110.	*Merremia aegyptia* (L.) Urb.	Fisuaal Val, Panjapani Potiyal	Climber
111.	*Merremia emarginata* (Burm. f.) Hall. f.	Undarkani	Climber
112.	*Merremia tridentata* (L.) Hall. f. subsp. *tridentata*	Topriyal, Topraval, Jamar Val	Climber
113.	*Rivea hypocrateriformis* Choisy	Fang val	Climber
114.	*Seddera latifolia* Hochst. & Steud.	–	Shrub
	Cucurbitaceae		
115.	*Citrullus colocynthis* (L.) Soland.	Truja Val, Tru Val, Tru Deda	Climber
116.	*Citrullus fistulosus* Stocks	Karengla	Climber
117.	*Coccinia grandis* (L.) Voigt	Tindora, Ghiloda	Climber
118.	*Corallocarpus conocarpus* (D. & G.) Cl.	Navi Val	Climber
119.	*Corallocarpus epigaeus* (Rottl. & Willd.) Cl.	Navi Val, Naigi Val, Ajapad	Climber
120.	*Ctenolepis cerasiformis* (Stocks) Hk. f.	Dod Val, Aankh Futamna	Climber
121.	*Cucumis callosus* (Rottl.) Cogn.	Kotimbda vel, Nindhatru, Kotimbiyal	Climber
122.	*Cucumis prophetarum* L.	Indriyal, Kandhari Indriyan	Climber
123.	*Dactyliandra welwitschii* Hk. f.	Dod Val, Aankh Futamna	Climber
124.	*Luffa acutangula* (L.) Roxb. var. *acutangula*	Adbau Gisodi, Vad Gisodi	Climber
125.	*Mukia maderespatensis* (L.) M. Roem.	Ankhfutmani	Climber

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
	Cuscutaceae		
126.	*Cuscuta hyalina* Roth	Sani Piri Val	Climber
127.	*Cuscuta reflexa* Roxb.	Makani, Makaniyal, Makan Val	Climber
	Cyperaceae		
128.	*Cyperus alopecuroides* Rottb.	–	Sedge
129.	*Cyperus bulbosus* Vahl	–	Sedge
130.	*Cyperus compressus* L.	–	Sedge
131.	*Cyperus difformis* L.	Chiyo	Sedge
132.	*Cyperus haspan* L.	Chiyo, Nidan moth	Sedge
133.	*Cyperus iria* L. var. *iria*	–	Sedge
134.	*Cyperus rotundus* L. subsp. *rotundus*	Kaluro, Mutha, Moth	Sedge
135.	*Cyperus triceps* (Rottb.) Endl.	–	Sedge
136.	*Fimbristylis miliacea* (L.) Vahl	–	Sedge
137.	*Scirpus affinis* Roth.	–	Sedge
	Ehretiaceae		
138.	*Cordia perrottetii* Wt.	Adbau Gundi, Jangli Gundi	Shrub
	Elatinaceae		
139.	*Bergia ammannioides* Roxb. ex Roth	Jal Ukharad	Herb
140.	*Bergia capensis* L.	Rapatri	Herb
141.	*Bergia suffruticosa* (Del.) Fenzl	Jal jambu	Herb
	Ephedraceae		
142.	Ephedra foliata Boiss. & Kotschy ex Boiss.	Andhoi Khip	Shrub
	Euphorbiaceae		
143.	*Acalypha indica* L.	Dadar Jo Zad	Herb
144.	*Dalechampia scandens* L. var. *cordofana*	Char Val, Khaj Val	Climber
145.	*Euphorbia caducifolia* Hains.	Thor	Shrub
146.	*Euphorbia heterophylla* L.	Lal Pati	Herb
147.	*Euphorbia hirta* L.	Vadi Dudheli	Herb
148.	*Euphorbia milii* Ch.	–	Herb
149.	*Phyllanthus fraternus* Webst.	Pat Amari, Amari	Herb
150.	*Phyllanthus maderaspatensis* L.	Amario	Herb
151.	*Securinega leucopyrus* (Willd.) Muell.-Arg.	Shini	Shrub
152.	*Securinega virosa* (Roxb. ex Willd.) Pax & Hoffm	Shini	Shrub
	Fabaceae		
153.	*Abrus precatorius* L.	Chanothi Ji Val	Climber
154.	*Alysicarpus longifolius* (Rottl. ex Spr.) W. & A.	Vado Sanervo	Herb
155.	*Alysicarpus monilifer* (L.) DC. var. *monilifer*	–	Herb
156.	*Arachis hypogaea* L.	Mung Fali	Herb

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
157.	*Butea monosperma* (Lam.) Taub.	Kesudijo Zad, Khkhar, Khakharo	Tree
158.	*Clitora ternatea* L.	Gaeni, Kari Koagi Val	Climber
159.	*Crotalaria burhia* Buch-Ham. ex Bth	Khirasan, Khadasan, Sangiro, Achhi Khadasan	Shrub
160.	*Crotalaria evolvuloides* Wt. ex W.& A.	Val Fatakdi	Herb
161.	*Derris indica* (Lam.) Bennet	Karanj Jo Zad	Tree
162.	*Desmodium dichotomum* (Klein ex Willd.) DC	Trapani Samervo	Herb
163.	*Goniogyna hirta* (Willd.) Ali	Undarkani	Herb
164.	*Indigofera caerulea* Roxb. var. *monosperma* (Sant.) Sant.	Rangagi Gari	Herb
165.	*Indigofera cordifolia* Heyne ex Willd.	Gadar Gari, Ridha Gari	Herb
166.	*Indigofera linifolia* Retz. var. *linifolia*	Sani Gari	Herb
167.	*Indigofera linnaei* Ali.	Pat Gari, Bhoyan Gari	Herb
168.	*Indigofera tinctoria* L.	Nili Gari, Gudi, Gari Jo Zad	Shrub
169.	*Rhynchosia minima* (L.) DC. var. *minima*	Mogariyal, Sanari, Mungarial	Climber
170.	*Sesbania sesban* (L.) Meer. subsp. s*esban* var. *sesban*	Ekad	Shrub
171.	*Taverniera cuneifolia* (Roth) Arn.	Jathi madh	Herb
172.	*Tephrosia falciformis* Ramaswami	Sarpankho	Shrub
173.	*Tephrosia purpurea* (L.) Pers.	Sarpankho, Vado Sarpankho, Bikanjo Zad	Herb
174.	*Tephrosia strigosa* (Dalz.) Sant.& Mahesh	Sani Sarpankhi, Asmani Sarpankho, Sanero Sarpankho	Herb
175.	*Tephrosia uniflora* Pers. subsp. *petrosa*	Sarpankhi	Herb
176.	*Tephrosia villosa* (L.) Pers.	Rushad Sirpankho, Kinojo Zad	Herb
	Gentianaceae		
177.	*Enicostema axillare* (Lamk.) Roynal	MameCho, Mamej, Kadvi Bhaji	Herb
	Hydrocharitaceae		
178.	*Hydrilla verticillata* (L. f.) Royle	Paniji Sevar	Herb
	Lamiaceae		
179.	*Leucas aspera* (Willd.) Spr.	Gumu	Herb
180.	*Ocimum gratissimum* L.	Vadi Tulsi, Mara Tulsi	Herb
181.	*Ocimum sanctum* L.	Tulsi	Herb
	Lemnaceae		
182.	*Lemna gibba* L.	Paniji Sevar	Herb
	Liliaceae		
183.	*Asparagus dumosus* Baker	–	Shrub
184.	*Asparagus racemosus* Willd. var. *javanicus* (Kunth) Baker	Akal Kandha Ni Val, Chini Ji val	Shrub
185.	*Chlorophytum tuberosum* (Roxb.) Baker	Karli, Karliji Bhaji	Herb

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
	Lythraceae		
186.	*Ammannia baccifera* L.	Rato Jal Agio	Herb
	Malvaceae		
187.	*Abutilon fruticosum* Guill. var. *fruticosum*	Saneri Dabariar	Shrub
188.	*Abutilon indicum* (L.) Sw. subsp. *guineense* (Schum.) Borss.	Khapato, Dabaliar	Shrub
189.	*Abutilon ramosum* Guill.	–	Shrub
190.	*Althea rosea* (L.) Cav.	–	Herb
191.	*Hibiscus ovalifolius* (Forsk.) Vahl	San Bhindo, Kurad Val	Shrub
192.	*Pavonia arabica* Steud. var. *Arabica*	Rato Balbuwaro	Herb
193.	*Pavonia zeylanica* Cav.	–	Herb
194.	*Sida acuta* Burm. f.	Adbau Balbuwaro, Vado Balbuwaro	Herb
195.	*Sida alba* L.	Bal Buvaro, Kharanto, Kandharo	Herb
196.	*Sida cordata* (Burm. f.) Borss	Pat balbuwaro, Nidhi Dhatuval	Herb
197.	*Sida cordifolia* L.	Barabovaro, Bal Bunwero, Bal Bunwarejo Zad	Herb
198.	*Sida ovata* Forsk.	–	Herb
199.	*Sida retusa* L.	Khetrau Barbuvaro	Herb
200.	*Sida tiagii* Bhandari	Bulbuwaro	Herb
	Meliaceae		
201.	*Azadirachta indica* A. Juss.	Limbdo, Neem	Tree
	Menispermaceae		
202.	*Cocculus hirsutus* (L.) Diels	Vegai, Vagval, Asipal	Climber
203.	*Cocculus pendulus* (Forst.) Diels	Karipat, Karipad	Climber
204.	*Cyclea peltata* (lam) Hk. F.&Th	–	Climber
205.	*Tinospora cordifolia* Roxb.	Guddaval, Gadu, Gaduji Val	Climber
	Mimosaceae		
206.	*Acacia* sp.	Acacia binosa	Shrub
207.	*Acacia leucophloea* (Roxb.) Willd.	Hirmo, Haramu	Tree
208.	*Acacia nilotica* (L.) Del. subsp. *indica* (Bth.) Brenan	Deshi Baval, Bavar	Tree
209.	*Acacia senegal* (L.) Willd.	Kher, Gorad	Tree
210.	*Acacia tortilis* (Forssk.) Hayne.	Israil Baval	Tree
211.	*Albizia amara* Boivin var. *amara*	Aso Sarsado	Tree
212.	*Mimosa hamata* Willd.	Kai bavari, Kai, Zanjani, Zinjani	Shrub
213.	*Prosopis cineraria* (L.) Druce	Kandhi, Khajdo, Kando	Tree
214.	Prosopis juliflora SW (DC.)	Vilayati Baval	Shrub
215.	*Acacia jacquemontii* Bth.	Harmo Baval	Shrub
	Molluginaceae		
216.	*Gisekia pharnaceoides* L. var. *pharnaceoides*	–	Herb

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
217.	*Glinus lotoides* L.	Aso Okharad	Herb
218.	*Mollugo pentaphylla* L.	–	Herb
	Moraceae		
219.	*Ficus benghalensis* L. var. *benghalensis*	Vad Jo Zad	Tree
	Moringaceae		
220.	*Moringa concanensis* Nimmo	Kharo Saragvo, Kadvi Saragvo, Dungar Jo Sargave Jo Zad	Tree
	Nyctaginaceae		
221.	*Boerhavia diffusa* L.	Sunny Dhokariaur	Herb
222.	*Commicarpus verticillatus* (Poir.) Standl.	Dhokariyar	Herb
	Papaverceae		
223.	*Argemone mexicana* L.	Darudi, Uzar Kandho, Piri Aakandho	Herb
	Pedaliaceae		
224.	*Pedalium murex* L.	Ubhera Gokhru, Kadua Gokhru	Herb
225.	*Senra incana* Cav.	Jangli kala, Aadbau Kapas	Shrub
226.	*Sesamum laciniatum* Klein ex Willd.	Adbau Tal, Vagdau Tir, Kag Tir	Herb
	Plumbaginaceae		
227.	*Plumbago zeylanica* L.	Vara Val, Gadar Zipto	Herb
	Poaceae		
228.	*Acrachne racemosa* (Heyne ex R. & S.) Oswi	Chinkhiyu	Grass
229.	*Aeluropus lagopoides* (L.) Trin. ex Thw.	Khario Ga, Kharo Ga	Grass
230.	*Apluda mutica* L.	Bhungario Ga, Fulari Ga	Grass
231.	*Aristida adscensionis* L. subsp. *adscensionis*	Jandhar Lambha Ga, Lampdo	Grass
232.	*Aristida funiculata* Trin. & Rupr.	Laso Lambh	Grass
233.	*Bothriochloa glabra* (Roxb.) A. Camus	Dharfo	Grass
234.	*Cenchrus biflorus* auct.	Dhaman Gha, Anajaniyo	Grass
235.	*Cenchrus ciliaris* L.	Dhaman Gha	Grass
236.	*Cenchrus setigerus* Vahl	Dhaman Gha	Grass
237.	*Chloris barbata* Sw.	Rusad Gha, Punjaniu Ga	Grass
238.	*Chrysopogon fulvus* (Spr.) Shiov.	Khad Sundhiyu Ga	Grass
239.	*Cymbopogon jwarancusa* (Jones) Schult.	–	Grass
240.	*Cymbopogon martinii* (Roxb.) Wats	Rosha Gha	Grass
241.	*Cynodon dactylon* (L.) Pers.	Chhabbar Gha	Grass
242.	*Dactyloctenium aegyptium* (L.) P. Beauv.	Kagatango Gha, Vado Mandanu	Grass
243.	*Dactyloctenium sindicum* Boiss.	Chund Gha, Sano Madanu, Nindho Madanu	Grass
244.	*Desmostachya bipinnata* (L.) Stapf	Darab, Gha, Dab	Grass

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
245.	*Dichanthium annulatum* (Forssk.) Stapf	Dunuhi gha, Jinjavo	Grass
246.	*Digitaria pennata* (Hochst.) Cooke	–	Grass
247.	*Dinebra retroflexa* (Vahl) Panz	–	Grass
248.	*Echinochloa colonum* (L.) Link	Sanvadha Sau, Samu	Grass
249.	*Eleusine compressa* (Forsk.) Aschers. & Schweinf.	Gandhiro Gha, Mandanu Gha, Gaantharo, Mandanu	Grass
250.	*Eleusine indica* (L.) Gaertn.	Adbau Madanu	Grass
251.	*Elyonurus royleanus* Nees ex A. Rich.	–	Grass
252.	*Eragrostis ciliaris* (L.) R. Br. var. *ciliaris*	Fuliyu Gah	Grass
253.	*Eragrostis pilosa* (L.) P. Beauv.	–	Grass
254.	*Eragrostis tenella* (L.) P. Beauv. ex R. & S.	Limor, Kalavo	Grass
255.	*Halopyrum mucronatum* (L.) Stapf	Dariyai Kans, Sari Ga, Kans	Grass
256.	*Heteropogon contortus* (L.) P. Beauv. ex. R. & S.	Dungar Gha, Surianadha, Chhuro	Grass
257.	*Melanocenchrus jacquemontii* J. & S.	Vekar	Grass
258.	*Panicum antidotale* Retz.	Gum Gha, Dham Gha	Grass
259.	*Pennisetum typhoides* A. Rich.	Bajri	Grass
260.	*Phragmites karka* (Retz.) Trin. Ex Steud.	Anchi, Nadi	Grass
261.	*Saccharum bengalense* Retz.	Munj	Grass
262.	*Setaria glauca* (L.) P. Beauv.	Sani Bhichdi, Sani Zipti	Grass
263.	*Sorghum halepense* (L.) Pers.	Baru Gha	Grass
264.	*Sporobolus coromandelianus* (Retz.) Kunth	Khariyu Ga	Grass
265.	*Sporobolus fertilis* (Steud.) Clayton	Ganthiar, Khari Ga, Palangi	Grass
266.	*Sporobolus helvolus* (Trin.) Th. Dur. et Sch	Khevai	Grass
267.	*Sporobolus maderaspatensis* Bor	Khevai Ga	Grass
268.	*Sporobolus marginatus* Hochst. ex A. Rich.	Khevai Ga	Grass
269.	*Tragus biflorus* (Roxb.) Schult.	Gah	Grass
270.	*Triticum aestivum* L.	Gahu, Gaun	Grass
271.	*Urochondra setulosus* (Trin.) Hubb	Kkariyu Gah	Grass
272.	*Zea mays* L.	Makai	Grass
	Polygalaceae		
273.	*Polycarpaea corymbosa* (L.) Lam.	Jangali soa, Rupa phali	Herb
274.	*Polygala chinensis* L.	Piri Patsan	Herb
275.	*Polygala erioptera* DC. var. *erioptera*	Patsan	Herb
276.	*Polygala irregularis* Boiss.	Patsan	Herb
	Polygonaceae		
277.	*Antigonon leptopus* Hk. & Arn.	Icecream Val	Climber
278.	*Polygonum plebeium* R. Br. var. *indica* (Heyne ex Roth) Hook.	Ratanjyot	Herb

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
	Portulacaceae		
279.	*Portulaca oleracea* L.	Lakha Luni, Vadiluni, Kunbo	Herb
	Periplocaceae		
280.	*Periploca aphylla* Decne	Rati Khip, Siriyar Khip, Shingadiyo	Shrub
	Rhamnaceae		
281.	*Zizyphus nummularia* (Burm. F.) W. & A.	Bordi, Boedi, Chania Bor	Shrub
	Rubiaceae		
282.	*Borreria articularis* (L.f.) F.N. Will.	Bikan, Baakan Jo Zad	Herb
283.	*Borreria pusilla* (Wall.) DC.	Bikan	Herb
284.	*Oldenlandia corymbosa* L.	–	Herb
	Salvadoraceae		
285.	*Salvadora oleoides* Decne.	Mithi Zar, Mithi Pilujo Zad	Tree
286.	*Salvadora persica* L.	Khari Zar, Pailu	Tree
	Sapindaceae		
287.	*Cardiospermum halicacabum* L.	Bkan Fofti, Tridhari Val, Popti	Climber
	Scrophulariaceae		
288.	*Bacopa monnieri* (L.) Pennell	Kadvi Naveri, Naveri	Herb
289.	*Campylanthus ramosissimus* Wt.	–	Shrub
290.	*Kickxia ramosissima* (Wall.) Janch.	Bhit Val, Bhi Chatti	Herb
291.	*Striga angustifolia* (D. Don) Saldhana	Kunvario	Herb
	Solanaceae		
292.	*Lindenbergia muraria* (Roxb. Ex D. Don) P. Bruehl	Piri Sadedi, Zamar Val	Herb
293.	*Lycium barbarum L.*	Garothi, Gerati, Gerothi, Khareti	Shrub
294.	*Physalis longifolia* Nutt.	Fofati, Fad, Fotaji Val	Herb
295.	*Physalis minima* L.	Fofati, Fad, Fotaji Val	Herb
296.	*Solanum albicaule* Kotschy ex Dunal	–	Shrub
297.	*Solanum indicum* L.	Vad Ringni, Mot Ringni	Herb
298.	*Solanum nigrum* L.	Kamperu	Herb
299.	*Solanum surattense* Burm. f.	Jangali Ringani, Pat Ringani	Herb
	Sterculiaceae		
300.	*Melhania futteyporensis* Munro ex Masters var. *major* (Blatt. & Hallb.) Santapau	Adbau Khapat	Herb
301.	*Vernonia cinerea* (L.) Less.	Sadodi, Kadu Kariyato, Sap Val	Herb
302.	*Waltheria indica* L.	Pilu Fulaju Zadvu	Shrub
303.	*Melhania futteyporensis* Munro ex Masters var. *futteyporensis*	Adbau Khapat	Shrub
304.	*Helicteres isora* L.	Aatadi, Anati Maeda, Singi	Shrub

(continued)

Table 7.2 (continued)

S. no.	Plant species	Local name	Habit
	Tamaricaceae		
305.	*Tamarix aphylla* (L.) Karst.	Lai	Tree
306.	*Tamarix ericoides* Rottl.	Lai Jo Zad	Shrub
307.	*Tamarix troupii* Hole	Lai, Ratilai	Shrub
	Tiliaceae		
308.	*Corchorus aestuans* L.	Kag Gisodi, Kag Kela	Herb
309.	*Corchorus depressus* (L.) Stocks	Munderi, Munderi	Herb
310.	*Corchorus olitorius* L.	Kag Gisoda, Gunpat	Herb
311.	*Corchorus tridens* L.	–	Herb
312.	*Corchorus urticaefolius* W.&.A.	Khetrau Surval	Herb
313.	*Grewia tenax* (Forsk.) Fiori	Gangati, Gangi, Gangni	Shrub
314.	*Grewia villosa* Willd.	Luo, Luejo Zad, Luskejo Zad	Shrub
315.	*Triumfetta rhomboidea* Jacq.	Bhurati, Zepati	Herb
	Typhaceae		
316.	*Typha angustata* Bory & Chaub	Gha Bajariu	Herb
	Verbenaceae		
317.	*Clerodendrum phlomidis* L.	Tankaro, Arani	Shrub
318.	*Phyla nodiflora* (L.) Greene	Rato Ukharar, Ratval	Herb
319.	*Premna resinosa* Schau	Nidhi Kundher	Shrub
	Vitaceae		
320.	*Cayratia carnosa* (Lam.) Gagnep.	Khatumbadi Ji Val	Climber
	Zygophyllaceae		
321.	*Fagonia bruguieri* DC. var. *bruguieri*	Dhramau, Dhamaso, Kandhera	Herb
322.	*Fagonia schweinfurthii* (Hadidi) Hadidi	Dhramau, Dhamaso, Kandhera	Herb
323.	*Tribulus rajasthanensis* Bhandari et Sharma	Akanthi, Mitha Gokharu	Herb
324.	*Tribulus terrestris* L.	Akanthi, Mitha Gokharu	Herb
325.	*Zornia gibbosa* Span	Bepani	Herb
326.	*Zygophyllum simplex* L.	Pat Lani	Herb

122.58 ± 5.75, 285 ± 8.97 and 56.32 ± 3.72, respectively. Shannon diversity index values for tree, shrub and climber are with mean ± SD of 1.01 ± 0.03, 1.71 ± 0.05 and 0.88 ± 0.05, respectively. Species richness index (Menhinick index) values of tree, shrub and climber are with mean ± SD of 0.91 ± 0.029, 1.21 ± 0.03 and 1.00 ± 0.032, respectively. Species evenness for tree, shrub and climber are with mean ± SD 0.75 ± 0.01, 0.71 ± 0.01 and 0.88 ± 0.007, respectively.

Table 7.3 Plant species with conservation significance

Sr. no.	Conservation significance species	Local name	Habit	Family
1.	*Campylanthus ramosissimus* Wt.	–	Shrub	Scrophulariaceae
2.	*Citrullus colocynthis* (L.) Soland.	Truja Val	Climber	Cucurbitaceae
3.	*Commiphora wightii* (Arn.) Bhandari	Gugar	Tree	Burseraceae
4.	*Convolvulus stocksii* Boiss.	–	Herb	Convolvulaceae
5.	*Corallocarpus conocarpus* (D. & G.) Cl.	Navi Val	Climber	Cucurbitaceae
6.	*Dactyliandra welwitschii* Hk. f.	Aankh Futamna	Climber	Cucurbitaceae
7.	Ephedra foliata Boiss. & Kotschy ex Boiss.	Andhoi Khip	Shrub	Ephedraceae
8.	*Helichrysum cutchicum* (C.B.CI.) Rolla Rao et Des.	Dholu Fuladu	Herb	Asteraceae
9.	*Heliotropium bacciferum* Forsk. var. *suberosum* (Clarke) Bhandari	–	Herb	Boraginaceae
10.	*Heliotropium rariflorum* Stocks	Jakhau	Herb	Boraginaceae
11.	*Indigofera caerulea* Roxb. var. *monosperma* (Sant.) Sant.	Rangagi Gari	Herb	Fabaceae
12.	*Ipomoea kotschyana* Hoc. ex Choisy	Bhoyan Fotiyargi Val	Herb	Convolvulaceae
13.	*Sida tiagii* Bhandari	Bulbuwaro	Herb	Malvaceae
14.	*Tribulus rajasthanensis* Bhandari et Sharma	Akanthi, Mitha Gokharu	Herb	Zygophyllaceae

7.4 Impact of Mining Activities on Plant Community Structure

7.4.1 Overall Description of Impact of Mining

Around the mining area, major *Prosopis* forest was found because of the high tolerance value of *Prosopis juliflora* against the extreme edaphic condition and some patches of *Euphorbia-Salvadora* and *Acacia* forest, but they were confronted of the tremendous pressure of extinction. *Campylanthus ramosissimus*, *Commiphora wightii*, *Dactyliandra welwitschii*, *Helichrysum cutchicum*, *Heliotropium bacciferum* var. *suberosum*, *H. rariflorum*, etc. are conservation significant plant species found around the mining area. Including mining activities, other disturbance was also occurring which causes the impact on the biodiversity. ANOVA results reveal that there was no significant difference in plant communities between nine zones in terms of various diversity indices, viz. number of species, density, Shannon diversity, Menhinick and Margalef species richness, evenness, etc.

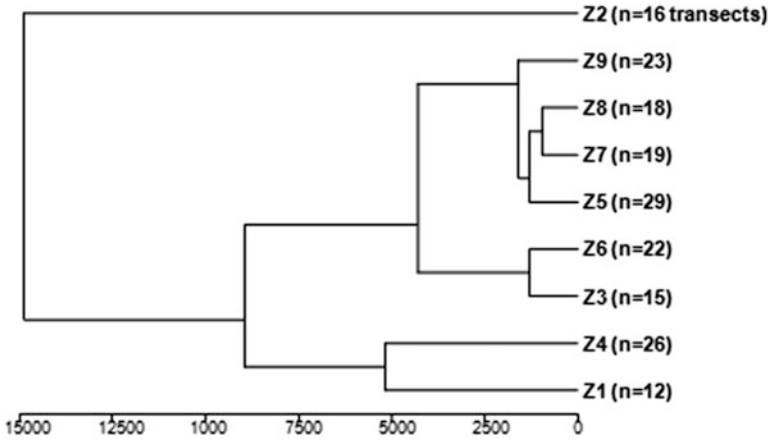

Fig. 7.2 Zone-wise clustering of tree species

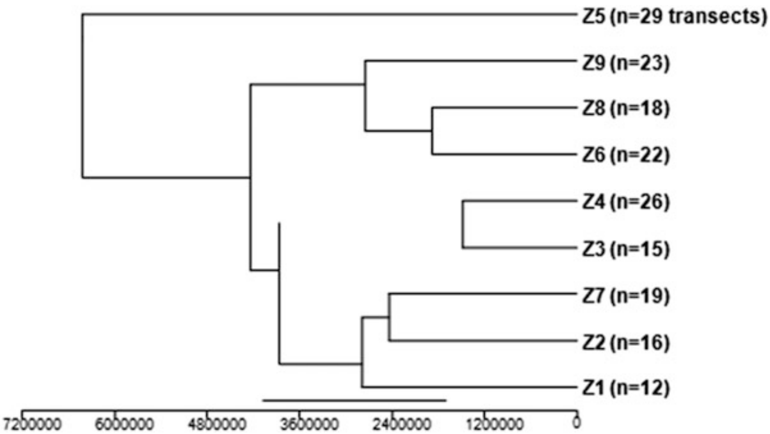

Fig. 7.3 Zone-wise clustering of shrub species

Cluster analysis reveals that the greater similarity among sampling points belongs to the same kind of habitat. Four distinct groups (Z2, Z9:Z8:Z7:Z5, Z6:Z3, Z1:Z4) were clearly identified from abundance data of tree species, while on the basis of shrub species, four distinct groups (Z5, Z9:Z8:Z6, Z4:Z3, Z7:Z2:Z1) were clearly identified also (Figs. 7.2, 7.3 and 7.4).

7.4.1.1 Zone-Wise Description of Floristic Diversity

Zone One (Z1)

A total of 147 plant species were recorded from the zone one (Z1) including 12 trees, 26 shrubs, 15 climbers, 74 herbs and 20 grasses. Abundance and % frequency ratio reveals that all tree, shrub and climber species were contagiously distributed within

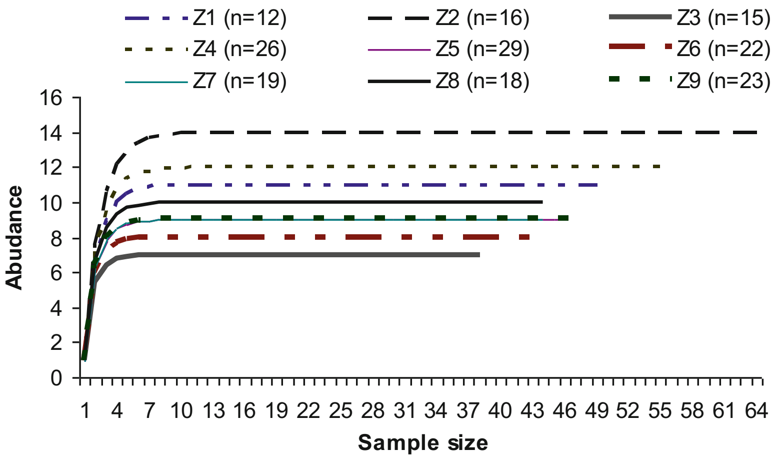

Fig. 7.4 Rarefaction curve of various mining zones for tree species

area. Important value index shows that the *Acacia senegal* was the most dominant species (IVI = 114.68) followed by *A. nilotica* (101.50). Frequency diagram of the tree, shrub and climber reveals that the zone was heterogeneous in nature. Various diversity indices were obtained from the data of tree, shrub and climber. Mean ± SD numbers of species occurring in transect were 4.5 ± 2.54, 9.26 ± 4.04 and 2.66 ± 1.66 for tree, shrub and climber, respectively, while densities of the said habitat were 118.75 ± 76.10, 248.33 ± 84.80 and 48.33 ± 39.56. Shannon diversities of the tree, shrub and climber were in mean ± SD, 1.11 ± 0.47, 1.82 ± 0.53 and 0.71 ± 0.60, respectively, while Menhinick species richness values with mean ± SD were 0.98 ± 0.49, 1.29 ± 0.43 and 0.93 ± 0.30 for tree, shrub and climber, respectively. Evenness values of tree, shrub and climber with mean ± SD were 0.78 ± 0.14, 0.74 ± 0.13 and 0.93 ± 0.09, respectively (Figs. 7.5 and 7.6).

Zone Two (Z2)

A total of 199 plant species were recorded from the zone two including 14 trees, 26 shrubs, 20 climbers, 112 herbs and 27 grasses. Tree, shrub and climber species were contagiously distributed within area, which was revealed from % frequency and abundance ratio. *Acacia nilotica* was the most dominant and ecologically successful species with high IVI value (142.05) followed by *A. senegal* (78.51). Frequency diagram of all habit tree, shrub and climber reveals that the community of the zone two was heterogeneous in nature. A number of species of tree, shrub and climber with mean ± SD were 4.81 ± 2.88, 8.31 ± 3.62 and 3.41 ± 2.77, respectively, while densities with mean ± SD were 120.62 ± 73.45, 250 ± 96.64 and 69.16 ± 64.87 of tree, shrub and climber, respectively. Shannon diversities of tree, shrub and climber with mean ± SD were 1.05 ± 0.54, 1.63 ± 0.61 and 0.85 ± 0.62, respectively, while Menhinick species richness values of tree, shrub and climber with mean ± SD were 1.02 ± 0.41, 1.17 ± 0.36 and 0.92 ± 0.32, respectively.

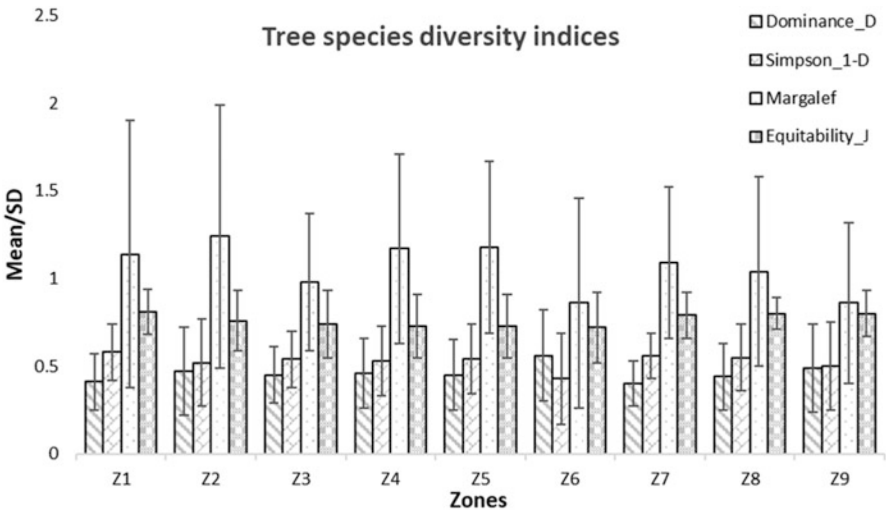

Fig. 7.5 Zone-wise diversity indices of tree species

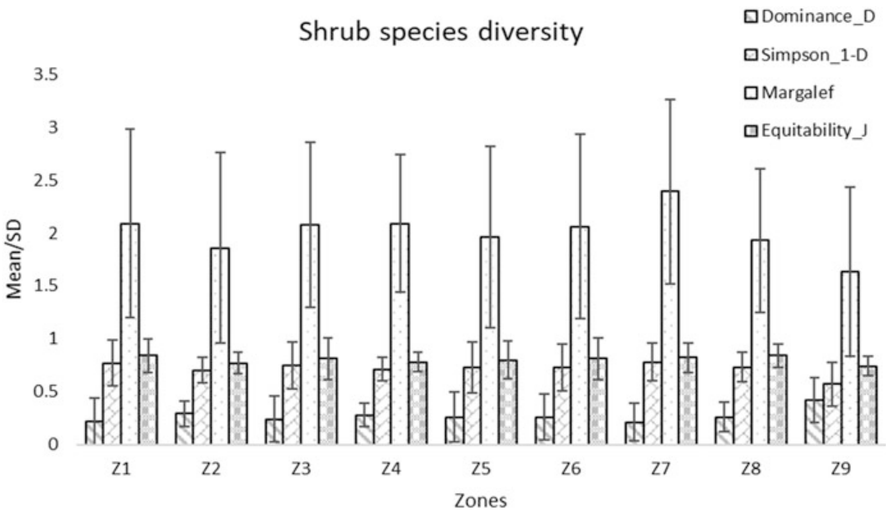

Fig. 7.6 Zone-wise diversity indices of shrub species

Species evenness values with mean ± SD were 0.75 ± 0.20, 0.69 ± 0.12 and 0.89 ± 0.11 of tree, shrub and climber, respectively (Figs. 7.5 and 7.6).

Zone Three (Z3)

Two hundred and eight plant species were recorded from the mining zone three with 7 trees, 33 shrubs, 19 climbers, 117 herbs and 32 grasses. Abundance and % frequency ratio reveals the all tree, shrub and climber species were contagiously distributed within area, while *Acacia nilotica* was ecologically successful and well-established species with high IVI value (126.90) followed by *A. senegal* (100.04). Comparative results with frequency diagram reveal that the plant community was heterogeneous in nature. Mean ± SD numbers of species were 4 ± 1.55, 9.33 ± 3.39 and 3.28 ± 2.67 of tree, shrub and climber respectively, while densities were 130.66 ± 85.70, 271 ± 129.99 and 63.57 ± 68.82 for tree, shrub and climber, respectively. Shannon diversities of tree, shrub and climber with mean ± SD were 0.98 ± 0.35, 1.77 ± 0.40 and 0.81 ± 0.70, respectively, while Menhinick species richness were 0.87 ± 0.29, 1.28 ± 0.25 and 0.95 ± 0.40 of tree, shrub and climber, respectively. Species evenness values of tree, shrub and climber with mean ± SD were 0.74 ± 0.15, 0.69 ± 0.13 and 0.90 ± 0.10, respectively (Figs. 7.5 and 7.6).

Zone Four (Z4)

A total of 219 higher plant species were recorded from zone four, in which there are 12 trees, 35 shrubs, 22 climbers, 124 herbs and 26 grasses. Abundance and frequency ratio of the tree, shrub and climber reveals that all species of the said habitat were contagiously distributed within area. Prepared frequency diagram compared with the normal frequency diagram reveals that the vegetation was heterogeneous in terms of nature. In that heterogeneous vegetation, the most dominant and ecologically successful tree species was *Acacia senegal* with high IVI value (106.25) followed by *Salvadora oleoides* (81.14) and *A. nilotica* (76.99). A number of species occurring during the transect were with mean ± SD for tree, shrub and climber, 4.42 ± 1.64, 9.42 ± 3.89 and 3.17 ± 2.05, respectively, while densities of the tree, shrub and climber were 108.46 ± 63.25, 288.84 ± 105.96 and 46.30 ± 30.90, respectively. Shannon diversity index values with mean ± SD of tree, shrub and climber were 10.4 ± 0.42, 1.72 ± 0.65 and 0.84 ± 0.65, respectively, while the Menhinick species richness index values were 1.03 ± 0.39, 1.26 ± 0.44 and 1.07 ± 0.45, respectively. Species evenness values of the tree, shrub and climber with mean ± SD were 0.71 ± 0.17, 0.69 ± 0.14 and 0.91 ± 0.10, respectively (Figs. 7.5 and 7.6).

Zone Five (Z5)

A total of 251 plant species were recorded in which there were 9 trees, 38 shrubs, 26 climbers, 142 herbs and 36 grasses. Abundance and % frequency ratio of each species of the tree, shrub and climbers reveals that all species were contagiously distributed within area, while a comparison of the frequency diagram of the various species with normal frequency diagram reveals that the plant community was heterogeneous in terms of nature. Among the heterogeneous communities, *Acacia senegal* was the most dominant and well-established species with high IVI value (102.38) followed by *Salvadora oleoides* (101.08). Mean ± SD numbers of species occurring during transect of tree, shrub and climber were 4.5 ± 1.64, 9 ± 3.91 and 3.46 ± 2.08, respectively, while densities with mean ± SD were 139.28 ± 84.18, 290 ± 3.91 and 56.15 ± 37.26 of tree, shrub and climber, respectively. Shannon diversity values of tree, shrub and climber with mean ± SD were 1.06 ± 0.42, 1.75 ± 0.65 and 0.92 ± 0.60, respectively, while Menhinick species richness values with mean ± SD were 0.97 ± 0.40, 1.18 ± 0.41 and 1.05 ± 0.35 of tree, shrub and climber, respectively. Species evenness values of tree, shrub and climber were 0.71 ± 0.20, 0.73 ± 0.10, 0.87 ± 0.09, respectively (Figs. 7.5 and 7.6).

Zone Six (Z6)

Two hundred and forty-four total plant species were recorded from zone six including 8 trees, 39 shrubs, 27 climbers, 137 herbs and 33 grasses. Abundance and % frequency ratio reveals that all tree, shrub and climber species were contagiously distributed within area, while a comparative result of frequency diagram shows heterogeneous nature of community. The important value index (IVI) reveals that the *Acacia senegal* (93.78) was most dominant species followed by *Salvadora oleoides* (88.02). Mean ± SD numbers of species of tree, shrub and climber were 3.36 ± 1.86, 9.45 ± 4.47 and 4.09 ± 3.08, respectively, while densities were 115 ± 73.58, 320.22 ± 192.91 and 76.19 ± 69.85, respectively. Shannon diversity index mean values of tree, shrub and climber were 0.80 ± 0.54, 1.75 ± 0.65 and 1.03 ± 0.63, respectively, while Menhinick species richness index values of tree, shrub and climber were 0.81 ± 0.45, 1.22 ± 0.39 and 1.05 ± 0.37, respectively. Species evenness means ± SD value of tree, shrub and climber were 0.79 ± 0.26, 0.72 ± 0.14 and 0.85 ± 0.08, respectively (Figs. 7.5 and 7.6).

Zone Seven (Z7)

A total of 236 plant species were recorded from the zone seven including 9 trees, 41 shrubs, 19 climbers, 133 herbs and 34 grasses. Distribution pattern of the tree, shrub and climber species within area was contagious as revealed by the ratio of abundance and % frequency, while comparative results of frequency diagram show that the plant community of this zone was heterogeneous in nature. Mean ± SD numbers of species forming transect were 4.36 ± 1.30, 11 ± 3.24 and 3.38 ± 1.68 of tree, shrub and climber, respectively, while densities were 132 ± 69.96, 325 ± 95.81 and 64.72 ± 47.04, of tree, shrub and climber, respectively. Shannon diversity index mean ± SD values of tree, shrub and climber were 1.11 ± 0.30, 1.96 ± 0.47 and 0.90 ± 0.55, respectively, while Menhinick species richness index mean ± SD values were 0.93 ± 0.34, 1.36 ± 0.30 and 1.01 ± 0.39 of tree, shrub and climber, respectively. Species evenness mean ± SD values of tree, shrub and climber were 0.75 ± 0.14, 0.69 ± 0.13 and 0.85 ± 0.10, respectively (Figs. 7.5 and 7.6).

Zone Eight (Z8)

A total of 237 plant species were recorded from the community of zone eight (Z8) in which there are 10 trees, 33 shrubs, 18 climbers, 139 herbs and 37 grasses. All of the tree, shrub and climber species were contagiously distributed within area, which were results of abundance and % frequency ratio. The nature of community was heterogeneous, which was revealed by the comparison of frequency diagram to normal frequency diagram. Among this heterogeneous plant community, *Salvadora oleoides* was the dominant and ecologically successful species with high IVI value (92.97) followed by *Acacia senegal* (71.96). Mean ± SD numbers of species of tree, shrub and climber were 4.22 ± 1.89, 8.72 ± 3.56 and 3.16 ± 1.85, respectively, while densities of tree, shrub and climber were 115.27 ± 72.07, 276.38 ± 113.05 and 40.83 ± 31.63, respectively. Shannon diversity index mean values of tree, shrub and climber were 1.05 ± 0.46, 1.72 ± 0.60 and 0.90 ± 0.52, respectively, while Menhinick species richness index mean (±SD) values of tree, shrub and climber were 0.93 ± 0.31, 1.19 ± 0.41 and 1.13 ± 0.28, respectively. Species evenness mean ± SD values of tree, shrub and climber were 0.77 ± 0.13, 0.69 ± 0.13 and 0.90 ± 0.07, respectively (Figs. 7.5 and 7.6).

Zone Nine (Z9)

A total of 225 species were recorded from the plant community of zone nine in which there were 9 trees, 31 shrubs, 23 climbers, 129 herbs and 33 grasses. Abundance and % frequency ratio reveals that all tree, shrub and climber species were contagiously distributed within area, while the frequency diagram reveals that the plane community was heterogeneous in nature. Important value index reveals that the *Salvadora oleoides* (135.69) was the most dominant species followed by *Acacia senegal* (119.70) of that community. Mean ± SD numbers of species of tree, shrub and climber were 3.59 ± 1.79, 7.78 ± 5.59 and 3.36 ± 2.05, respectively, while mean ± SD density values of tree, shrub and climber were 121.13 ± 96.44, 270.65 ± 110.10 and 46.59 ± 34.37, respectively. Shannon diversity index mean (±SD) values of tree, shrub and climber were 0.92 ± 0.52), 1.35 ± 0.89 and 0.89 ± 0.60, respectively, while Menhinick species richness index mean ± SD values of tree, shrub and climber were 0.83 ± 0.25, 0.99 ± 0.60 and 1.11 ± 0.39, respectively. Species evenness mean ± SD values of tree, shrub and climber were 0.82 ± 0.12, 0.71 ± 0.16 and 0.88 ± 0.10), respectively (Figs. 7.5 and 7.6).

Vegetation of the study area is mainly composed of thorny plant species. Upper canopy consists of the most dominant plant species like *Acacia nilotica*, *A. senegal* and *Salvadora oleoides* while major component lower canopy mainly comprising shrubby vegetation are *Prosopis juliflora*, *Euphorbia caducifolia*, *Capparis decidua*, *Grewia tenax* and *G. villosa*. Higher species diversity, richness and evenness of shrubs suggest their dominance over tree community in our study area. Kachchh region has specific forest type called tropical thorn forest, which consists the thorny shrub species. Shrub vegetation is dominated by thorny shrub species, while open areas are dominated by the annual plants which are mainly supported by scanty rainfall during monsoon. Most of the species were contagiously distributed within area and create heterogeneous plant community in nature. A total of 326 plant species were recorded including trees, shrubs, climbers/twiners, herbs and grasses.

The results of impact assessment of mining activities on vegetation of the total nine circular zones were identified within 2 km width because mining causes massive damage to landscape and biological communities, creating unfavourable habitat condition for plant growth. It was found that there was more or less impact in the inner zones of mining impact areas delineated for the present study. The number of tree and shrub species drastically decreased in their number due to mining. The unfavourable habitat conditions prevailing the coal-mined area have reduced the chances of regeneration of species, thereby, reducing the number of species in the mined areas. Habitat was changed by dumping of the contaminated soil on the natural habitat and by succession of extreme condition-tolerant plant species like *Prosopis juliflora* that occupies the landscape. Results of the study reveal that the positive impact on the vegetation of mining and associated activities creates the anthropogenic pressure on the local plant community structure and diversity. The main tree species like *Acacia senegal*, *A. nilotica* and *Salvadora oleoides* face heavy threats of extinction from the area. The present study led to the conclusions that phytosociological analysis can be used as important tools for predicting the suitability of mine-spoil habitats for plant growth, which would be helpful to revegetation of the mined areas. To minimize the impact of mining on the local vegetation, conservation strategies and extensive plantation drive of the local or native plant species in contaminated mining area are urgently required by long-term monitoring of the plantation.

7.5 Conservation and Management Strategies

With the clear understanding of environmental, ecological and social component with respect to the vegetation formation in the western Kachchh and widely available management options, the following strategies are suggested as conservation measures for rare, endangered and threatened (RET) plants and ecologically sensitive areas (ESAs).

A. In view of high floral diversity and increasing biotic pressures on vegetation, the following management strategies for NSS and LBS are suggested for the conservation of threatened floral species:
   - A detailed status survey of threatened floral species needs to be done, and the habitats supporting high floral diversity should be identified and notified as mini-core areas (MCAs) of the sanctuary.
   - Strict protection should be given to these MCAs to prevent wood cutting, grazing and collection of other natural resources.
   - Degraded habitats should be restored through restoration programmes with threatened species and their associate species.
   - Herbaceous cover (including grass cover), of both dense and sparse grasslands, provides potential habitat for seven rare herbaceous species such as *Helichrysum cutchicum* (470 nos.), *Heliotropium bacciferum* (375), *Heliotropium rariflorum* (325), *Tribulus rajasthanensis* (95) and *Indigofera caerulea* (24). A detailed status survey of these herbaceous covers and identification of the location where there is very high abundance was recorded.
   - There are 26 villages with the population of 10,872 located in and around the sanctuary (recent survey part of this project), and they depend on the sanctuary area for grass, firewood, fodder and other nontimber forest produce. Based on the dependency level, few villages, i.e. Ratipar, Gugariyana, Midhiyari and Amiyu, should be considered for eco-development.

- Creation of village-level eco-development committees, distribution of fuel-efficient stoves, development of fodder and fuel wood plantation, restoration of grassland and creation of employment alternative for economically poor villagers should be included in management planning for the overall conservation of threatened biological diversity of NSS and LBS.

B. Within the study area like Lifri, Guneri, Siyot, Haripar, Walka nana, Walka mota and Lakhapar, out of seven localities, eight species of threatened plants were recorded. Even though these RFs were under control, severe wood cutting and grazing pressures were reported from the neighbouring villages. Based on the abundance of threatened species and existing threats, the following management strategies are suggested:
   - RFs like Gugaryani, Chakrai, Mindhiari, Kaniari, Maniyara and Khirsara RFs and adjoining forest stretches should be resurveyed for the complete status assessment of RET plants.
   - Within these RFs, the areas with the abundance of above-mentioned threatened species need to be identified.
   - The identified stretches should be protected by providing natural green fence by planting *Euphorbia caducifolia* and *Balanites aegyptiaca*.
   - Local villagers should be informed to avoid grazing and cutting of trees in the potential locations identified.
   - Apart from the protection measures, the concerned forest staff should be employed for monitoring these protected sites to assess and understand the productive potential of the threatened species.
   - These protected sites in RFs should be resorted with the threatened plants, and it can act as natural seed banks for the threatened species.

C. Biodiversity is under varying degrees of protection in the protected and normal areas, but considerable proportion of biodiversity is manifested outside these areas and is existing without any protection. Realizing the limitation in declaring more areas as protected areas, and the need of participation of local communities in conservation efforts, the concept of ESAs is gaining popularity. During this study the following areas have been reported with diverse plant species and some threatened flora. Since these areas are not having any protected area status, they are under severe biotic pressures from the local villagers. (However for these areas reported for high floral diversity, area-specific floral richness is not discussed.)

I. *Piper*: It is a hilly tract located close to Narayan Sarovar and provides high diversity of floral species. A total of 108 plant species were reported during this study. Further it has been found that this hilly area provides habitat for six threatened species.

II. *Kharai*: This area is dominated by thorn scrub forest holding 127 plant species. Out of these plant species, around 42 were medicinal plants and 5 of conservation significance.

III. *Punrajpur*: This unprotected area supports 106 plant species in which 5 are of conservation significance.

IV. *Vayor and Vagoth*: This village area, i.e. hedges of agriculture and common grazing land, harboured the total five plant species of conservation significance including highly endangered plant species *Corallocarpus conocarpus*.
   - Considering the high floral diversity of these village areas, it has been suggested that these microhabitats should be declared as ecologically sensitive areas (ESAs).
   - Villager's dependency on the identified hot spots for their natural resources like fodder and fuel wood collection should be identified.
   - Many government, nongovernment (Shrujan, Ashapura Foundation, Setu-Abhiyan, KMVS and VRTI) and research organizations are currently working with the villagers of proposed ESAs. In order to reduce the biotic pressures on the identified hot spot areas, the dependent villagers should be connected with these organizations to get socio-economic benefit.
   - All the identified hot spots should be strictly prohibited for grazing and wood cutting by providing alternate resources through the ongoing developmental programmes.
   - Creation of village-level forest and resources management committees and monitoring of the ESA are suggested.

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Sodic Soil: Management and Reclamation Strategies

8

Priyanka Gangwar, Rachana Singh, Mala Trivedi, and Rajesh K. Tiwari

Abstract

The sodic soil is an important problem that reduces crop productivity. Sodic conditions are expected to adversely affect soil productivity because these conditions lead to poor ventilation, limited root development, and increased root diseases. From an agricultural perspective, enough exchangeable sodium present in soil has a negative effect on the growth of the plants.

Soil containing enough soluble salts to dissipate its productivity is called saline soil. Under natural condition, when excess sodium is absorbed by the negative charge of the clay particles, the force that holds clay particles together is greatly reduced. And when it gets dry, these clay particles form dense layers and block pores. This weakens aggregation of soil and causes structural collapse, due to limited movement of water and air through it.

The reclamation and improvement of sodic soil is an important step to increase the productivity of agricultural lands. There are a number of methods to reclaim sodic soil; the first method is tillage, which helps to improve the physical properties of sodic soil and turns soil into a fine tilth. The second method of reclamation is construction of parallel drainage by hydraulic technology. Other includes application of gypsum, leaching of water that removes excess salt from the surface. Phytoremediation is also one of the latest approaches for soil reclamation. These methods were found useful to reclaim sodic soil.

Keywords

Bioremediation · Gypsum · Soil Reclamation · Sodicity · Tillage

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_8

8.1 Introduction

The value and efficiency of substantial areas of land have declined due to sodic and saline soil throughout the world. These soils are considered to be problematic soil and require specific treatment measures and management practices for agricultural purposes. At the beginning of the twenty-first century, environmental pollution, a global shortage of water resources, and increasing salinity of soil and water have been noticed. Increasing population and reducing arable land area are two major threats to the sustainable development of agriculture (Shahbaz and Ashraf 2013; Shrivastava and Kumar 2015). It is predicted that by 2050, the world's demand for food and feed crops will almost double (Foley et al. 2011). High winds, extreme temperatures, soil salinity, droughts, and floods are major environmental factors which affect the production and cultivation of crops. Soil salinization is one of the most destructive environmental stresses, among them resulting in a large decline in cropland area, productivity, and its quality (Shahbaz and Ashraf 2013; Yamaguchi and Blumwald 2005). However the term soil salinity refers to the presence of excess salt content in the soil. Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- are major ions present in soil and water for salinization.

Soil that contains enough soluble salts to dissipate its productivity is called saline soil. Likewise, sufficient occurrence of exchangeable sodium in the soil, which affects its productivity, is called sodic or alkali soil (Hanay et al. 2004). When more than 15% of all cations of sodium bound to clay particles, structural problems began to appear, and then the soil is called sodic (Davis et al. 2007). The amount of sodium in the soil is the key measure of sodicity and is referred to as exchangeable sodium percentage (ESP).

In natural condition, when excess sodium is absorbed by the negative charge of the clay particles, the force of the clay particles that gathers is greatly reduced. Then if the soil becomes wet, it overswells because of high sodicity resulting in decomposition or dispersion from the larger soil mass (Seelig 2000). Once it gets dried, these clay particles settle in form of dense layers and block the pores. This weakens aggregation of soil that causes structural collapse, and plugging off the soil pores resulted in the limited movement of water and air through sodic soils (Qadir and Schubert 2002). In vegetable crops, the sodic soil may prevent water storage during irrigation because swelling and dispersion block the pores and reduce the internal drainage of the soil. The sodicity of the surface soil is likely to cause surface aggregates to disperse, also leading to surface crusting. Poor physical structure of sodic soil results in difficult soil tilling, poor seed germination, limited root growth, and also vulnerability to wind and water erosion (Oster et al. 1999; Rengasamy and Sumner 1998; Shainberg and Letey 1984). As the degree of swelling increases, the soil dispersion that affects the bloated clay becomes more serious, leading to greater blockage of the soil pores.

Ions present in soil and water get adsorbed on the soil particles and remain on their surfaces. Cation adsorption occurs due to the presence of charge on the surface of the soil particles, whereas adsorbed cations chemically bonded to the soil particles (Li and Keren 2009; Sadiq et al. 2007; Wong et al. 2009). Although these cations may be replaced by other cations that are present in the soil solution, the reaction in which a cation present in particular solution is replaced by an adsorbed cation is called cation exchange (Cutler and Cook 1953; Hanay et al. 2004). Calcium, magnesium, and sodium ions are always easy to exchange. Other cations, such as potassium and ammonium, are said to be fixed because they maybe detained in some position on the certain soil particles, so the exchange between them is very difficult.

Calcium and magnesium are the major cations generally found in soil. It has also been seen that the sodic soil may or may not contain excessive soluble salts. When excess soluble salts accumulate in these soils with water, sodium often becomes the main cation in the soil solution due to the precipitation of calcium and magnesium compounds (Qadir and Schubert 2002). The solubility limit of calcium sulfate, calcium carbonate, and magnesium carbonate exceeds, when the soil solution becomes intense by evaporation or water absorption by plants, at that time they precipitate with a corresponding increase in the relative proportion of sodium. In these circumstances, sodium is replaced with some of the original exchange complexes like calcium and magnesium (Hamza and Anderson 2003; Hanay et al. 2004; Keren 1996; Qadir and Schubert 2002; Sadiq et al. 2003).

Although it is fortunate that natural exchange complexes adsorb calcium and magnesium cations more strongly than sodium from the soil, the adsorption of calcium and magnesium is more frequent than that of sodium at equivalent solution concentrations. Nevertheless, there is a need for continuous research on sodic soil and its management issues. The reclamation of sodic soil can improve water management, water use efficiency, and crop production. Key management practices for reducing the effects of sodic soil and for its reclamation include surface water flow management, use of pest and insect controllers, and the use of amendments (e.g., gypsum, organic matter, polyacrylamides) to modify ESP. This chapter focuses on the current scenario of sodic soil, describes its properties, provides an overview of the strategies for soil reclamation, and highlights some of the field problems and management practices associated with sodic soil.

8.2 Global Scenario of Salt-Affected Soil

8.2.1 Present Land Affected

There is no accurate statistical data available on the global scale for sodicity; thus it becomes a major issue in the management of natural resources in different continents. The Asia-Pacific region (including India) has the largest range of soils affected by the salt damage. Countries mainly affected by land salinization include Argentina, Australia, China, Egypt, India, Iran, Iraq, Pakistan, Thailand, the former Soviet Union, and the United States. Using the FAO/UNESCO World Soil Map (1970–1980), FAO estimates that the total area of saline soils is 397 mha and sodic soil is 434 mha in the world (Table 8.1). The most recent estimates suggest that worldwide 932 million hectares are affected by salinization and alkalization, of

Table 8.1 Area of salt-affected soil in different regions of the world

Regions	Total area (mha)	Saline soils (mha)	Sodic soils (mha)
Africa	1899.1	38.7	33.5
North America	1923.7	4.6	14.5
Europe	2010.8	6.7	72.7
Near East	1801.9	91.5	14.1
Latin America	2038.6	60.5	50.9
Asia and the Pacific and Australia	3107.2	195.1	248.6
Total	12,781.3	397.1	434.3

Source: FAO/UNESCO World Soil Map (1970–1980)

Table 8.2 Area of salt-affected soil in different regions of India

Sr. no.	State	Saline soils (mha)	Alkali soils (mha)	Coastal saline soil (mha)	Total (mha)
1	Gujarat	1.22	0.54	0.46	2.22
2	Uttar Pradesh	0.02	1.35	0.00	1.37
3	Maharashtra	0.18	0.42	0.01	0.61
4	West Bengal	0.00	0.00	0.44	0.44
5	Rajasthan	0.20	0.18	0.00	0.37
6	Tamil Nadu	0.00	0.35	0.01	0.37
7	Andhra Pradesh	0.00	0.20	0.08	0.27
8	Haryana	0.05	0.18	0.00	0.23
9	Bihar	0.05	0.11	0.00	0.15
10	Punjab	0.00	0.15	0.00	0.15
11	Karnataka	0.00	0.15	0.00	0.15
12	Orissa	0.00	0.00	0.15	0.15
13	Madhya Pradesh	0.00	0.14	0.00	0.14
14	A & N Islands	0.00	0.00	0.08	0.08
15	Kerala	0.00	0.00	0.02	0.02
16	J & K	0.00	0.02	0.00	0.02
	Total	**1.71**	**3.79**	**1.25**	**6.74**

CSSRI-Karnal (2015)

which 351 million hectares are affected by salinity and 581 million hectares are affected by alkalinity (CSSRI-Karnal 2015).

The total salt-affected area in India is 6.74 mha, out of which 3.79 mha is affected with sodicity and the rest 1.71 mha is suffering from salinity problems (Table 8.2). Salt-affected soils cover 16 states/union territories of India. The most affected soil is in Gujarat (2.22 ha), followed by Uttar Pradesh (1.37 ha) (CSSRI-Karnal 2015).

8.3 Properties

Soil which has pH value, sodium adsorption rate (SAR), and exchangeable sodium percentage (ESP) of more than 8.5, 13, and 15, respectively, and electrical conductivity (EC) of less than 4.0 dS m^{-1} is said to be sodic (Levy et al. 1998). A model sodic soil contains an excess of exchangeable sodium (ES) in the soil and soluble carbonates. Excess exchangeable sodium adversely disturbs the physical and nutritional properties of the soil, resulting in a considerable or complete reduction in crop growth. The sodium-induced dispersion of the clay causes an increase in surface crusts caused by rainfall (Wang et al. 2012). Soil dispersion, clay platelet, and aggregate swelling are the main physical processes associated with high sodium concentrations. When too much large sodium ions enter between them, the force from which clay particles bind together is destroyed. As a result, the clay particles expand which cause swelling and soil dispersion. Dispersed soil blocks the macropores of surface soil, which prevents movement of water and roots in the soil.

Further, when the soil is dry, they form a cement-like surface layer, which limits water penetration and plant appearance (Wang et al. 2012). After irrigation or rainfall in the field, sodic soils usually have bulge surfaces. It is dry and hard, while soil few centimeters below the surface may be saturated with water. Dry surface cracks 1–2 cm across and a few centimeters deep, and these cracks are sealed when soil comes in contact with water and becomes wet. Cracks usually appear at the same location on the surface each time when the soil is dry. Among the several soil components, the part that significantly determines the physical behavior of the soil is colloidal clay (Levy et al. 1998). However, the swelling and dispersing component of soil clays varies significantly from the swelling and dispersing behavior of pure clay systems, probably because soil clays are usually in the form of a mixture with other minerals, oxides, and organic matter present in the soil.

Soil structure is generally referred to as an arrangement of particles, their size, and shape. Sodium-induced dispersion causes reduced permeability, reduced hydraulic conductivity, and surface crusting. High alkalinity increases the overall sensitivity to decomposition and digestion (Sumner and Naidu 1998). The dependency of hydraulic conductivity on EC has a significant impact on soil properties as the response of soil in sodic conditions varies from soil to soil. The rate at which water flows through the soil is called hydraulic conductivity. A well-structured soil contains a large number of large pores and cracks, for easy flow of water through the soil. In response to the sodic conditions and the low level of EC, swelling and dispersion of the clay change the size of the conductive pores and hence affect the HC (Chi et al. 2012). This leads to anaerobic conditions in soil, which can reduce or prevent plant growth and reduce the rate of decomposition of organic matter.

The decrease in HC in the soil was observed because the salt concentration in the soil solution was insufficient to prevent swelling and clay dispersion (Levy et al. 1998). In the rainy season, the salt present in soil is leached in the first rain, causing drastic decline in HC which results in waterlog. For soils with medium and high clay content, HC is generally more sensitive to sodic conditions. When the clay content is high, swelling of the clay can significantly decrease the size of the water-conducting pores and lead to low HC. On the contrary, in sandy soils, due to the low clay content, HC has limited effects. Calcium and magnesium salts are smaller and tend to be closer to clay particles; thus they often cause the soil to flocculate because they compete with sodium for space to bind clay particles (Schultz et al. 2017). Higher amounts of calcium and magnesium reduce soil dispersion caused by sodicity.

8.4 Effect on Plant Growth

The sodic soil is one of the most important soil problems causing reduced crop productivity. Sodic conditions adversely affect soil productivity because these conditions can lead to poor ventilation, limited root development, and increased root diseases. From an agricultural perspective, enough exchangeable sodium present in soil has a negative effect on the growth of the plants (Läuchli and Epstein 1990; Levy et al. 1998). It has a noticeable effect on the physical properties of the soil. As the proportion of exchangeable sodium increases, it markedly influences the physical properties of the soil. The soil tends to become more dispersed, resulting in the formation of an intense, impermeable surface that affects the germination of the seedling. In addition, due to alteration in soil redox potential, pH, dissolved organic carbon concentration, and Na^+ concentration, sodic soil leads to reduced microbial activity (Rietz and Haynes 2003; Yuan et al. 2007), nutritional imbalances, and micronutrient deficiencies. This made a negative effect on the growth and function of the root system that may result in induction of the toxic reactions and made plant nutrient deficient (Curtin and Naidu 1998; Prasad et al. 2006; Qadir et al. 2007).

Another reason for poor plant growth in sodic soil is soil pH. Although there is no direct negative impact of high pH on the development of the plant, it often causes to decrease the availability of some essential plant nutrients. For example, on increasing soil pH, the concentration of calcium and magnesium ions in the soil solution decreases due to the formation of relatively insoluble calcium carbonate, magnesium carbonate, etc. (Bernstein 2003; Greenway and Munns 1980; Prasad et al. 2003). Similarly, several other essential nutrients such as phosphorus, iron, manganese, and zinc may be affected.

8.4.1 Specific Ion Effects

Certain specific ions may produce toxic reactions in some plants. The accumulation of these ions at toxic levels in plants can cause limited growth or damage to the plants or even death. The more common toxic elements in sodic soil include sodium, molybdenum, and boron. Grieve and Fujiyama (1987) reported that there is limited growth of rice owing to Na-induced inhibition of Ca uptake and transport than Na toxicity. Jumberi et al. (2002) concluded that tolerant cereal crops have an important mechanism to maintain enough ionic balance and to absorb little accessible micronutrients [iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu)] from soil at high sodicity condition. However, He and Cramer (1993) stated that in the *Brassica* species, the K/Na ratio is not related to salt tolerance and is not suitable for selection of salt tolerance genotypes. Crop quality is also affected by salinity and sodicity in the root zone. Deprived plant growth in the sodic land leads to a physiological desert (Hopkins et al. 1991) and reduces the input of organic matter thus leading to a slower rate of soil carbon (C) turnover (Chatterjee et al. 2015). Addition of leaching agents and soil conditioners for removal of exchangeable sodium is the only practical modification of the sodic soil (Dua 1998).

8.5 Strategies for Soil Reclamation

The reclamation and improvement of sodic soil are very important, to increase the productivity of agricultural land for cultivation (Nelson and Ham 2000; Oster and Jayawardane 1998). Essentially, the recovery or modification of sodic soil requires removal or replacement of exchangeable sodium. This can be done in many ways, preferably by local conditions, available resources, and the types of crops grown on recycled soil. If the amendments are expensive, cultivator could not afford to spend for soil reclamation. Yet soil may be reclaimed by various ways including physical, hydro-technical, chemical, biological, and phytoremediation techniques.

There are a number of amendment methods founded in modern days to reclaim sodic soil like tillage, help improve the physical properties of sodic soil, and turn soil into a fine tilth. Then, the construction of parallel drainage by hydraulic technology. Another is the application of gypsum and the leaching of good quality water to remove excess salt from the surface, which helps in cultivation (Jayawardane et al. 1987). The next approach is the organic correction, and its decomposition will lead to the evolution of carbon dioxide and certain organic acids, which will reduce the soil pH and release cations through the solubility of $CaCO_3$ (Swarup 1981; Seenivasan et al. 2014). Phytoremediation is also one of the latest approaches to reclaim sodic soil by planting salt-tolerant plant species to make optimal use of land to increase forest coverage (Sharma et al. 2008).

8.5.1 Physical Method

Cultivation improves soil coverage and infiltration rates and helps to leach salts from the surface to deeper soils and thus helps to recover sodic soils. Some physical methods for recovering salt-affected soils include deep tillage, intervallic water application to flush salt out through the soil column, subsoiling, etc.

8.5.1.1 Deep Tillage and Subsoiling

Tillage can help to recover sodic soil as it can effectively break down the soil plows, increase total porosity (especially large porosity), reduce soil bulk density, and thereby promote root extension into deep soil layers (Mu et al. 2016; Mosaddeghi et al. 2009; Nitant and Singh 1995). It has also been shown to significantly improve microbial diversity, rhizosphere microbes, and soil water storage capacity, thereby creating ideal conditions for root development and effectively delaying plant senescence (Djm et al. 2010; Liang et al. 2010; Qin et al. 2008). Deep plowing (1–2 m) or tearing destroys the cement-like hard soil layer, which usually leads to a permanent improvement of the soil structure and physical properties. However, due to deep tillage, sodic subsoil comes out to surface which sometimes leads to logging and infiltration problems. In this case, an alternative approach with use of ridges becomes helpful. In this plants are located about 0.25 m above the furrows, so the aeration is improved, although it needs to be repeated from time to time.

It has been reported that deep tilling and rice-wheat crop rotations have been found to be most effective in the recovery of sodic soils (Mclean 1982; Sadiq et al. 2002). Deep tilling can increase grain yield and planting density by 1.08–5.21% (Hou et al. 2013). However, deep plowing alone does not help in the recovery of sodic soil because the soil will sink again when wet and will harden after drying. Ghafoor et al. (1985) observed a marvelous increase in wheat grain yield with the combined effect of gypsum ($CaSO_4 \cdot 2H_2O$) and tilling.

8.5.1.2 Successive Dilutions of High-Salt Water

Sodic soil recovery can be achieved in those areas where water is not a limiting factor. It can be done by continuously diluting the soil with high-salt water containing divalent cations. The use of high EC in water prevents soil from the dispersion and induces flocculation of soil colloids (Murtaza et al. 2009). At the same time, the Ca ions in the water reduce the sodicity by displacing the exchangeable Na. To ensure successful soil recovery, the depth of water should be at least nine to ten times the depth of the soil to be reclaimed (Levy et al. 1998).

8.5.2 Chemical Reclamation

Quick recovery of sodic soil by addition of divalent cations can be achieved through the use of chemical modifications. Divalent cations release soluble calcium sources or dissolve calcium ions into the soil and replace exchangeable sodium. Common chemical modification materials include gypsum, lime, $CaCl_2$, sulfuric acid, and sulfur (Oster 1993). The chemical modification of sodic soil can be divided into three categories as follows:

8.5.2.1 Calcium Salts of Low Solubility

The nature of soil and expenditure will decide the suitability of amendment methods for sodic soil reclamation. The soil having pH below about 7 is suitable for ground limestone and $CaCO_3$ amendment, because, when the pH is higher than 7.0, the effectiveness of limestone as a corrector is significantly reduced as its solubility decreases with increasing soil pH (Oster and Frenkel 1980). Some sodic soils which contain an excess of exchangeable sodium also contain significant amounts of exchangeable hydrogen. In presence of exchangeable hydrogen, an acidic reaction occurs which made the low pH of the soil.

8.5.2.2 Soluble Calcium Salts

Most of the sodic soil have high pH, because it contains a measurable amount of free sodium carbonate, which gives these soils a high pH, mostly greater than 8.2. Thus, in such case, limestone does not work as an effective amendment. In these soils, only soluble calcium salts like gypsum and calcium chloride substances are beneficial.

Gypsum ($CaSO_4$) from natural and nonnatural sources is most frequently used for sodic soil treatment. It is most popular chemical treatment mainly because of its low cost, good solubility, and easy availability. By increasing EC and cation exchange effect of sodic soil, gypsum can increase soil permeability (Murtaza et al. 2013). The required amount of gypsum depends on the amount of exchangeable Na present in the selected soil.

The amount of exchangeable Na to be exchanged per unit land area during reclamation depends on the initial and desired final exchangeable Na percentage and also on the cation exchange capacity of the soil (Abrol et al. 1975). Thus, the amount of gypsum required to reclaim the soil is called as “gypsum requirement” (GR) and is calculated as follows:

$$Gypsum\ Requirement\ (GR) = ESP\ (initial) - ESP\ (final)\ \tilde{\mathrm{A}} - CEC/100$$

where ESP (initial) is obtained from the analysis of soil before reclamation or application of gypsum, ESP (final) is usually kept at 10, and CEC is the cation exchange capacity in GR or Cmol (pp^+) kg^{-1} of the soil.

The efficiency and rate of exchange of Ca from adsorbed Na will vary with ESP. GR models provide a powerful tool for quantitative prediction of the water and gypsum needed to recover the soil (Sakai et al. 2004). Calcium chloride ($CaCl_2{\cdot}2H_2O$) is also a highly soluble salt that provides soluble calcium directly. Its reaction is the same as gypsum in sodic soil.

8.5.2.3 Acids or Acid-Forming Substances

Sulfuric acid is an oily, caustic liquid and usually has a purity of about 95%. When applied to a soil containing calcium carbonate, it immediately reacts to form calcium sulfate, thereby providing indirectly soluble calcium. Similarly, iron sulfate and aluminum sulfate (alum) are usually highly pure and soluble in water. When applied into the soil, in presence of water, it dissolves and hydrolysis reaction occurs. As a result sulfuric acid forms, and it reacts with the calcium carbonate present in the sodic soil and provides soluble calcium (Miyamoto et al. 1975).

Sulfur is another acid-forming substance, which is a yellow powder with a purity ranging from 50% to over 99%. It is insoluble in water and, thus, does not supply calcium directly as a substitute for adsorbed sodium. It oxidized itself in presence of soil water and forms sulfuric acid (Overstreet et al. 1980). Pyrite (FeS_2) is one of the popular materials that is considered as a possible amendment. The reactions leading to oxidation of pyrite is complicated and appears to consist of chemical and biological processes (Verma and Abrol 1980). Temple and Delchamps in 1953 proposed reaction's steps for the oxidation of pyrite. In the very first step, oxidation is abiotic in which ferrous sulfate II (ferrous) is formed. This reaction is then followed by the bacterial oxidation of iron sulfate II, which is a reaction usually performed by *Thiobacillus ferrooxidans*, and iron sulfate III forms. In next step, pyrite oxidized and iron sulfate III reduced. The elemental sulfur thus produced is then oxidized by *T. thiooxidans*, and the resulting acidity facilitates the continuation of the process.

8.5.3 Biological Method

In order to quickly restore the sodic soil, gypsum is mainly used as a chemical modification in India. However, both physical and chemical methods for sodic soil reclamation are not cost-effective. Thus plant bioremediation or phytoremediation is another possible method, as an alternative to chemical modification, mainly by planting salt-tolerant plant species (Mishra and Sharma 2003; Seenivasan et al. 2014). Microbial and enzyme activity such as microbial counts, microbial biomass, and dehydrogenase, glucosidase, arylsulfatase, protease, alkaline, and acid phosphatase activity inhibits in sodic soil (Tripathi et al. 2007; Yuan et al. 2007). The bioremediation of sodic soil is a promising option, which increases the rate of dissolution of calcite by soil-root interface process, resulting in an increased level of Ca^{2+} in the soil solution.

8.5.3.1 Use of Organic Matters

Insoluble calcium compounds are present in most of the soil. Use of organic matter, compost, and plant roots helps to dissolve these calcium compounds. Although this technique has been extensively tried, it is commonly accepted that choosing the suitable recovery strategy relies on the geography and physicochemical property of soil. Plant roots can stimulate changes in physical characteristics of the root zone in several different ways, such as removal of air entrapped in larger conducting pores, generation of alternate wetting and drying cycles, and creation of macropores (Qadir and Oster 2004). In addition, Tisdall (1991) found that the stability of the aggregates is enhanced due to the in situ production of polysaccharides and fungal hyphae at the root-soil interface process. It has been reported that sodic soil improvement by agroforestry systems can also improve the biological production of sodic soil (Singh 1996; Singh and Singh 1997).

8.5.3.2 Plant-Microbe Interaction

Another biological method to deal with salt stress is "plant-microbe interactions" that has recently paid significant attention from many researchers from all around the world. Plant-microbe interaction is a beneficial link between plants and

microorganisms, and it is an efficient method for reclamation of soil (Trivedi and Arora 2013). Rhizosphere bacteria are found responsible to positively increase the absorption of nutrients by plants or produce those compounds, which help to promote plant growth and thus regenerate soil quality. It can affect plant growth directly or indirectly. It makes physiological and biochemical changes by inducing some modifications in cell wal
l structure or by leading to the synthesis of proteins and chemicals involved in plant defense mechanisms, respectively, thus prevents deleterious effects of phytopathogenic organisms, and promotes plant growth indirectly (Arora and Vanza 2017). However, biological methods are a little bit slower than chemical methods to make positive changes and depend on the presence of calcite in the soil. In addition, its range is limited in highly sodic soils, because the growth of bioremediation crops may vary, and the use of chemical modifiers such as gypsum is unavoidable.

8.6 Management Practices

A good management practice for reclaiming soil is necessary for today's era as it can eliminate or reduce the factors responsible for hazard. The management of sodic soil needs to be combined with good agronomic practices based on chemical amendments; water quality and local conditions like climate; crop economic, political, and cultural environment; and existing farming systems. There is usually no single way to control salinity problems. However, there are several approaches that can be combined into a comprehensive system which gave satisfactory results (Mashali 1995; Qadir et al. 2006). The type and amount of chemical modifiers used to replace the exchangeable sodium in the soil totally depend on soil properties, including the degree of soil degradation, the desired level of soil improvement (including the crop to be planted), and economic considerations.

There are usually two options for managing issues related to high sodium:

1. Change the plant species/variety to a more tolerant species/variety.
2. Soil improvement.

In general, improving the soil is difficult in itself. There are some important management practices, which should always be followed to recover sodicity.

8.6.1 Determine Soil Sodicity Status

At the initiation of sodic soil reclamation, the first important step is to know how much soil is sodic. Because of different approaches used for sodic soil amendment if applied to saline (not sodic) soils by mistake, it will increase the salt content further and aggravates the salinity problem. In this case, a soil test was performed to calculate the exchangeable sodium percentage (ESP). When the content of sodium in the soil is high, the goal is to replace the sodium with calcium and then leach out sodium. There are two possible ways to do this:

1. Dissolve the calcium carbonate or calcium sulfate already present in the soil.
2. Add calcium in form of gypsum or limestone to the soil.

Sufficiently high EC water must be added to leach out the displaced sodium away from the root zone once gypsum is applied and mixed in the soil. The recovery of sodic soil is always slow because once the soil is disturbed its structure slowly improves. At initial stages of reclamation, planting salt-tolerant crops, adding organic matter, and cultivating crop residues will increase the permeability and infiltration of water, thus accelerating the process of reclamation. Before modifying the soil, make sure that the drainage is sufficient, and then bring out the sodium using high-quality water and by applying the sulfur product or calcium source.

The most common management practice is to remove maximum adsorbed sodium from the top 6–12 inches of soil. This can improve the physical condition of the topsoil in a very short period, so that the farmer can grow crops. Further, to reduce the adsorption of sodium in the soil, cultivator should continue use of quality irrigation water, good irrigation methods, and good cropping techniques (Davis et al. 2007).

Chemical-mediated deep tilling, crop residues, compost, or planting salt-tolerant crop may improve the tilth and increase the water infiltration of sodic soils. Planting salt-tolerant crops during reclamation is usually better than leaving the field blank (Singh et al. 2004). Moreover, deep plowing can destroy restrictive hard layering and mix calcium from deeper soil layers. The successful sodic soil reclamation mainly depends on the cost and reaction rate of soluble calcium, which is directly or indirectly provided by the different amendment methods (Davis et al. 2007).

It is recommended to continuously cultivate the land and never leave a field fallow, once the amendment of sodic soil is started. Continuous cropping will improve the soil and gradually reduce the ESP. It is advisable to introduce rice crop alternatively during continuous cropping. In submerged conditions during the growth phase, rice crop will provide effective leaching of exchange products. Over the time, it has been observed that the results of improved soil with continuous cropping system were almost the same as gypsum-treated plots.

8.7 Future Prospects

The level of sodium content in soils around the world may have an adverse effect on their performance and should be considered sodic soils. It is expected that the area affected by sodium content will be increased by time due to use of low-quality irrigated water and faulty irrigation methods in agriculture. When the soil is exposed to low EC water, the detrimental effects of sodic conditions on the physical and hydraulic properties of the soil are exacerbated. The limitations of sodic soil are not only physical degradation but also nutritional imbalances, especially nitrogen and calcium, which made it responsible for low productivity. Sodicity leads to both cultivated fields and environmental damages by increasing runoff and soil erosion. However, sodium-related soil degradation and productivity loss are reversible to a certain extent because sodic soil can be recovered by making amendments.

Plant-microbe interaction is also one of the important bioremediation approaches for sodic soil. Researchers in different disciplines, such as agronomy, soil science, microbiology, biochemistry, forestry, ecology, analytical chemistry, and genetic engineering, can develop comprehensive methods to study the functional basis of chemical-mediated plant-microbe interactions. In this direction, modern research techniques can help to develop this combined technology for reclamation of sodic soil. It will further open up new directions for the better development of all beneficial soil bacterial communities (methane-oxidizing bacteria, PGPR, cyanobacteria, salt-tolerant bacteria, etc.).

It is very important that management practices of sodic soil should be taken seriously, which will help to alleviate the adverse effects of sodic conditions on soil physical and hydraulic properties. Subsequent use of appropriate management tools allows us to safe and sustainable use of soils affected by sodium without being abandoned.

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9 Microbe-based Inoculants: Role in Next Green Revolution

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Abstract

Increasing food demand, with growing population, has been a major concern throughout the globe. The aim can only be achieved with the onset of next green revolution being much defined by sustainable approaches. The past green revolution had its negative impact due to excessive use of agrochemicals contaminating the environment and further challenging the food security. Henceforth, designing the blueprint of next green revolution requires the application of effective and sustainable approaches which enhance the yield of plants while still maintaining the decorum of sustainability. In this regard, microbes have been concluded as the best players finding their roles in plant growth promotion and also stress management. Currently, there are several bacterial-, fungal-based inoculants available in the market along with genetically modified organisms, forming the base of upcoming green revolution. Thus, the future of sustainable agriculture is related to the efficiency and action of these microbes.

Keywords

Microbial inoculants · Green revolution · Environmental sustainability · Plant growth-promoting rhizobacteria (PGPR) · Stress

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_9

9.1 Introduction

Agricultural productivity has always been a worldwide concern since centuries due to ever-growing population. The pressure to meet the demands of population and to lessen the problem of hunger led to the evolution of new scientific technologies through which advancement in agronomic practices was made possible in order to increase yield of crops (Pinstrup-Andersen and Hazell 1985). These improved mechanizations in scientific field contributed to the emergence of "green revolution" (GR) (Rena 2004). This revolution was also named as modern agriculture technology or seed-fertilizer-water technology (Das 2017). The extraordinary era of crop productivity evolved in 1966 and lasted till 1985, and the later two decades are known as post-GR period (Pingali 2012). New technologies that enabled an increase in agricultural productivity included better quality seeds, improved water supplies, and the use of fertilizers and pesticides for plant protection (García-Fraile et al. 2017; Arora 2018a). Professor Norman Borlaug, a plant pathologist and a wheat breeder, with the help of his associates developed a high-yielding variety of wheat, and later, for his contribution, he was awarded the Nobel Prize in 1970 (Dalrymple et al. 1974; Barker et al. 1985). This led to an increase of 5000–6000 kg production of wheat in Mexico in 1965. In other developed nations, the yield of products also increased manyfold between 1975 and 1995, e.g., there was an increment of 78% in cereals, 113% in fishing, 127% in beef, 331% in eggs, and 280% in poultry products (FAO 1998). This strategy was later adopted by many other developing countries. The establishment of over-expanding list of hybrid technologies in the form of genetically modified (GM) crops and discovery of Ti-plasmid in *Agrobacterium tumefaciens* by J Schell in 1974 was also noticeable which also set a milestone in advancement of GR (Zanden 1991). GM crops whose genetic code has been with desirable characteristics by introducing foreign genes have been very close to green revolution, and this technique emerged as a gene revolution (Pingali and Raney 2005; Jain 2010). In modern farming, agricultural biotechnology based on genetically engineered crops represents one of the major advanced technological innovations (Chern 2006). Some of the well-known examples of genetically engineered crops include Bt cotton, insect resistance varieties of eggplant, maize, and herbicide-tolerant crops of soybean, canola, and alfalfa (Brookes and Barfoot 2015).

In India, the advent of green revolution began in the mid of 1960s in the kharif season under the name 'High Yielding Varieties Program' (HYVP) with the main focus to introduce such variety of crops which could withstand the expanded use of fertilizers and pesticide (Sebby 2010). Kalyansona wheat (1967) and Jaya rice (1968) were first two modern varieties that kicked off the onset of green revolution in India (Janaih et al. 2005). With the implementation of transgenic crops and other improved varieties of crops, there was an undisputed increment in the production but at the cost of losing the sustainability of the ecosystem (Evenson and Gollin 2003). Excessive use of GM crops, inorganic fertilizers and pesticides, and plant protection chemicals in the past decades has led to a number of long-term environmental problems (Arora et al. 2012) including ecosystem degradation on a large scale and loss of productivity promoting deterioration of physical, chemical, and biological health of cultivated land including degradation of soil, deforestation, greenhouse gas emissions, accumulation of chemical pesticides and fertilizers, groundwater pollution, and decrease in water table due to excessive irrigation (Tilman et al. 2002; Foley et al. 2011). The strategy of HYVP worked well in increasing the yield but failed to retain the genetic base resulting in loss of indigenous varieties as well as useful conventional agricultural practices (Shiva 1993). On the other hand, shift of traditional methods to monoculture technique is known to degrade quality of soil making it prone to soil erosion and hence rendering it unproductive (LaSalle and Hepperly 2008). The unprecedented use of fertilizers also increased drastically during this period which led to imbalance in the threshold of nitrogen (N), phosphorous (P), and potassium (K) contents and loss of other micronutrients in soil (Das and Mandal 2015). Estimates reveal that production of global N and P fertilizer increased by 8 and 3 times, respectively, during 1961 and increment of N/P ratio was observed by 0.8 g N g^{-1} P per decade during 1961–2013. Global pesticide production was reported to increase at a rate of about 11% per year from 0.2 million tons in 1950 to 5 million tons by 2000 (FAO 2017; Carvalho 2017). These fertilizers and pesticides are also one of the greatest sources of greenhouse gases (GHGs) like nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) of which N_2O is 310 times more potent than CO_2 (IPCC 1996). Nitrogenous fertilizers like ammonium nitrate, calcium ammonium nitrate, urea, and urea ammonium nitrate are its major sources (Wood and Cowie 2004). On the other hand, phosphate fertilizers such as mono- and diammonium phosphates, single superphosphates, and tri-superphosphates result in CO_2 emissions (Davis and Haglund 1999), whereas NPK fertilizers were found to release CO_2 and N_2O, and most of the CO_2 was liberated during production of ammonia, and 100% N_2O was produced during nitric acid production (Kongshaug 1998). GHGs thus produced add to the adversities like global warming, air pollution, and climate change (Pardis and Devakumar 2014). Climate change gives rise to several other abiotic stresses like drought and flood and also contribute to salinization of the agricultural soils that intercepts growth and development of plants along with effects like nutrient imbalance (Tewari and Arora 2013), osmotic stress, toxicity of Na^+ and Cl^-, production of ethylene, adverse result on plasmolysis, and disturbance in soil fertility (Drew et al. 1990; Arora et al. 2018). In case of pesticides which are recalcitrant in nature and persist in the environment for centuries causing biomagnifications at trophic levels, such compounds are highly carcinogenic, and their toxicity gets accumulated in the soils deteriorating its biology. The crops planted in such soils absorb these toxic compounds adversely affecting human health leading to generation of diseases such as cancer, neurological imbalance, and infertility in humans (Zahn and Ward 1998; Adesemoye et al. 2017).

The increase in fertilizers and pesticides significantly decreased the biodiversity of different ecosystems (terrestrial and aquatic) and has rapidly increased rate of extinction since the last 50 years (Singh et al. 2016). Birds, fishes, and many other nontargeted species are often reported to be affected by pesticides contamination leading to their high mortality. In this way, it has resulted in the genetic erosion of the keystone species especially in case of microbial biodiversity (Aktar et al. 2009;

Arora 2018b). Microbes are sensitive to slight changes in the environment; hence, indiscriminate use of plant protectants deteriorates structure and functioning of microbes in soil leading to loss of important ecological processes such as biogeochemical cycling of nutrients (Hartman and Richardson 2013). It was reported by de Vries et al. (2006) that organic fertilization technique increases the bacterial/fungal biomass ratio in soil, and a vice versa effect was observed when inorganic fertilizers were used establishing the fact that sustainable agriculture practices favor microbial biomass. Nitrogen-fixing ability by free-living bacteria is known to decrease in presence of glyphosates in soil (Santos and Flores 1995). Similarly 2,4-Dichlorophenoxyacetic acid (2,4 D) reduces nitrogen fixation in cyanobacteria and is also known to affect their growth (Çalgan and Sivaci-Güner 1993). Mycorrhizal fungi are also affected in similar ways and were reported to reduce in number in presence of triclopyr and oxadiazon (organic pesticides) (Chakravarty and Sidhu 1987; Moorman 1989). Many European countries have banned the use of such synthetic plant protectants, but still on large part of agricultural lands, intensive chemical inputs are being applied on crops causing several environmental issues (Baez-Rogelio et al. 2017).

To halt this loss, major efforts should be adopted which are organic in origin and, most importantly, which promise to ensure the sustainability of the environment. This could be achieved when farming practices would incline toward the use of biological agents in order to protect plants from pests and diseases, to enhance their growth, and, above all, to maintain an eco-friendly environment. In this regard, microbial inoculants are seen as a substantial example and as an excellent substitutes having capability to reduce the use of synthetic fertilizers and pesticides (Trabelsi and Mhamdi 2013). Soil is a complex biota and harbors dynamic varieties of microorganisms. Approximately 10^{10} bacterial species reside in a gram of soil along with approximately 4×10^3 to 5×10^4 species of other organisms (Torsvik et al. 1990; Roesch et al. 2007). Hence, soil is considered as a black box of microbial diversity (Prashar and Shah 2016). Among this huge diversity of microbiota reside certain microbial communities which are known to promote growth of plants by several mechanisms and are known as “plant growth-promoting microorganisms” (PGPM). They promote growth by acting as biofertilizers for the plants in order to provide nutrients such as growth regulators or by providing resistance to the plants from phytopathogens thus acting as biocontrol agents (Abhilash et al. 2016). In this way, microbial inoculants are the best alternatives to their chemical counterparts. Scientists from different parts of the world are already exploiting the use of these inoculants in different ways such as a single inoculum of bacteria, in combination with two or more different bacterial inocula or consortia of fungal and bacterial species (Malusá et al. 2012). Therefore use of such beneficial microorganisms as biocontrol agents and as biofertilizers could be a step toward “second green revolution” or more aptly the “era of evergreen revolution.” In this chapter, the role of these bioinoculants in next green revolution as an approach to sustainable agricultural practice has been explained. In further sections, various types of bioinoculants such as bacterial, fungal, and other types of inoculants have also been discussed.

9.2 Beneficial Soil Microorganisms and Their Role in Next Green Revolution

A plant microbiome encompassing a lot of microbes in the soil is much similar to human microbiome and functions by lending a hand to nutrient absorption and protection from vicious and harmful microbes. Consequences and harmful side effects of using chemical fertilizers and pesticides in excessive amounts are already known. This also comprises of degradation in soil fertility, environmental pollution, disruption in the environment, and harmful effect on human health (Ayala and Rao 2002). Microorganisms are very well expected to pave way for the next agricultural green revolution and can be the great option for better and improved sustainable organic farming practices. A number of microbial bioformulations are commercially available throughout the globe providing effective way to eradicate chemical fertilizer and pesticides. Microbe-based bioinoculants gained attention mainly because of their eco-friendly nature and threats affiliated with chemical fertilizers. Considering the good impact of microbial inoculants in terms of nutrient supplementation, biofortification, biocontrol, and bioremediation, they need to be encouraged in the future for implementation in agriculture for a stable and productive agroecosystem. The mechanisms involving role of microorganisms in growth promotion in addition to microbial inoculants and their types have been discussed below in detail.

9.2.1 Nutrient Assimilation and Biofortification

Mineral elements including phosphorous (P), nitrogen (N), calcium (Ca), iron (Fe), zinc (Zn), and manganese (Mn) have the most pivotal role in all living organisms, and an appropriate balance is required to achieve proper growth and development of plants. Among these P and N are the critical and important macronutrients responsible for building of nucleotides, amino acids, and proteins. Micronutrients such as Ca, Mg, Zn, Mn, boron (B), molybdenum (Mb), and sulfur (S) are required in small quantities and play a significant role in plant metabolism by acting as cofactors in enzymatic reactions (López-Arredondo 2013). Microbial inoculants have emerged as the most reliable approach to assimilate nutrients and increase their bioavailability to plants and improve the fertility of soil (Rashid et al. 2016). Nutrient assimilation in plants is a complex cascade involving bacteria, fungi, protists, and animals (Müller et al. 2016). Diverse microbes are known to play noteworthy role in the acquisition of nutrients and favoring the plant health (Vessey 2003). PGPR thriving in the vicinity of roots increase the plant growth by enhancing the nutrient uptake through nitrogen fixation, phosphate solubilization and iron and zinc chelation through various mechanisms (Stamenković et al. 2018).

Nitrogen is an essential macronutrient needed in significant amount by plants for their growth, physiological and developmental processes, and metabolism, but often its limited availability renders the soil unhealthy for cultivation (Bouguyon et al. 2015). Although there is huge abundance of nitrogen in atmosphere, yet the availability of N_2 to plants is only around 50%, while 25% is exuded to atmosphere, 20%

runs off into water bodies, and only 5% persists in the soil (Postgate 1982; Galloway et al. 2008). The capability of microbes to fix nitrogen to ammonia has been used to overcome the excessive use of chemical N fertilizers. Both free-living and symbiotic nitrogen fixers are known to thrive in the rhizosphere. This capability to fix the nitrogen by converting elemental nitrogen into plant utilizable form (Gothwal et al. 2009; Kuan et al. 2016) is confined to some of the bacteria and few of methanogenic archaea (Bae et al. 2018), and the process is known as biological nitrogen fixation (BNF). Approximately 200 million tonnes of nitrogen is fixed annually by BNF (that is two thirds of nitrogen fixed globally) (Peoples et al. 2009; Gouda et al. 2018) which is a very cost-effective solution allowing the farmers to save millions of dollars which otherwise would be spent on chemical fertilizers. Symbiotic nitrogen fixation is an essential biological process which governs the sustainability of agriculture and maintains the nitrogen content of soil. Inside de novo organs called as nodules formed on leguminous roots, bacteria fix nitrogen with the aid of enzyme nitrogenase (Sulieman and Tran 2014). The nitrogen-fixing symbiosis initially involves molecular dialogue between the plants and microbes, involving signals predominantly flavonoids and isoflavonoids attracting the rhizospheric microbes toward plants. Endosymbionts like rhizobia (including *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium*, and *Mesorhizobium*) take up these signals and bind to the transcriptional regulator NodD of conserved nod genes, inducing the cascade of releasing nod factors which later aid in infection stages and nodule formation in leguminous plants (Long 1996; Mus et al. 2016). Rhizobia possesses large genomes (about 10.5 Mbp), with multiple replicons for symbiosis (MacLean et al. 2007). *Sinorhizobium meliloti* and *Medicago* species endosymbiont has 3.65 Mbp chromosome and two megaplasmids, pSymA and pSymB (1.35 and 1.68 Mbp), majority of which carry symbiotic genes. With the starvation of nitrogen, *Rhizobium*-legume symbiosis is triggered selecting the specific *Rhizobium* partner from the population of bacteria in the rhizosphere (Maróti and Kondorosi 2014). The genera of *Frankia* member of actinomycete family are symbionts of non-leguminous plants often referred to as actinorhizal plants. Their successful symbiosis forms root nodules where the microbe provides nitrogen to plant in exchange of carbon. A tripartite symbiosis of actinorhizal plant-*Frankia*-mycorrhiza has also been reported which forms a much stable association and has the efficiency even in poor marginal soils (Dawson 2008). Cyanobionts including *Nostoc* are characterized by mechanism of nitrogen fixation including heterocysts (nitrogen-fixing cells), akinetes (spore-forming resting spores), and hormogonia (motile filaments), all of which lead to infection of plants for symbiotic nitrogen-fixing associations (Adams and Duggan 2008; Santi et al. 2013).

Phosphate is another limiting nutrient found in soil (Shi et al. 2013) as only the anionic form can be obtained and consumed by plants. In average soil, the normal content of phosphorous available to the plants is about 0.05% (w/w), out of which only 0.1% is procurable by the plants (Achal et al. 2007; Zhu et al. 2011). It has been reported that plants are unable to avail 80% of phosphorous applied to the soil and nearly 5.7 billion hectares land globally are deficient of phosphate naturally (Vassilev et al. 2006). In the last few years, attention has been given to the biological processes using phosphate-solubilizing microorganisms for making phosphorous available to plants and soils (Fasim et al. 2002). These microbes regulate the organic transformation of the insoluble form to an assessable form of phosphate, i.e., orthophosphate, thus controlling immobilization and mineralization of phosphate occurring in the soil. The mechanism behind phosphate chelation involves synthesis of assimilating compounds including organic acids, hydroxyl ions, siderophores, protons, and CO_2 (Sharma et al. 2013). Organic acids like gluconic acid, aspartic acid, malonic acid, glycolic acid, glutamic acid, malic acid, oxalic acid, etc. along with hydroxyl ions or protons lower the pH and chelate cations releasing P by substitution of H^+ for Ca^{+2} (Goldstein 2000; Alori et al. 2017). Another mechanism involves direct exchange of H^+ for cation uptake or through H^+ translocation ATPase (Rodríguez and Fraga 1999). Enzyme-based mobilization includes via phytases and phosphatases (Calvo et al. 2014; Owen et al. 2015). Both fungi and bacteria are known to solubilize P in the soil. Arbuscular mycorrhizal fungi (AMF) through their extended radical hyphae are able to fix P from allochthonous sites (up to 8 cm) (Millner and Wright 2002; Smith and Read 2008). Gram-negative bacteria directly solubilize phosphorous through direct oxidation of glucose to gluconic acid (Goldstein 2000; Alori et al. 2017). These are important attributes found in phosphate-solubilizing bacteria (PSB) and AMF being used predominantly in inoculations (Fankem et al. 2006; Khan et al. 2007; Sharma et al. 2013).

Another vital nutrient needed for stabilized growth of the plant is potassium (K) on which variety of indispensable mechanisms are dependent directly or indirectly. It is involved in several key functions including energy transfer and activation of enzymes in many plant physiological reactions such as photosynthesis, protein synthesis, and starch synthesis, and it also helps in combating phytopathogens and disease resistance (Rehm and Schmitt 2002). The concentration of K in the soil differs extensively ranging from 0.04% to 3%, although 2.5% of lithosphere is depleted of K (Sparks and Huang 1985). Beneficial soil microbes including saprophytic bacteria, fungi, and actinomycetes enhance the fertility of soil and growth of plants through chelation of soluble K forms from insoluble complexes by various mechanisms such as synthesis of organic and inorganic acids and polysaccharides, acidolysis, complex reactions, chelations, exchange reactions, etc. (Meena et al. 2015; Saha et al. 2016a; Etesami et al. 2017).

Iron, the fourth most abundant element found in the Earth's crust, is needed by all the life forms. The availability of both forms, i.e., ferrous (II) and ferric (III), rely upon the oxygen level and pH in the soil. The concentration of iron in the soil ranges from 7000 to 500,000 mg kg^{-1}. The ferric form of iron has been found to preponderate in the soil, while plants can consume and uptake the ferrous ion form (Kobayashi and Nishizawa 2012). The activity of some microorganisms increases the concentration of ferrous ions in the soil including the rhizosphere. The mechanism behind Fe chelation involves lowering of the redox potential (Nikolic and Römheld 1999) commended by chelators known as siderophores (Neilands 1995; Jin et al. 2014). For example, pyoverdine, a type of siderophore, has been reported to show affinity toward Fe^{3+} and is known to be secreted by fluorescent pseudomonads (Schalk and Guillon 2013; Chen et al. 2016). Many studies favor that microbe-mediated uptake of Fe even at very low concentration consequently enhances the agricultural productivity (Fageria et al. 2009; Saha et al. 2016b).

Micronutrient deficiency often termed as hidden hunger along with decrement in crop yields is a matter of serious concern nowadays, gaining attention worldwide and accounts for increased human mortality rate in conjunction with reduced socioeconomic development. The phenomenon of adding essential mineral elements to improve the nutritional quality of staple crops is known as biofortification which renders a sustainable eco-friendly solution to this issue of malnutrition. Biofortification technologies still need to go beyond these programs in the coming years for excelled and upgraded nutritional quality of food crops. Microorganisms are well known to be engaged in one or more direct or indirect mechanisms, and their function to improve the quality of food crops has gained attention worldwide (de Souza et al. 2015). There are many reports available which support the use of microorganisms as key biofortification agents resulting in improvement of bioavailability and concentration of micro and macronutrients content in various crops (Rana et al. 2012).

Zn is an influential micronutrient for all the living forms and is found in a range of 10–300 ppm in soil (Lindsay 1972). It is important for plants helping in photosynthesis, phytohormone activity, disease resistance, carbohydrate metabolism, gene expression, enzyme activity, seed production, protein synthesis, etc. (Jaivel et al. 2017). Approximately 50% of the soils are known to be deficient in zinc (Review 2008), and this scarcity may lead to inappropriate development of the plants (Alloway 2004). Rhizospheric microbes have shown mechanisms of zinc solubilization involving production of organic and inorganic acids and acidification, whereby they lower the surrounding pH and chelate Zn and also the anions trap Zn and enhance their solubility (Alexander 1977; Jones and Darrah 1994). Production of siderophores, protons and oxido-reductive reactions on cell membranes and trapped ligands also solubilize Zn (Wakatsuki 1995; Chang et al. 2005).

Manganese is another essential micronutrient that participates in the photosynthetic proteins and enzymatic structure. It influences the water splitting PS II complex that is known to supply electrons for photosynthesis, and thereby its deficiency can be detrimental for chloroplasts (Millaleo et al. 2010). The oxidized form of Mn (Mn^{4+}) is unavailable to plants, while the reduced form (Mn^{2+}) is utilized for plant processes (Rengel 2014). The reduction of Mn is chiefly based upon occurrence of electron-carrying reducing agents and presence of protons. Arbuscular mycorrhizal fungi (AMF) are known to facilitate Mn reduction making it available to the plants (Cely et al. 2016; Chen et al. 2017).

9.2.2 Combating Phytopathogens

Phytopathogens are known to be present with plants in the rhizosphere from the very genesis of agriculture. FAO (2015) reported 20–40% annual reduction of the global crop yield caused by pests and plant diseases. Application of chemical pesticides during green revolution had exacerbated the scenario by addition of xenobiotics such as DDT and methyl parathion, which are still persisting in the soil as nondegradable moieties (Singh and Arora 2016). Thus, the concept of next green revolution cannot be enacted until this issue is mitigated through sustainable approaches. Microbial inoculants have shown influential results in sublimating phytopathogenic biotic stress and reclaiming the quality and quantity of agricultural production (Arora et al. 2007; Mishra et al. 2015). The offensive biocontrol strategies enabled by microbes include synthesis of allelochemicals, niche exclusion, and competition for nutrients. Antibiosis is the major biocontrol mechanism gaining popularity over the last two decades. Antibiosis operating cascade involves GacA/GacS or GrrA/GrrS, RpoD, and RpoS, *N*-acyl homoserine lactone derivatives for quorum sensing (Bloemberg and Lugtenberg 2001; Haas and Keel 2003). Antibiotics produced include pyoluteorin, pyrrolnitrin, tensin, tropolone, 2,4-diacetylphloroglucinol (DAPG), zwittermicin A, kanosamine, cyclic lipopeptides, oomycin A, DDR, viscosinamide, butyrolactones, N-BBS, pantocin A and B (Bhattacharyya and Jha 2012), etc. Microbes also cause biocontrol through production of cell wall-hydrolyzing enzymes such as chitinase, laminarinase, cellulase, protease or proteinase, and glucanase (Jadhav and Sayyed 2016). These enzymes show inhibitory activity against oomycetes and fungal sporulation and mycelial extension (Saraf et al. 2014). Similar to the regulatory mechanism of antibiotics, lytic enzymes also are controlled by GacA/GacS or GrrA/GrrS (Sacherer et al. 1994; Corbell and Loper 1995). Apart from these, microbes suppress the pathogens by producing toxic secondary metabolites such as HCN (Mishra et al. 2015; Tewari and Arora 2016), δ-endotoxins or Cry protein (Loper and Gross 2007; López-Pazos et al. 2009), exopolysaccharides (Tewari and Arora 2014a), biosurfactants (Banat et al. 2010), microbial components including homoserine lactones, flagella, lipopolysaccharides, and volatiles like acetoin and 2,3-butanediol (Lugtenberg and Kamilova 2009; Ahemad and Kibret 2014). δ-Endotoxins or Cry protein show toxic influence upon ingestion by various classes of insects/nematodes including Lepidoptera, Diptera, Coleoptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, Siphonaptera, and Thysanoptera (Schünemann et al. 2014). Exopolysaccharides produced by beneficial microbes protect them from pathogens through their bio-filming ability, protecting in a hydrated and nutrient-rich local environment. Biosurfactants are amphiphilic low molecular weight surface-active compounds that are important for reducing surface tension at air/water interface and interfacial tension at oil/water interfaces (Sachdev and Cameotra 2013). Biosurfactants form channels in pathogens' cell wall and disturb their cell surface properties (Raaijmakers et al. 2006). Rhamnolipids and cyclic lipopeptides are the best-known biocontrol biosurfactant types (Debode et al. 2007). Another mechanism of biocontrol reported by microbes is triggering of induced systemic resistance (ISR) in plants. Triggered ISR in plants leads to increased cell wall protection; alteration of physiological and metabolic pathways to enhance synthesis of biocontrol-active compounds in plants, for example, phenolic compounds at the site of infection; and formation of structural barriers with heavy deposition of callose to restrict entry of pathogens. ISR also challenges the pathogen via higher accumulation of pathogenesis-related proteins (PR proteins) or even peroxidase, phenylalanine ammonia lyase, phytoalexins, polyphenol oxidase, and/or chalcone synthase as defensive compounds (Compant et al. 2005). The other way of microbial biocontrol is nutrient chelation (like Fe), through production of siderophores which chelate the ferric ion, depriving the pathogenic fungi of the micronutrient as fungal siderophores show low affinity toward iron, also solubilization of phosphorous and zinc by beneficial microbes depriving the pathogens of these nutrients (Whipps 2001; Compant et al. 2005). Niche exclusion is another mechanistic approach of beneficial microbes in excluding the pathogens from the rhizosphere and inhibiting their pathogenesis (Pathak et al. 2017).

9.2.3 Amelioration of Abiotic Stress

Dynamics in climate has inflicted agriculture due to soil erosion, inception of marginal lands, loss of pioneer or keystone species, compromised quantitative and qualitative crop yield, and soil contamination and infertility. Catalyzing the scenario, anthropogenic activities have a menacing effect and result in and shrinking of fertile lands. The State of the World's Land and Water Resources for Food and Agriculture (SOLAW 2011) flagged the warning that almost 25% of the global land has been totally degraded, 8% being in the moderate, 38% stable or slightly, and 10% as improving. Coming up with eco-friendly strategy is the exigency to restrain the land loss and ameliorate the quality of soil. Microbial inoculations have emerged as a promising trend in uplifting the quality of soil in comparison to chemical fertilizers (Carvajal-Muñoz and Carmona-Garcia 2012).

Abiotic stresses are the major problems faced by the world limiting the productivity of agriculture. Various abiotic stresses include salinity, drought, flood, pH, and temperature which challenge the growth of plants and fertility of soil. Microbial inoculants have paved their way in ameliorating the aforementioned stresses ensuring the food security. Microbes influence the biological, physical, and chemical properties of soil by forming stable aggregates with pore spaces trapping water and nutrients under healthy and stressed conditions (Helliwell et al. 2014).

Salinity is a major global problem degrading 240,000 square miles of land, with loss of 7.7 square miles of land in arid and semiarid areas every day (Qadir et al. 2014). Saline conditions induce various physiological and biochemical changes in plants and render the soil infertile for cultivation. The adverse salinity symptoms include osmotic imbalance, reduced photosynthetic rate, inhibited seed germination, ethylene stress, disturbed microbial population and plant-microbe interactions, Na^{+} toxicity, Ca^{+2}, K^{+} deficiency, and oxidative stress due to reactive oxygen species (ROS) (Wang et al. 2016a, b; Negrão et al. 2017; Mishra et al. 2017). Microbes have shown tolerance against salinity and have been reported as ameliorators of stressed plants and soils. The initial stress-combating strategy includes efflux of Ca^{+2}, K^{+} by synthesis of compatible solutes/osmoregulators such as soluble sugars, amino acids and derivatives, and tetrahydropyrimidines (Arora et al. 2006; Fernandez-Aunión et al. 2010; Tewari and Arora 2013). Osmoregulators stabilize the osmotic balance across the membrane, maintain the turgor pressure, and ensure the correct folding of proteins (Kim et al. 2014; Mishra et al. 2018). In addition, under saline conditions, EPS-producing bacterial inoculants encounter Na^+ toxicity by immobilizing the ions stabilizing the soil ionic balance. Additionally, these biopolymers aggregate soil particles trapping water molecules, hydrating soil, and maintaining water retention capacity under salinity stress (Sandhya et al. 2009; Tewari and Arora 2014a, b). EPS-producing fungi are also responsible for mitigating stress constraints by entangling and enmeshing soil particles in macroaggregates formed through EPS adhesion or hyphal networks (Bossuyt et al. 2001). AMF modify the soil structure through production of a glycoprotein glomalin, adept at increasing hydrophobicity and forming soil aggregates with attachment sites and chelated nutrients (Rillig et al. 2002; Rillig and Mummey 2006; Wright and Anderson 2000). Ethylene stress in plants under saline conditions is mitigated through the synthesis of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which acts as a sink to ACC (a precursor to ethylene), thus mitigating the senescence-related problems in plants (Saleem et al. 2018).

Drought has recently been a recurrent phenomenon due to increasing climate change and related anthropogenic activities. Drought restricts the growth of plants and fertility of soil leading to major productivity loss across the globe. Drought disturbs the plant water potential, impairs seed germination, stunted root and shoot growth, lowered water and nutrient content in plants and soils, disturbed C/N ratio, loss in population of beneficial microbes, etc. (Geng et al. 2017; Fahad et al. 2017). Microbial inoculants facilitate the amelioration of drought stress by production of cytokinin, antioxidants, ACC deaminase, EPS, and other growth-associated metabolites. Cytokinins increase the abscisic acid (ABA) content of plants which further closes the stomata to reduce foliar water loss (Ngumbi and Kloepper 2014). ACC deaminase acts in a way similar to that discussed in salinity stress. Antioxidants act in reducing the damaging effects of ROS, thus securing the cell, membranes, and biomolecules (Grover et al. 2011). EPS produced by microbes help in maintaining the hydrological balance of the soil through aggregation of soil particles trapping water molecules, thereby increasing nutrient uptake (Sandhya et al. 2009). Molecular mechanism behind the tolerance includes upregulation of marker drought response genes (Gagné-Bourque et al. 2015).

Flooding is another abiotic stress faced globally, negatively impacting the growth and yield of lands and plants. Waterlogging causes anoxia in the plant rhizosphere leading to stomatal closure, reduced photosynthesis, stunted growth, and shutdown of oxidative phosphorylation leading to anaerobic fermentation (Liao and Lin 1994). Inoculation with microbes has shown adaptive stratagem supporting growth of plants even under anoxic conditions. The tolerance mechanisms include synthesis of ACC deaminase to sink ethylene, use of rhizobia to support nodulation and nitrogenase activity as they can use nitrogenous oxides as terminal electron acceptor and enhance nodule formation, and trapping of nutrients where mycorrhizal associations have found to spread their mycelial extensions increasing the absorption power of roots (Harley and Smith 1983; Tewari and Arora 2016).

Global warming and related anthropogenic activities have altered the temperature of the earth with a much hotter climate and the temperature continuing to increase. With lesser rainfall, increasing temperature has given rise to the problem of heat stress. Under the stress condition, soils lose their water due to excessive evaporation and get prone to erosion by wind and water. Plants also show attenuated growth due to lowered water and nutrient uptake, impaired photosynthesis, and increased leaf senescence (Fahad et al. 2017). To promote growth of plants and to revive the fertility of soils, microbes have been a sustainable solution configuring the tolerance mechanism. Microbes induce production of osmoregulants to regulate the osmotic equilibrium across the membranes preventing plasmolysis and increased synthesis of heat shock proteins (HSPs) which could tolerate temperature stress and regulate the biological enzymatic mechanisms. HSPs like chaperons instruct the correct folding of proteins ensuring the proper enzymatic functioning of plants/microbes even under high temperature stress (Münchbach et al. 1999; Ali et al. 2014) and accumulation of trehalose to protect against thermal injury and fungi; trehalose inhibits protein denaturation and supports aggregation maintaining the normal conformation under stressed conditions. Contrasting to heat stress, cold stress is also a climatic extremity which adversely effects the growth of plants. At lower temperatures cellular metabolism of plants disrupts, destabilizing the membrane fluidity and nucleic acids leading to incorrect transcription, translation, and degradation (Phadtare 2004). Under such conditions, cold-tolerant microbes can be inoculated to counteract the adversity. Tolerance mechanisms of cold-tolerant microbes include increased concentration of unsaturated fatty acids in cell membrane to enhance the fluidity (Vorachek-Warren et al. 2002), cold shock proteins (CSPs) like chaperons ensuring the correct folding of proteins, normal RNA metabolism (Barria et al. 2013) and accumulation of trehalose (Li et al. 2009).

pH stress is another challenge which limits the productivity of agriculture. Extremities in pH lead to abnormal growth and respiration rate, loss of beneficial plant-microbe interactions, reduced chelation of nutrients, and loss of essential anions (Sakano 2001). Shift from normal pH shows substantial changes in gene expression and cell biochemistry mediated by pH-sensitive cellular signaling cascades (Arst and Peñalva 2003). Microbes initiate the adapting responses to support growth even under stressed environment. Halophilic or alkaliphilic bacteria get adapted to high alkalinity by retaining their cellular pH in the surrounding of 9–11. Controlling their metabolic activities, these alkaliphilic microbes use proton transfer systems in their cytoplasm to maintain osmotic balance and cellular vitality (Horikoshi 1999; Torbaghan et al. 2017). With the onset of pH stress, microbes start producing enzymes supporting their tolerance and growth. AMF extend their hyphae to absorb more nutrients and also protect the roots of plants securing from stress (Chen et al. 2006). Biofilming/flocculation (composed of EPS) is also a mechanism by which microbes form a local environment protecting from outer pH extremes.

9.3 Microbe-based Inoculant Types

Microbial inoculants contain agriculturally advantageous microorganisms which due to their plant growth-promoting attributes, better tolerance under adverse conditions, and eco-friendly nature (unlike their chemical counterparts) are playing significant roles in crop production in a sustainable way (Vessey 2003). A wide range of beneficial microbial diversity (*Bacillus*, pseudomonads, rhizobia, blue-green algae, *Trichoderma*, mycorrhiza, endophytes, etc.) are now being used as bioinoculants (Sarma et al. 2015; Egamberdieva et al. 2018). The indispensable properties of such green inoculants have now been commercialized successfully in the market, and they are being exploited as biofertilizers and biopesticides with no harmful effects (Malusá et al. 2012). According to the reports of Market Data Forecast (2018), the current market of microbial soil inoculants at global level has been stated up to USD 396.07 million in 2018 and is expected to rise at annual growth rate of 9.5% to reach the projection of USD 623.51 million by 2023 (www.marketdataforecast.com/market-reports/microbial-soil-inoculants-market-5373/). Various kinds of bioinoculants are being used nowadays such as solid or liquid with bacterial or fungal cells or both, pure culture, and consortia- and metabolite-based (Reddy and Saravanan 2013; Mishra and Arora 2016). The seeds are either bioprimed with microbial suspension followed by air-drying, inoculant is film coated on the surface of the seed, or the seeds are pelleted with the help of additives (O'Callaghan 2016). Some of inoculants being used nowadays with their mechanism of action are mentioned in the table with their key constitutional microbial communities (Table 9.1). However, a tripartite interaction between the microbiota, the soil, and the host is of utmost importance for a microbial inoculant to be better adapted to field conditions in order to ensure growth-promoting effects on plants (Baez-Rogelio et al. 2017). Therefore, detailed dynamics of the interaction and the mass production of bioinoculant plays a crucial role and serves as a prerequisite in order to understand the fate of the microbe in field conditions (Terrazas et al. 2016). The section describes various bacterial, fungal, and other types of microbe-based inoculants that are being successfully used in market as biofertilizers and biopesticides along with suitable examples of plant growth promotion (Table 9.2), hence confirming them as stepping stones for next green revolution, achieving the demand of sustainability of agroecosystems.

9.3.1 Bacterial Inoculants

At present, bacterial-based bioformulations are flourishing in comparison to other types of inoculants and are dominating the industry of microbe based formulations. Major bacterial inoculants contain genera of PGPR such as rhizobia, *Azotobacter*, *Azospirillum*, *Pseudomonas*, *Acetobacter*, *Herbaspirillum*, *Burkholderia*, and *Bacillus* (Glick 1995; Probanza et al. 1996; Artursson et al. 2006; Adesemoye and Kloepper 2009). Rhizobiaceae comprise of a group of Gram-negative diazotrophic rhizobacteria, and have been well recognized as efficient nitrogen (N_2) fixers by

Table 9.1 Mechanisms of plant growth promotion by microbes

S. no	Mechanisms involved	Associated microbes	Role in agriculture	References
Direct plant growth promotion				
Phytohormone production				
1.	Auxin	*Bacillus*, *Bradyrhizobium*, *Enterobacter cloacae*, *Paenibacillus*, *Rhizobium*, *Azospirillum brasilense*, *A. lipoferum, P. fluorescens*, *P. chlororaphis*, *P. auruginosa*, *Saccharomyces cerevisiae*, *B. megaterium*, *B. marinus*, *Sphingomonas* sp., *Microbacterium* sp., *Mycobacterium* sp., *Piriformospora indica*	Modifies the structure of plant roots inducing branching of roots and root hair formation, promotes growth of plants by enhancing nutrient and water uptake	Tsavkelova et al. (2005), Sirrenberg et al. (2007), Spaepen and Vanderleyden (2011), Mohite (2013) and Xu et al. (2014)
2.	Gibberellic acid (GA)	*Pseudomonas monteilii*, *Azotobacter* spp., *Pseudomonas* spp., *Sphaceloma*, *Neurospora*, *Phaeosphaeria*, *P. fluorescens*, *B. subtilis*, *P. stutzeri*, *Stenotrophomonas maltophilia*, *P. putida*, *Rhizobium* spp., *Bradyrhizobium japonicum*, *Mesorhizobium loti*, *Sinorhizobium fredii* and *Rhizobium etli*, *Acetobacter diazotrophicus* and *Herbaspirillum seropedicae*	GAs initiate various developmental processes in plants including stem elongation and germination increasing plant growth and yield	Karadeniz et al. (2006) and Sivasakthi et al. (2013), Pandya and Desai (2014), Ambika et al. (2015), Desai (2017), Patel and Saraf (2017) and Salazar-Cerezo et al. (2018)
3.	Cytokinins	*Azotobacter* spp., *Rhizobium* spp., *Pantoea agglomerans*, *Rhodospirillum rubrum*, *P. fluorescens*, *B. subtilis*, *P. polymyxa*	Promote growth of plants under various conditions by maintenance of diverse aspects including embryogenesis, development of roots and shoot meristems, nodule formation, apical dominance	Glick (2012), Dawwam et al. (2013), Olanrewaju et al. (2017) and Numan et al. (2018)

Nutrient assimilation				
1.	N_2 fixation	Rhizobia spp., *Azospirillum* spp., *S. meliloti*, *R. leguminosarum*, *Bradyrhizobium* sp., *Pantoea*, *Bacillus*, *Klebsiella*, *Gluconacetobacter diazotrophicus*, *Rhizobium etli*, *P. putida*, *Azotobacter*	Helps in fixing of nitrogen for plants increasing their growth and nodulation and also maintaining the fertility of soil	Helman et al. (2011), Glick (2012) and De Souza et al. (2015)
2.	Phosphate (P) chelation	*P. fluorescens*, *B. megaterium*, *Enterobacter*, *Pantoea*, *Klebsiella*, *Rhodococcus*, *Arthrobacter*, *Serratia*, *Chryseobacterium*, *Gordonia*, *Phyllobacterium*, *Delftia*, *Kushneria*, *Aspergilli*, *Penicillium*, *Sinomonas*, *Thiobacillus*, *Achrothcium*, *Alternaria*, *Arthrobotrys*, *Aspergillus*, *Cephalosporium*, *Cladosporium*, *Curvularia*, *Cunninghamella*, *Chaetomium*, *Glomus*, *Helminthosporium*, *Micromonospora*, *Mortierella*, *Myrothecium*, *Oidiodendron*, *Paecilomyces*, *Penicillium*, *Phoma*, *Pichia fermentans*, *Populospora*, *Saccharomyces*, *Schizosaccharomyces*, *Schwanniomyces*, *Sclerotium*, *Torula*, *Trichoderma*, and *Yarrowia*	Availing P to plants, supporting their growth and metabolism and also enriching the quality of soil	Postma and Lynch (2010), Zhu et al. (2011), Tajini et al. (2012), Srinivasan et al. (2012), Sharma et al. (2013), Zhao et al. (2014), David et al. (2014), Istina et al. (2015) and Adnan et al. (2017)

(continued)

Table 9.1 (continued)

S. no	Mechanisms involved	Associated microbes	Role in agriculture	References
3.	Potassium (K) solubilization	*B. mucilaginosus*, *B. circulanscan*, *B. edaphicus*, *Burkholderia*, *A. ferrooxidans*, *Arthrobacter* sp., *Enterobacter hormaechei*, *Paenibacillus mucilaginosus*, *P. frequentans*, *Cladosporium*, *Aminobacter*, *Sphingomonas*, *Paenibacillus glucanolyticus*	The availability of potassium to plants adjusts the osmotic balance under stress, promotes photosynthesis, and also enhances productivity of soil	Zhang and Kong (2014), Ahmad et al. (2016), Setiawati and Mutmainnah (2016), Meena et al. (2016) and Etesami et al. (2017)
4.	Iron chelation (siderophore production)	*Acinetobacter baumannii*, *P. aeruginosa*, *Staphylococcus aureus*, *K. pneumoniae*, *E. coli*, *Bacillus spp.*, *Rhizobium*, *Serratia*, *Mycobacterium*, *Nocardia*, *Rhodococcus*, *Streptomyces* spp., *Enterobacteriaceae*, *Arthrobacter* spp., *P. stutzeri*	Chelated Fe is used by plants and microbes for their metabolic actions, acts as catalyst in various biological processes and also helpful for biofilm formation leading to stress tolerance under various inhospitable conditions	Ahmed and Holmström (2014) and Saha et al. (2016b)
5.	Other micronutrients	*Anabaena*, *Trichoderma asperellum*, *Providencia* sp., *B. juncea*, *Pseudomonas*, *Rhizobium*, *Azotobacter*, *Azospirillum*	Enhance the nutrition level of plants for their better growth and biofortified products	Yaseen et al. (2013), Adak et al. (2016) and Garg et al. (2018)
Other metabolites				
1.	Exopolysaccharides (EPS)	*P. fluorescens*, *E. hormaechei*, *P. migulae*, *Rhizobium* sp., *P. polymyxa*, *Azotobacter vinelandii*, *Xanthomonas* sp., *Azotobacter*, *P. anguilliseptica*, *Ganoderma lucidum*, *Agaricus blazei*, *Cordycep* ssp., *Lentinus edodes*, *Grifola frondosa*, *P. tenuipes*	Help in tolerance under various stress conditions by regulating osmotic balance, water and nutrient content	Selbmann et al. (2003), Mahapatra and Banerjee (2013), Viscardi et al. (2016), Niu et al. (2017) and Mohammed (2018)

2.	Biosurfactant	*Bacillus sp.*, *B. subtilis*, *B. licheniformis*, *P. aeruginosa*, *S. aureus*, *E. coli*, *B. amyloliquefaciens*, *Penicillium*, *Candida bombicola*, *Candida lipolytica*, *C. ishiwadae*, *C. batistae*, *A. ustus*, *Ustilago maydis*, *Trichosporon ashii*	Help in amelioration of heavy metal polluted soils and promote growth of plants	Bodour et al. (2003), Nitschke et al. (2005), Bhardwaj et al. (2013), Rajesh et al. (2017), Prasad et al. (2018) and Sena et al. (2018)
Indirect plant growth promotion				
1.	HCN	*Bacillus* sp., *Paenibacillus* sp., *B. thuringiensis*, *P. stutzeri*, *Staphylococcus* sp., *Pseudomonas* sp.	Shows antagonism against various phytopathogens including *Rhizoctonia solani*, *F. oxysporum*, *F. proliferatum*, *F. graminearum*, *Colletotrichum capsici*, *P. syringae* pv. *syringae* z1, *P. syringae* pv. *coronafaciens* z1238, *Erwinia carotovora* pv. *carotovora* z87, *Xanthomonas campestris* pv. *campestris* z1352, *Macrophomina phaseolina*	Passari et al. (2016), Rijavec and Lapanje (2016) and Tewari and Arora (2016)
2.	Antibiotic production	*P. fluorescens*, *P. chlororaphis*, *Penicillium*, *Pseudomonas* sp., *P. aeruginosa*, *P. brassicacearum*, *P. protegens*, *B. cepacia*, *Serratia plymuthica*, *Ochrobactrum intermedium*, *Pantoea ananatis*, *P. agglomerans*, *B. cereus*, *B. thuringiensis*, *Trichoderma*, *Aspergillus*	A wide array of antibiotics suppress phytopathogens and indirectly help in plant growth promotion	Mavrodi et al. (2012) and Kawaguchi and Inoue (2012), Wang et al. (2015, 2016a, b), Pandey et al. (2018), Sun et al. (2016), Cheng et al. (2016) Zhou et al. (2016) and Yao et al. (2015)

(continued)

Table 9.1 (continued)

S. no	Mechanisms involved	Associated microbes	Role in agriculture	References
3.	Bacteriocins	*B. cereus*, *B. thuringiensis*, *B. clausii*, *B. subtilis*, *B. licheniformis*, *P. putida*, *Lysinibacillus*	Help in suppression of phytopathogens including *Agrobacterium tumefaciens*, *Candida tropicalis*, *A. solani*, *A. niger*, *A. fumigatus*, *A. flavus*, *Cryphonectria parasitica*, *Monilia sitophila*, *M. hiemalis*, *P. digitatum*, and *Rhizopus* sp.	Smitha and Bhat (2013), Grinter et al. (2012), Mouloud et al. (2013) and Subramanian and Smith (2015)
4.	Lytic enzymes	*S. plymuthica*, *Paenibacillus* sp., *Streptomyces* sp., *B. cepacia*, *S. marcescens*, *Lysobacter enzymogenes*	These enzymes help in hydrolysis of various polymers of pathogens reducing their virulence factor suppressing their pathogenic activity directly	Singh and Singh (1989), Frankowski et al. (2001) and Pal and McSpadden (2006)
5.	δ endotoxins or Cry protein	*B. thuringiensis*	Suppresses disease and yield loss by controlling caterpillars, beetles, mosquitoes, blackflies, lepidopteran, coleopteran, and some homopteran pests	Loper and Gross (2007), López-Pazos et al. (2009), Palma et al. (2014), Rubio-Infante and Moreno-Fierros (2016) and Mukhija and Khanna (2018)
6.	Volatile organic compounds (VOCs)	*P. fluorescens*, *B. amyloliquefaciens*, *B. megaterium*, *P. protegens*	Inhibit the growth of disease-causing fungi (*R. solanacearum*, *F. oxysporum* f. sp. *cubense*, *S. sclerotiorum*, *Aspergillus*, *Penicillium* spp.)	Yuan et al. (2012), Giorgio et al. (2015), Manaa and Kim (2018) and Van Agtmaal et al. (2015)
7.	Induced systemic resistance (ISR)	*Bacillus*, *S. marcescens*, *Burkholderia phytofirmans*, *P. denitrificans*, *P. putida*, *P. fluorescens*	Triggering of ISR in plants by microbes activates their defense system and helps in combating phytopathogens	Compant et al. (2005), Choudhary et al. (2007) and Beneduzi et al. (2012)

8.	Biosurfactants	*Ustilago maydis*, *Candida bombicola*, *B. subtilis*, *B. licheniformis*, *B. amyloliquefaciens*, *B. atrophaeus*	The antibacterial and antifungal activities of CLPs (cyclic lipopeptides) are effective against phytopathogens including *Colletotrichum dematium*, *R. solani*, *P. ultimum*, *F. graminearum*	Yu et al. (2002, D'aes et al. (2010) and Sarwar et al. (2018)
9.	Exopolysaccharides (EPS)	*Burkholderia gladioli*, *Bacillus*, *Pseudomonas*, *P. polymyxa*	EPS forms a protective biofilm layer across the plants and microbes protecting from pathogens and also chelate nutrients	Haggag (2010) and Upadhyay et al. (2011)
10.	Niche and nutrient exclusion	Pseudomonads, *Bacillus*, *Fusarium*, *Trichoderma* species, *Cladorrhinum foecundissimum*, *Glomus intraradices*, *Idriella bolleyi*, *Pythium mycoparasiticum*, *Trichoderma hamatum*, *T. virens*	Excludes availability of nutrients (N, P, K, Fe) and increase niche competition inhibiting the growth of phytopathogens	Whipps (2001), Winding et al. (2004) and Hibbing et al. (2010)

Table 9.2 Various microbe-based inoculants available throughout the globe and their roles

S. no	Name of bioinoculants	Associated microbes	Applications	References
Fungal inoculants				
1.	PlantShield®	*Trichoderma harzianum* Rifai strain KRL-AG2	Used as a biopesticide against *Fusarium*, *Pythium*, and *Rhizoctonia*	https://ohioline.osu.edu/factsheet/SAG-18
2.	Bioten WP; Tenet WP; Remedier WP	*T. gamsii* strain ICC 080	Fungicide controlling soilborne pathogens	BRAD (2010)
3.	Nutri-Life Root-Guard™	*Arthrobotrys conoides*, *Purpureocillium lilacinus*, and *Pochonia chlamydosporium*	Bio-balancer maintaining the ratio of beneficial and detrimental organisms in the root zone	http://www.nutri-tech.com.au/
4.	Polyversum® and Technical DV 74	*Pythium oligandrum* DV 74	Used as fungicide for many food crops, ornamental plants, and turfs acting against almost 20 pathogenic fungi including *Alternaria*, *Botrytis*, *Fusarium*, etc.	https://www3.epa.gov/
5.	BioMal WP (22359)	*Colletotrichum gloeosporioides* f.sp. *Malvae*	As a herbicide to control round-leaved mallow infection in crops	PMRA (2006)
6.	Acceleron® B-300 SAT and JumpStart®	*Penicillium bilaiae*	Increases plants ability to uptake nutrients significantly increasing yield of corns by an average of 3 bushels per acres, stress tolerance	Novozymes® https://www.novozymes.com/
7.	Ambiphos	*Aspergillus niger*	Chelates undissolved phosphorous and makes it available to plants	Ambika Biotech & Agro Services, Madhya Pradesh; Pal et al. (2015)
8.	Met52 EC and Met52/BIO1020	*Metarhizium anisopliae*	Efficient biological insecticides used for control of ticks, whiteflies, and black vine weevil (pests), applicable for many crops	Novozymes® https://www.novozymes.com/

9.	MycoUp Activ, MycoUp, Resid HC, Resid MG	*Glomus iranicum* var. *tenuihypharum* var. nov.	Intensifying mycorrhizal colonization, nutrient and water from soil, resistance against external stressing factors, much efficient under saline conditions and deteriorated lands	Symborg http://www.symborg.com/
10.	GlioMix	*Gliocladium* fungi	Improving seedling emergence and promoting plant growth, stress tolerance, and protection against plant diseases	Vedara http://verdera.fi/
11.	TRICHOSOIL	*T. harzianum*	Prominent efficacy against *Rhizoctonia*, *Pythium*, *Sclerotium* (damping-off complex), *Sclerotinia*, and *Botrytis* phytopathogens	Lage y Cía. S.A http://www.lageycia.com/
Bacterial inoculants				
1.	MON 89034	*B. thuringiensis* Cry1A.105, and Cry2Ab2 insecticidal protein	Plant-incorporated protectant used to target pests such as *Ostrinia nubilalis*, *Diatraea grandiosella*, *D. crambidoides*, *Helicoverpa zea*, *Papaipema nebris*, *D. saccharalis*, *Spodoptera frugiperda*	BRAD (2008)
2.	Nutri-Life B.Sub™	*B. subtilis*	Aids in plant growth promotion and production of phytoalexins	http://www.nutri-tech.com.au/
3.	Siron	Iron- and sulfur-mobilizing bacteria	Conversion of insoluble S and Fe to absorbable forms, aids in balancing the soil pH, increase in flowers, fruits, grains number and size, stimulating plant respiration processes	International Panaacea Ltd. (http://www.iplbiologicals.com/)
4.	Novodor Flowable Concentrate (24068)	*B.thuringiensis* subsp. *Tenebrionis*	Biocontrol action against Colorado potato beetle larvae on potatoes and tomatoes and elm leaf beetle	PMRA (2006)
5.	Actinovate®	*Streptomyces lydicus WYEC 108*	Biofungicide against powdery mildew, *Botrytis*, *Pythium*, *Rhizoctonia*,	Novozymes® https://www.novozymes.com/

(continued)

Table 9.2 (continued)

S. no	Name of bioinoculants	Associated microbes	Applications	References
			Fusarium, *Phytophthora*, *Verticillium*, potential siderophores, and chitinase producer complementing plant growth	
6.	Mycostop®	*Streptomyces* ray bacteria isolated from Finnish Sphagnum peat	Biocontrol against damping-off, wilt, and root diseases caused by *Fusarium*, *Phytophthora*, *Alternaria*, and *Pythium* fungi, also resistive against *Rhizoctonia* sp. and *Botrytis* sp. phytopathogens, promotes growth and yield of crops	Verdara http://verdera.fi/ www.lallemand.com/
7.	VitaSoil WP	Selected rhizosphere microorganisms (unspecified)	Helping in recycling nutrients in infertile soils, stimulating biological regeneration, applicable for horticultural crops, strawberry, maize, cereals, and woody plants	Symborg http://www.symborg.com/
8.	Rizos®	*B. subtilis* UFPEDA 764	Stimulates metabolite production affecting germination, larger radicular growth, improved plant's resistance to stress, enhanced yield	Lallemand http://labfarroupilha.com/
9.	Onix®	*B. methylotrophicus* UFPEDA 20	Elevating plant growth and yield even under stress conditions	Lallemand http://labfarroupilha.com/
10.	Azos®	*A. brasilense* abv-5	Decreases the concentration of ethylene of leaf boosting photosynthetic activity, increases water and nutrient absorption, provides resistance against water stress	Lallemand http://labfarroupilha.com/
11.	LIKUIQ® + ADD-IT AZUL	*Bradyrhizobium elkanii* strains	Specific for soybean, increases adhesion of rhizobia to seed promoting the infection of plant's roots	Lage y Cía. S.A. http://www.lageycia.com/

12.	*GRAMINOSOIL*	*Azospirillum*	Efficient in plant growth promotion of maize, sorghum, and wheat crops	Lage y Cía. S.A. http://www.lageycia.com/
Genetically modified organisms (GMOs)				
1.	Transgenic soybean	*Agrobacterium tumefaciens* strain CP4	Herbicide tolerance conferred by expression of 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) isolated from the bacterium	Phillips (2008)
2.	Corn	*Bacillus thuringiensis*	Tolerance to insect pests due to expression of insecticidal protein Cry1Ab	
3.	Plum	Virus	Resistance to plum pox virus through incorporation of coat protein gene	
4.	Phytaseed™ Canola (MPS 961-965)	*Azospirillum brasilense*, *Azotobacter vinelandii* along with bacterial genes (*idi*, *crtE*, *crtB*, *crtI*, *crtY*, *crtW*, and *crtZ*)	Engineered for phytase degradation for enhancement of phosphorous level	Yu et al. (2008) and Fujisawa et al. (2000)
5.	Sorghum	*Azospirillum*, arbuscular mycorrhizal fungi	Improvement of N and P status to increase the yield	Patidar and Mali (2004) and Faten et al. (2016)
6.	Chickpea	Arbuscular mycorrhizal fungi	Helps in chelation of Fe, Zn, Ca, Cu, Mn, and Mg	Pellegrino and Bedini (2014)
Other microbe-based inoculants				
1.	Madex	Granulosis viruses	Active in pest control against *Cydia pomonella*	Erayya et al. (2013)
2.	Gypcheck	Nuclear polyhedrosis viruses	Shows biocontrol action against *Lymantria dispar*	Erayya et al. (2013)
3.	Multiplex Nalapak	Consortia of *Azotobacter* + *Azospirillum* + phosphate solubilizer + potash mobilizer	Promotes plant growth by production of phytohormones IAA, GA, and cytokines; also improves the quality of soil	Multiplex Bio-Tech Pvt. Ltd., Karnataka; Pal et al. (2015)
4.	QuickRoots®	*B. amyloliquefaciens* and *T. virens*	Microbial seed inoculant enhancing availability of N and K to stimulate expanded roots increasing growth and yield of plants	Novozymes® https://www.novozymes.com/

(continued)

Table 9.2 (continued)

S. no	Name of bioinoculants	Associated microbes	Applications	References
5.	Accomplish®	Viable microorganisms plus enzymes, organic acids, and chelators	Increasing availability of nutrients stimulating root size and branching	Loveland Products, Inc. García-Fraile et al. (2015)
6.	Micro-Blaze® Emergency Liquid Spill Control	Biosurfactant-producing microbes (unspecified by manufacturers)	Used as bioremediation agent degrading hydrocarbons, pollutants, and other organic wastes	http://micro-blaze.com/
7.	Micro-Blaze® AGRO	Spore-forming microbes (unspecified by manufacturers)	Improving root zone and increasing uptake of moisture and nutrients (N and P) for better plant growth, degradation of toxic chemicals, prevention of diseases	http://micro-blaze.com/
8.	Arka Microbial Consortium	NPK chelating microbes (unspecified)	Early seed germination, increased seedling vigor, yield increase of plants, increased N, P, K availability	http://www.iihr.ernet.in/

establishing a symbiotic and mutualistic relationship with leguminous plants (Sessitsch et al. 2002). Rhizobia have been known to be used as biofertilizers with crops since more than a century (Arora et al. 2017). Nobbe and Hiltner (1896) patented "Nitragin," the first biofertilizer in the market, followed by a number of microbial products containing rhizobia as a prime constituent (Arora et al. 2017). There have been many studies that reported to substantiate the role of live rhizobial-containing inoculants as a valuable option to be used with legumes instead of chemical N fertilizers (Arora et al. 2010). Biofertilizers witnessed substantial growth and have been projected to reach up to USD 2653.48 million by 2023 at an annual growth rate of 14.42%. Nitrogen fixers as bioinoculants cover the highest share in market among other biofertilizers and accounted up to 73% in 2017 with highest market in North America (www.marketresearchfuture.com/reports/bio-fertilizers-market-1386). In various countries, liquid formulations of free-living nitrogen-fixing bacteria *Azotobacter* and *Azospirillum* including cyanobacteria have also been commercialized (Vendan and Thangaraju 2006). In the future we need to further explore the role and enhnce the share of formulations of rhizobia commercially for an eco-friendly supply of nitrogen (Arora et al. 2017). Along with the symbiotic nitrogen fixers, there is also a dense population of free-living N assimilators including pseudomonads, *Azoarcus*, *Beijerinckia*, cyanobacteria (*Nostoc* and *Anabaena*), *Klebsiella*, *Pantoea*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Herbaspirillum*, and *Gluconacetobacter diazotrophicus*, which enhance the N content of the soil-enriching productive potential of the habitat (Mehnaz et al. 2001). Karimi et al. (2018) studied the potential of *Azospirillum* species as biofertilizers on wheat plants under semiarid conditions. Results of field trials showed an increment in the yield of inoculated plants by 18% in comparison to uninoculated plants. Rawat et al. (2013) expounded that a total of 78.8 kg ha^{-1} year^{-1} N was added to soil under inoculation of *Azotobacter* and *Rhizobium* to soybean-wheat crop rotation. Soil Shakti, Soil Gold, Premium Azotolus, and Premium Azoto from International Panaacea Ltd. (IPL) are some of the N-fixing *Azotobacter* sp.-based inoculants available in market.

Phosphate-solubilizing microbial inoculants have also gained much attention and currently hold the second in market share of global biofertilizers accounting for 14.6% (Novozymes). The solubilization of rock phosphates in the culture filtrates because of production of gluconic acid, lactic acid, formic acid, citric acid, oxalic acid, 2-ketogluconic acid, and malic acid by 19 strains of phosphate-solubilizing fluorescent pseudomonads including *Pseudomonas fluorescens*, *P. poae*, *P. trivialis*, and *Pseudomonas* spp. was reported (Vyas and Gulati 2009). Some of PSB-based products marketed commercially are FOSFOSOL, containing *Penicillium janthinellium*, which is used at big scale in Colombia, and P Sol B in India that contain *Pseudomonas striata* possessing broad approach in agriculture (Moreno-Sarmiento et al. 2007).

Potassium, the third most important element required by plants, is also known to be solubilized by bacteria such as *Bacillus extroquens*, *Clostridium pasteurianum*, and *Thiobacillus* (Shanware et al. 2014). Reports show that their exopolysaccharides and inorganic and organic production are found to solubilize potassium (Groudev

1987). It is reported that India ranks fourth in the world, whereas countries like the USA, China, and Brazil are on the top in total consumption of potassium bioinoculants (Investing News Network 2015). Symbion-K, K Sol B, and BioSol-K are some bioproducts that are available in the market and are effectively known for their potassium-mobilizing ability.

Chelation of Fe by microbes has supported the inoculation of plants with iron-trapping microbes influencing the growth of plants under various habitable and stressed conditions. Many studies favor the microbe-mediated uptake of Fe, showing utilization of microbial inoculants even at low concentrations that consequently enhances the agricultural productivity (Fageria 2009; Saha et al. 2016a). Commercially available bioformulations used for uptake of Fe by plants are rare, and one of the recently recognized in India is Fe Sol B traded under Agri Life Bio Solutions (Mishra and Arora 2016).

Zn-solubilizing microbial inoculants are also widespread and are being used to improve the phytoavailability of Zn in soil and foliage with an aim to enhance yield of crops (White and Broadley 2009). *Bacillus*, *Pseudomonas*, *Gluconacetobacter*, and *Acinetobacter* are among prominent genera which are used as Zn solubilizers. Among them bacilli are the most significant candidates which are being used as Zn bioinoculants. *B. aryabhattai* MDSR7 and MDSR14 have been studied and found to increase the concentration of Zn in edible portions of soybean and wheat and can be successfully utilized as a biofertilizer or in biofortification (Ramesh et al. 2014). The study by Kamran et al. (2017) also supports the Zn solubilization by rhizobacteria comprising of *Pantoea dispersa*, *Enterobacter cloacae*, and especially *Pseudomonas fragi* to wheat resulting in increased plant biomass.

The application of microbes under biotic stress is now a popular trend to reduce the use of chemical pesticides and promote agricultural productivity. With the above discussed mechanisms of biocontrol, there are numerous reports of microbial inoculants suppressing the pathogenicity and in return providing growth-stimulating nutrients and metabolites. Microbial inoculants have successfully curbed phytopathogens such as *Sclerotium rolfsii*, *Pythium*, *Ralstonia solanacearum*, *Fusarium oxysporum*, *Rhizoctonia solani*, *Fusarium udum*, *Macrophomina* and *Phytophthora* (fungi), *Meloidogyne incognita*, *Panagrellus redivivus*, *Bursaphelenchus xylophilus*, *Heterodera glycines* (nematodes), lepidopteran, beetle, redheaded pine sawfly, and Douglas-fir tussock moth (Tian et al. 2007; Sanchez et al. 2005; Maksimov et al. 2011). Omara et al. (2017) found that combined inoculation with *Methylobacterium* strains (*Methylobacterium aminovorans* and *M. rhodinum*), *Bradyrhizobium japonicum* (St. 110), *Bacillus megaterium* var. *phosphaticum*, and *T. viride* attenuated the pathogenicity of *R. solani* in soybean seedlings and also resulted in increased nodule number, NPK %, seed index, and seed yield. In lineation, Qiao et al. (2017) propounded that inoculation of tomato with strain *B. subtilis* PTS-394 stimulated ISR in the plant through production of lipopeptides and polyketides suppressing the adversity of *F. oxysporum.* Nematicidal activity of the microbial inoculants was discussed by Xiang et al. (2017) where in vitro trials showed elevated mortality rate of *H. glycines* on inoculation of *B. velezensis* strain Bve2, *B. safensis* strain Bsa27, and

B. mojavensis strain Bmo3 to soybean plant. Antibacterial activity of 2,4 DAPG (from *Pseudomonas* sp.) against black rot causative agent *Xanthomonas campestris* pv. *campestris* (Xcc) was assessed by Mishra and Arora (2012). Chin-A-Woeng et al. (1998) opined the combating property of antibiotic, pyrrolnitrin, produced by *P. fluorescens* BL915 strain against *R. solani* in cotton plant. Multifarious approaches regarding microbial quenching of phytopathogens also include biocontrol of *Macrophomina phaseolina* using siderophore-producing *R. meliloti* and exopolysaccharide-producing fluorescent pseudomonads (Arora et al. 2001; Tewari and Arora 2016); suppression of charcoal rot of chickpea by pyocyanin-producing fluorescent pseudomonads (Khare and Arora 2010; Khare et al. 2011); antifungal potential of fluorescent *Pseudomonas* isolates PGC1 and PGC2 against *R. solani* and *Phytophthora capsici* by producing chitinase, β-1,3-glucanase, and also non-enzymatic antifungal metabolites (Arora et al. 2007); protection against *M. phaseolina* in *Mucuna pruriens* using combined inoculation with *Ensifer meliloti* RMP6 $Ery^{+}Kan^{+}$ and *Bradyrhizobium* sp. BMP7 $Tet^{+}Kan^{+}$ (Aeron et al. 2011); antagonism by *Bacillus pumilus* against *Gaeumannomyces graminis* var. *tritici* in wheat and nematicidal activity of *Azospirillum lipoferum* against *Heterodera avenae* in wheat (Bansal et al. 1999); anti-parasitism evinced by *Bacillus cereus* strain S2 against *M. incognita* (mortality rate 90.96%) and *Caenorhabditis elegans* (77.89%) (Gao et al. 2016); and enterotoxin-like binary protein-producing strain *Pseudomonas protegens* strain 15G2 exhibiting nematicidal potential against *Pristionchus pacificus*, *P. redivivus*, and *Acrobeloides* sp. (Wei et al. 2014). At global level, annual production of biopesticide is accounted for over 3000 tons and has been estimated to increase with a rate of 10% every year (Kumar and Singh 2015; Damalas and Koutroubas 2018). According to reports of Hubbard et al. (2014), over 225 microbial biopesticides are being manufactured in 30 OECD countries. On the other hand, North American Free Trade Agreement (NAFTA) countries (USA, Canada, and Mexico) have been reported to use around 45% of the biopesticides sold in the world with Asia having only 5% share (Bailey et al. 2010). Sudo-Shield™ designed using *P. fluorescens,* aids refurbishment of plants affected by damping off, rot and wilt diseases (http://www.nutri-tech.com.au/), Pest Managemnt Regulatory Agency (PMRA) registered biopesticide products (with Canadian registered number) include Dygall (21106) comprising *Agrobacterium agrobacter* strain 84 for preventing crown gall disease, Bioprotec CAF (26854) Bioprotec 3P (27750) DiPel 2X (26508), DiPel WP (11252), Thuricide HPC (11302), Novodor Flowable Concentrate (24068) with *B. thuringiensis* as active ingredient and used for control of various lepidopteran insects, Colorado potato beetle larvae, elm leaf beetle, , Bio-Save® 10LP3 incorporating strain *P. syringae* strain ESC 10 targeting biological decay, Bloomtime Biological™3, Bloomtime Biological™ FD3, *Pantoea agglomerans* strain E325 as the biocontrol organism mitigating Fireblight (*Erwinia amylovora*) (https://ohioline.osu.edu/). An efficient competent hostile strain of *Bacillus subtilis* was isolated and studied for deforming the structure of six pathogenic fungi by Chaurasia et al. (2005) under in vitro conditions. Some of the formulations based on these genera available commercially include BlightBan, Biocoat, Bio-Save, and Cedoman (Mishra and Arora 2016). Tewari and Arora

(2016) also reported a useful strain of *Pseudomonas aeruginosa* that causes ample increase in the yield of sunflower crop under arid and saline conditions by diminishing the incidence of charcoal rot disease in the plant.

Abiotic stresses like drought, flood, and salinity are well-known global constraints of agricultural sector. Mitigation of these stresses through application of bioinoculants has been proposed in several studies by different researchers around the world. *Azospirillum*, *Bacillus*, *Pseudomonas*, and *Rhizobium* sp. are known to impart drought tolerance in various plants. *B. subtilis* provided tolerance to *Platycladus orientalis* from drought by increasing levels of ABA and enhanced conductance of stomata (Liu et al. 2013). In case of flooding stress, *Bradyrhizobium japonicom*, a member of rhizobia, showed a positive response on the growth of soybean under flooding conditions by enhancing its nitrogen-fixing capability (Kadempir et al. 2014). Also capability of *Azospirillum* to thrive under submerged conditions could be exploited as a bioinoculant under flood stress (Sahoo et al. 2014). These studies suggest that PGPR could be used to attenuate the negative effects of stress caused by drought and flood. Likewise salinity stress was found to be reduced by many bacterial species such as *Bacillus*, *Pseudomonas*, *Enterobacter*, *P. aurantiaca* TSAU22, *Pseudomonas extremorientalis* TSAU6, and *P. extremorientalis* TSAU20. *P. extremorientalis* increased growth of wheat seedlings by up to 52% in comparison to control under 100 mM salinity (Egamberdieva 2009). *Enterobacter* sp. EJ0, procured from a halophytic condition, enhanced growth of *Arabidopsis* and tomato under 200 Mm NaCl stress (Kim et al. 2014). *Bacillus amyloliquefaciens* SQR9 have been observed to improve salinity stress (100 mM Na Cl) in maize seedlings along with increased chlorophyll and glutathione content and peroxidase and catalase activity (Chen et al. 2016). Tewari and Arora (2018) depicted the role of EPS-producing strain under saline conditions, where *Pseudomonas aeruginosa* PF23^{EPS+} showed maximum production of salicylic acid and biocontrol against *M. phaseolina* up to 500 mM NaCl, while mutant strains were found to be deficient in SA production and salt tolerance.

This explains that the products containing bacteria as main constituents can play a key role in agricultural sustainability and thus can be further used as active ingredients in many biological products. However, it is required to screen and select rhizobacteria in order to make a broad-spectrum efficient microbial bioformulation.

9.3.2 Fungal Inoculants

In addition to bacteria and their beneficial relationship with plant roots, fungi are also known to form mutualistic relationships with plants, particularly involved in transfer of nutrients and their cycling. Mycorrhizal fungi play an important role being symbiotic partners of most of the plant species (Adesemoye and Kloepper 2009) and help augment protection against environmental stresses, biological control of harmful pathogens, plant growth, and soil fertility by extending their hyphae in the soil matrices and increasing surface area of root (Adesemoye et al. 2009). Hyphae of mycorrhizal fungi are also known to improve quality of soil by directly affecting soil aggregation, stabilizing aeration and water dynamics (Rillig et al. 2002). They are able to access insoluble P from soil matrices which otherwise is inaccessible in absence of these beneficial fungi and hence known as excellent soil renovators (Smith and Read 1997). It has also been reported that the growth rate and germination of mycorrhizal fungi get directly affected by bacterial communities and are also highly responsible for bacterial community compositions in rhizosphere (Adesemoye et al. 2009). With the discovery of *Beauveria bassiana*, *Metarhizium* and *Trichoderma* spp., more efforts are now being made in order to develop commercial fungal preparations; however, they are still to be explored further for development of novel bioinoculants (McCoy 1990). Ectomycorrhizal fungi (EMF) and arbuscular mycorrhizal fungi (AMF) are important tools that are known to enhance the production of crops and also to protect crops from adverse conditions (Pal et al. 2015; Lenoir et al. 2016). ECM are reported to enhance growth of trees as these are known to break down complex organic compounds and minerals as compared to other fungi (Pal et al. 2015). The most common inoculum used in this class is the *Pisolithus tinctorius* which is used as vegetative mycelium with peat or clay as carrier (Schwartz et al. 2006). *Piriformospora indica* is another example of ECM used as growth promoter for plants and provides tolerance to environmental stresses (Tejesvi et al. 2010). AMF are the major plant habitants and are also notable P mobilizers, increasing soil amino acid and organic acid contents (Bolduc and Hijri 2011). AMF are also reported as K solubilizers, trapping K from mineral or inorganic sources (Sangeetha 2012; K chelation activity of AMF is found to be directly proportional to P solubilization (Cardoso and Kuyper 2006). Spores of AMF as inocula are known as the most reliable bioinoculants, whereas fragments of colonized roots are also used (Biermann and Linderman 1983). *Rhizophagus* (formerly *Glomus*) *intraradices* and *Funneliformis* (formerly *Glomus*) *mosseae* have commercially been used as inoculants in Europe and the USA (Kruger et al. 2012). Other fungal biofertilizers belong to *Penicillium*, *Aspergillus*, *Chaetomium*, and *Trichoderma* species and are known to increase plant biomass in different ways. Zn-solubilizing fungi (ZSF) such as *Penicillium citrinum* and *Aspergillus niger* in addition to *Aspergillus candidus* are also known for their Zn-solubilizing ability (Anitha et al. 2013; Shaikh and Saraf 2017). JumpStart®, a fungal biofertilizer containing *Penicillium bilaii*, is commercially being used to promote P uptake in wheat and canola with yield increment of ~6% (Harvey et al. 2009).

Biocontrol activity of *Trichoderma* spp. as biopesticides is well documented since 1930 (Ha 2010; Vinale et al. 2008) and is the most studied biocontrol fungal agent competing with many other organisms for nutrients and space. Nowadays, it has been commercialized successfully by companies like BioWorks, USA, with sales of worth several million dollars (Harman 2011). *Trichoderma harzianum* ATCC 20476 was the first registered fungus with the Environmental Protection Agency (EPA) for biocontrol of plant diseases in 1989 (Junaid et al. 2013). The current scenario of agricultural revolution affirms the availability of wide array of these microbe-based biopesticides throughout the globe with felicitous features in diluting the biotic stress (due to phytopathogens) (Mishra et al. 2015). Global data suggests that 27% of biopesticide products commercially available in market are fungal (Woo et al. 2014). Nutri-Life Tricho-Shield™ is a talc-based bioformulation of *T. harzianum*, *T. lignorum*, and *T. koningii* with excellent property of maintaining a balance between desirable and non-desirable microbes in soil and on plants surface. *Aspergillus flavus* AF36 under product name Alfa guard and manufactured by Circle One Global, USA, competes with aflatoxin producing strains of *A. flavus* and inhibits them along with controlling disease in cotton (Junaid et al. 2013). BioMal WP (22359) with *Colletotrichum gloeosporioides* f. sp. *malvae* as active constituent functions as effective herbicide controlling round-leaved mallow in field crops (PMRA 2006).

Fungal inoculants, like their bacterial counterparts, are also known to alleviate drought stress in many plants and are known to increase their growth under stress conditions. Effect of AMF on growth of plant sainfoin (*Onobrychis viciifolia* Scop.) has been studied by Jing et al. (2014). The fungus *G. mosseae* was found to increase the growth and drought tolerance of the plant by increasing water, N and P content in it. Similarly three treatments of *Funelliformis* sp., another AMF, were reported to increase growth of strawberry plants under drought-stress with increase in root colonization by the fungus (Boyer et al. 2015). Likewise, mycorrhizal fungi are known to provide resistance to plants under submerged or flooded conditions by forming symbiotic associations with them (Wang et al. 2011; Wu et al. 2013). *Rhizophagus irregularis*, another AMF, are reported to increase root hydraulic conductivity with higher expressions of aquaporins in tomato plant under waterlogging conditions, IAA playing the key role in absence of oxygen (Calvo-Polanco et al. 2014). AMF are known to provide tolerance under salt stress in plants and are well known as bioameliorators of saline-stressed soils (Yano-Melo et al. 2003). Mung bean plants when inoculated with AMF were reported for enhanced growth under different dilutions of seawater, in comparison to uninoculated plants (Rabie 2005). Also co-inoculation of AMF (e.g., *Glomus clarum*) with nitrogen-fixing bacteria (e.g., *Azospirillum brasilense*) is known to increase salinity tolerance in some leguminous plants like *Vicia faba*. Similarly, *T. harzianum* was also observed to alleviate salinity stress in wheat and rice plants when their seeds were bioprimed with the fungus (Rawal et al. 2013). Hence, from abovementioned examples, we conclude that fungal bioinoculants have substantial application in agricultural field to increase productivity and can be successfully used in restoration of infertile land, and further exploitation of their characteristic features would result in important commercial products which could curb many agronomic problems.

9.3.3 Genetically Engineered Microbes (GEMs)/Genetically Modified Organisms (GMOs)

In the present era, genetic engineering is emerging as an exciting technique comprehending the desired characters in microbes analogous with the demand. Construction of GEMs through recombinant DNA techniques has been a known fact since 1970s (Vidaver et al. 2013). With the rising divergent agricultural constraints, the need shifts to use condition-specific microbial strains, instead of applying basic plant growth promoters. GEMs have been popular through their beneficial traits including effective biocontrol agents (specific for various diseases), improving plant growth and productivity (Amarger 2002), degradation of pollutants (Dutta et al. 2003), as biosensors or biomarkers in determining the load of pollutants in soil and water (Belkin 2003), extraction of enzymes and other important phytohormones and encountering biotic and abiotic stresses (Viebahn et al. 2005). In the year 1971, Ananda Mohan Chakrabarty firstly introduced genetically engineered microbe *Pseudomonas putida* as superbug in the area of oil degradation (Ezezika and Singer 2010). 24th April, 1987 flagged as benchmark, when Advanced Genetic Sciences, Inc. (AGS), successfully conducted field trials of the GEM product FrostBan® (on strawberry), comprising of genetically engineered *P. syringae*, deleting the gene responsible for protein involved in ice nucleation (Lindow and Panopoulos 1988; Smith 1997). Subsequently, biopesticidal transformation systems were constructed by Crop Genetics International (CGI) using *B. thuringiensis* (Bt) and *Clavibacter xyli* ssp. *cynodontis* (endophyte of Bermuda grass, maize, etc.). Bt Cry1Ac δ-endotoxin was delivered in maize tissue by incorporating the associated transgenic sequences to *Clavibacter xyli* and then introducing them to plants, diluting the vulnerability to corn earworm and European corn borers (Turner et al. 1991; Lampel et al. 1994). The success story of the product did not gain much acknowledgment due to lack of consistent delivery, uncontrolled spread of the GEM, and also impaired plant yield (John Turner, personal communication 2011). Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) between 1991 and 1996 registered GEM comprising of *B. thuringiensis* d-endotoxins encapsulated in *P. fluorescens* (Shand 1989; Mycogen 1998). Bt crops with successful incorporation of *Cry* gene popularized and the area planted with genetically modified crops increased from million hectares in 1997 to about 66 million hectares in 2011 (James 1999, 2011). Commercial Bt products account for 90% of global microbial pest control agents (MPCAs) and about 80% of all global biopesticides sold (Whalon and Wingerd 2003; Castagnola and Jurat-Fuentes 2012). Each year about 13,000 tonnes of Bt products are produced using aerobic fermentation technology throughout the globe (WHO 1999). Presently, there are almost 63 genetically modified microbial pesticides (Vidaver et al. 2013) including bacteria, fungi, and viruses. Timms-Wilson et al. (2001) successfully inserted genes encoding phenazine-1-carboxylic acid (PCA) in *P. fluorescens* enhancing the survivability in microcosm systems. Delaney et al. (2001) corroborated increment in DAPG production by genetically engineered microbe as compared to the wild strain of *P. fluorescens* F113, inhibiting greater-fold pathogenicity of *Pythium* in incidence of damping-off disease. Furthermore, biodegradation and bioremediation are also additional aspects where GEMs have rooted in augmenting the process. Genetic manipulations catalyzing the degradation and remediation processes are impregnated, enhancing the microbial potential. Friello et al. (2001) engineered multiplasmid-containing *Pseudomonas* with the increased potential of oxidizing aliphatic, aromatic, terpenic, and polyaromatic hydrocarbons. Similarly, Monti et al. (2005) engineered 2,4-dinitrotoluene degradation pathway genes from

Burkholderia sp. strain DNT to *P. fluorescens* ATCC 17400, encompassing the ability of degrading DNT even at cold temperatures. Wu et al. (2006) used *Escherichia coli* as cloning host to assimilate genes from *Comamonas* sp. strain CNB-1 for 4-chloronitrobenzene and nitrobenzene reduction. This biotechnological approach has also been a popularly nominated solution to heavy metal stress amelioration. Renninger et al. (2004) speculated the tac-lac promoter controlled cloning of genes encoding polyphosphate production, in *P. aeruginosa*, thereby potentially remediating uranium contamination. *P. fluorescens* HK44 became the first genetically engineered bacterium approved by US EPA with the ability to degrade poly-aliphatic hydrocarbons (PAHs) (Ripp et al. 2000). Recombinant technology has also been implied to baculoviruses with the aim to enhance their insecticidal efficiency. Genome of baculoviruses is engineered by cloning several insecticidal proteinaceous toxins including juvenile hormone esterase, PTTH, melittin, trehalase, fungal insecticidal protease, and scorpion and mite toxins (Erayya et al. 2013). The examples discussed in the same study are toxin from *Androctonus australis* (foreign gene) into virus BmNPV (nuclear polyhedrosis virus (NPV) against *Bombyx mori*, toxin 34 from *Pyemotes tritici* (foreign gene) into virus zHPV against *Heliothis zea*, and neurotoxin from spider (foreign gene) into virus AcMNPV and HvJHE against *Spodoptera frugiperda*. Due to cost ineffectiveness and challenge to native wild species, this technique is yet steps away to reach farmlands. Therefore, work has to be done to overcome the problems and implement this technique to achieve next green revolution.

Transgenic approaches have also been applied in biofortification of foods to enhance the nutrient levels and counteract the problem of hidden hunger. Genetic manipulation is implied in various crops incorporating bacterial pathways into crops to exploit alternative pathways of nutrient assimilation. Improvement of rice protein quality has been achieved by targeting bacterial enzymes like aspartate kinase, dihydrodipicolinate synthase (DHPS) (Yang et al. 2016), and *E. coli* aspartate aminotransferase (Zhou et al. 2009). Provitamin A content of wheat is increased by incorporation of bacterial *PSY* and carotene desaturase genes (*CrtB*, *CrtI*) (Wang et al. 2014). Similarly, many transgenic legumes and pulses have been biofortified using essential genes from bacteria (other examples in Table 9.1).

9.3.4 Other Microbial Inoculants

The application of bacterial and fungal bioinoculants has been very useful in improving plant health. However these cell-based bioinoculants have their limitation in field conditions. New strategies and applications of using other inoculants such as use of microbial metabolites or other additives along with cell-based bioinoculants could enhance their performance. Apart from this, these bioinoculants can also be used in hostile conditions such as countering abiotic and biotic stresses. With the peaking impact of chemicals in agriculture, the resuscitating solutions are needed to maintain the dynamism so that there can be better and sustainable means to tackle the challenges being faced by plants. Direct application of microbial metabolites to plants is now an emerging strategy with propitious results along with cell-based inoculants (Arora and Mishra 2016). Microbial metabolites, viz., phytohormones, flavonoids, osmoprotectants, EPS, and biosurfactants, are of great importance (Morel et al. 2015). The application of metabolites has shown more concentrated and unidirectional results and functionality in comparison to traditional microbial inoculants. These metabolites are assimilated as additives/adjuvants or carriers in bioformulations or are exogenously applied to rhizospheric regions, which may enhance growth-promoting attributes in both plants and the inoculated microbe.

Among microbial metabolites, production of phytohormones is the most utilized trait providing substantial aid in development of microbial inoculants; even when present at low concentration, they induce cell proliferation and expansion (Perrot-Rechenmann 2010; Daviére and Achard 2013). Although plants and inoculated microbes do synthesize phytohormones, yet studies indicate using precursor of their biosynthesis, or exogenous application may enhance crop productivity by several folds (Arora et al. 2017). Auxins, GA, cytokinins, and jasmonic acid are the important phytohormones which reflect significant growth-promoting traits upon external inoculation. Auxins are the profoundly studied phytohormones regulating the plant growth by increasing the root volume, therewith incrementing the active sites for chelation of minerals and nutrients; also auxins induce establishment of beneficial plant-microbe symbiosis and expression of genes involved in plant colonization specifically under stress conditions (Spaepen et al. 2007; Morel et al. 2012) and biocontrol (Khare and Arora 2010). Their exogenous application has been corroborated proving that it may increase nodulation rate, shoot weight, and yield in many crops (Morel et al. 2016). Evidently, Zahir et al. (2010) revealed that L-tryptophan application to mung bean along with *Rhizobium phaseoli* strain enhanced the auxin biosynthesis supporting increased nodulation, growth, and yield.

Bacterial EPS has been categorized as an ample microbial metabolite with wide spectrum of agricultural benefits including plant growth promotion, bacterial survival, soil reclamation, plant-microbe interactions under hospitable and stress conditions, and also synthesis of biopolymers. There are pronounced reports on plant growth-promoting activity of EPS-producing microbes where EPS served as plant and microbe protector (from biotic and abiotic stresses), salinity and heavy metal sequester, hydrator in drought, soil aggregator (trapping moisture and nutrients), nutrient chelator, etc. (Tewari and Arora 2014a). With these multitudinous applications, crude EPS has been directly, or through bioformulations, applied to plants and soils enhancing their action abilities (Arora et al. 2017). Haggag et al. (2015) showed that 200 ppm of crude EPS purified from *Paenibacillus polymyxa*, on its foliar and seed application, elicited resistance against powdery mild dew and leaf rust in wheat plant. Liang et al. (2016) propounded 80% of free radical scavenging rate in EPS from *P. mucilaginous* TKU32 combating salinity stress and elevating growth. Tewari and Arora (2014b) checked the efficacy of EPS-augmented talc-based bioformulation on yield of sunflower and found positive results even under saline conditions. Impregnation of crude EPS in bioformulations thus can be an efficient delivery system/carrier assuring slow and constant microbial release, in the new generation bioinoculants (Arora and Mishra 2016).

Biosurfactants have paved their way in microbial green revolution by improving soil quality through removal of heavy metals and hydrocarbon contaminants (Sun et al. 2016), antimicrobial activity against plant pathogens (Nihorimbere et al. 2011; Khare et al. 2011), quorum sensing, facilitating important plant-microbe communication (Berti et al. 2007; Rosenberg and Ron 1999), and adjuvants in fungicides, insecticides, and herbicides (Rostas and Blassmann 2009). Moldes et al. (2011) found 58.6–62.8% reduction of octane hydrocarbon by biosurfactant from *Lactobacillus pentosus* explaining biodegradation property, replenishing the soil. Kim et al. (2011) demonstrated insecticidal activity by biosurfactants (from strain of *Pseudomonas*) against green peach aphid (*Myzus persicae*). There are also reports of different types of biosurfactants being used as adjuvants by many pesticide manufacturing companies (Mulqueen 2003). Jeneil Biotech Inc. company, USA, is manufacturing a rhamnolipid (purified from *P. aeruginosa*)-based product Zonix Biofungicide™ substantial for biocontrol against downy mildew, late blight, black rot, and all phytophthora and pythium diseases (http://www.jeneilbiotech.com/) (Thavasi et al. 2011).

Microbial osmoprotectants, lipochitooligosaccharides (LCO), and flavonoids are also being employed as inoculants to enhance stress tolerance, symbiotic association, and nodulation, respectively (Oldroyd 2013; Kaya et al. 2013; Morel et al. 2016). Dolatabadian et al. (2012, 2013) postulated increased nodulation, nitrogen fixation efficiency, growth parameters, and osmo-balancing metabolisms under salt stress in *Glycine max*-*Bradyrhizobium japonicum* association, upon inoculation with genistein-type flavonoid. Dyna-Start Max™ is a LCO-based product manufactured by company Loveland (http://www.lovelandproducts.com/) specifically for plant growth promotion of soybean and peanuts. Ratchet® and Torque® are other LCO-associated bioformulations. Nutri-Life BAM™ is a formulation blending lactic acid bacteria, purple non-sulfur bacteria plus beneficial yeasts, and also microbial exudates administered to increase propitious bacterial population in root zones and increase nutrient availability, better yield, and quality of plants (http://www.nutri-tech.com.au/).

Viruses have been noted as rancid elements imperiling the health and productivity of plants. But to the exception, there are reports where viruses have also affirmatively affected the agriculture through drought and cold tolerance and coping with biotic stress (Xu et al. 2008; Roossinck 2013). Viruses including *Baculoviridae*, *Reoviridae*, *Iridoviridae*, *Poxviridae*, *Parvoviridae*, *Picornaviridae*, and *Rhabdoviridae* are reported to cause infections in insects substantiating their role in biocontrol (Kalawate 2014). Among these the family of *Baculoviridae* is attaining much attention in the field of bioinsecticides (Harrison and Hoover 2012) with more than 20 species and 30 different products registered as commercially marketed bioinsecticides (Rao et al. 2015) providing resilience against Lepidoptera, Hymenoptera, Diptera, Neuroptera, Coleoptera, Trichoptera, Crustacea, and mites. Baculoviruses have strongly grasped the insecticidal market with the contribution of 60% of the total 1200 known insecticidal viruses, with potential of acting against approximately 30% of the food and fiber crops' pests (Erayya et al. 2013). The same study highlighted some of the majority of baculovirus-based insecticidal products used worldwide including Capex against *Adoxophyes orana* (Czechoslovakia), Agrovir Germany 1990 against *Agrotis segetum* (Germany), and Gypcheck against *Lymantria dispar* (USA). Furthermore, the viral product market in Europe and the USA is also proportionate, preceding China, including some of the available products: Granupom (AgrEvo), Carpovirusine (NPP-Calliope), Carposin (Agrichem), Virin-Gyap (NPO Vector), and CYD-X (Thermo Trilogy) (Mishra and Arora 2016). Six virus-based registered microbial biopesticides have also been reported (Steinwand 2008) of which phage products of USA's leading company Omnilytics have been popularly used in biocontrol against *Xanthomonas campestris* pv. *vesicatoria* (Frampton et al. 2012; Schofield et al. 2012; Mishra et al. 2015).

The other emerging strategy for microbial inoculants application is incorporation of mixed cultures in the bioformulations to achieve multifaceted approach toward plant growth promotion and stress adaptation. The three-way action system of using consortia involves (1) different microbes operating diverse tasks at the same time, (2) allocating stability among the cells against the dynamics of environment, and (3) furcating the functions into different modules of consortia reducing the load on single strain (Jia et al. 2016). Becerra-Castro et al. (2012) posited that upon the application of mixed cultures including *Bacillus pumilus* 28-11, *Alcaligenes faecalis* 212-2, *Micrococcus luteus* 212-4, and *Enterobacter* sp. 214-6, the degradation of *n*-alkanes and polycyclic aromatic hydrocarbons (PHA) from oil-contaminated soil was enhanced. Saxena et al. (2015) reported the dual inoculation of two microbial species: one phosphate-solubilizing bacteria *Bacillus* sp. and the other free-living phosphate-solubilizing fungi *Aspergillus niger* S-36 improving the growth and yield of chickpea. Rubiya (2006) developed "Multigeneric diazotrophic co-flocs" constituting *Azospirillum, Azotobacter*, and *Rhizobium*, improving growth and yield of rice. Abd-Alla et al. (2014) reported the co-inoculation of AMF and rhizobia to enhance yield and productivity of crops because of higher nutrient uptake. Similarly, Zhu et al. (2016) found elevated alfalfa yield under saline conditions upon combined inoculation with AMF and nitrogen-fixing bacteria (Arora et al. 2017). Singh et al. (2014) also opined the benefits of co-inoculation with root-nodulating *Rhizobium* sp. RASH6$^{Chl\ +\ Kan+}$ and phosphate-solubilizing *P. fluorescens* PB6$^{Amp\ +\ Str+}$ incrementing growth parameters and nodulation of chickpea. Therewith, apart from traditional inoculants, these advanced combinations and techniques can be a better picture of sustainable agriculture.

Mixing of bioinoculants with micro-/macronutrients or other additives including secondary metabolites or substrates is done to enhance the growth of plants. Nutrients including phosphates, K rocks, S, or insoluble Zn are amended in the bioformulations along with their solubilizing microbes enhancing their PGP activity (Abou-el-Seoud and Abdel-Megeed 2012). Similarly, chitin has also been used as an additive together with microbes showing biocontrol activity, resulting in their amplified chitinase activity and also acting as efficient carbon source for plants (Arora et al. 2007). Nutrients such as amino acids and sugars are also supplemented in the bioformulations serving as source of C and N (Arora and Mishra 2016). Omer (2010) reported higher plant growth promotion of bean seeds on application of talc-yeast and cellulose-added clay-based powdered bioformulation in comparison to without enriched bioformulations. Singh et al. (2014) concluded that the enrichment of sawdust-based bioformulation with molasses both in mono- and co-inoculation increased the shelf life and efficiency of *Rhizobium* sp. and P-solubilizing *P. fluorescens.* Aeron et al. (2011) also supported that CMC-amended rhizobial inoculant enhanced growth and protection of *Mucuna pruriens* against *M. phaseolina*.

9.4 Conclusion and Future Perspectives

In the context of climate change, increasing population, land degradation, and biotic and abiotic stress conditions, the demand for sustainable and cost-effective alternative methods is the prime call for securing the future needs. In lineation to the requirement, microbial inoculants have been the focus and the most potential ecologically acceptable candidates which can overcome the use of agrochemicals. Microbial inoculants have been in the market since long. The use of rhizobia as biofertilizer for legumes is reported since 1896 and the use of *B. thuringiensis* for biocontrol of pests since the 1930s (Russo et al. 2012). With the strategic advancement, the application of beneficial soil microbes can be included in bioremediation, phytoremediation, nutrient assimilation, soil aggregation and plant growth promotion (Baez-Rogelio et al. 2017). The future perspectives of microbial applications include advancement of both theoretical and technological concepts through implementation of various multidisciplinary technologies including omics, 3D printing, nanotechnology, and synthetic biology. The damage caused by chemicals (pesticides and fertilizers) demands the implementation of organic farming and introduction of eco-friendly technologies to sublimate the toxicity persisting in the environment from unsustainable actions. Synergism of both organic farming technologies and microorganisms can be the most efficacious proposal in enhancing the agricultural production as well as ameliorating the quality of soil. Products of microbial inoculants have gained attention among the farmers, yet there are many loopholes in the technology which are required to be fixed so as to further improve it. With little knowledge about uncultured microbes, the spectra of microbial inoculants can be widened by further studying these unknown entities and introducing their beneficial properties to agriculture.

The application of microbial inoculants to plants involves complex interaction between the microbe and cultivar which needs to be explored further to gain information about the ecosystem biology. This detailed information can be used to improve the microbe-cultivar adaptation relationship by designing the inoculants as per the demands of the plants. Furthermore, each plant has its own natural microbiome, which can also be detailed to formulate the biofertilizers depending on the need of the plant (Hunter 2016). The influential action of microbial inoculants also depends on the delivery methods deciding their vicinity in rhizosphere, availability to plants, maintenance of desired characteristics, and also the shelf life and cost of the bioformulation. Though there are many theoretical studies regarding natural carriers, cell encapsulation, nano-carriers, additives, and metabolite-based bioformulations, yet the practical potentialities of the strategies are still in the primary stage and need to be further advanced. Future studies could also include designing the bioformulations with multiple desirable traits like plant growth promotion and bioremediation in one consortium. Transfer of technology from lab to land demands the overcoming of in vitro and in vivo experimental failures and popularizing the microbial inoculants in farmers' fields.

In conclusion, it can be reported that commercialization and application of microbial inoculants is gaining attention, but their use is still lacking far behind the use of agrochemicals. Farmers are more influenced by conventional methods and do not risk the acceptance of new technologies. Thus, governmental policies can be key player in educating the farmers about green eco-friendly technologies. The microbial technology should successfully reach the fields, so as to establish a synergism between agricultural productivity and environmental sustainability. The already popular strategy of microbial inoculants could further be realized by decoding the plant-microbe communication and initiating the wide-scale application reducing the unsustainable means. Microbial inoculants are efficient models promoting plant growth by diverse mechanisms, and their cost-effectiveness and lesser maintenance are required to be further fine tuned to use them for ushering in a new era of sustainable agriculture. It is also important to convince the farming community by ensuring the consistency so that the substitution becomes easier and the target of next green revolution is achieved.

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Environmental Significance of Lichens and Biodeterioration

10

Gülşah Çobanoğlu Özyiğitoğlu

Abstract

This chapter underlines the environmental values of lichens, an important part of biodiversity on Earth, and at the same time addresses the subject of biodeterioration in detail. Diversity and sociology of lichens, ecological factors effective on growth and distribution of the lichens, bioindicative and biomonitoring roles of lichens in the air pollution and also roles of lichens in ecological events such as erosion prevention, succession and soil formation in nature were mentioned under the brief headings. Information was given on the occurrence of biological deterioration "biodeterioration", both physical and chemical properties and functions of the event and the organisms causing the biodeterioration. Biological deterioration occurring in the presence of living organisms such as lichens, fungi and mosses known as eroding stone surfaces, while qualifying as damaging in the case of historical monuments and works of art, also represents a fundamental process of the biosphere. The literature on biodeterioration of stone monuments and artiefacts, especially by lichen species and other organisms, and also the protective methods in this area have been reviewed. This compilation is intended to provide information on the importance of lichens for the environment as much as it is for biodeterioration and is thought to be a guide for the establishment of management and conservation strategies today.

Keywords

Biodeterioration · Biodeteriogen · Lichen diversity · Monument · Stonework · Biological weathering

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_10

10.1 Introduction

Lichens are an important part of biodiversity with more than 20,000 species, especially in clean air habitats, spreading from poles to deserts in different ecosystems. Some of them are in the rock slits or tree bark in the countryside, like a hidden, indeterminate crust, and some of them are obviously leafy, shrubby and threadlike and have a wide variety of colours and appearances. The lichens that distribute on most of the Earth's ecosystems live on specific environs the so-called substrate which can be natural environments such as rock, stone, soil and tree or sometimes man-made environments such as tile, wall, concrete and marble. For the last 30 years, almost all discussions on nature conservation have been about biological diversity and ways to protect it. The lichens are not excluded from these studies, and many current works highlight the importance of preserving lichens and habitats, since the natural roles of these organisms are of great importance in the shaping of the physical and biological environment of our planet.

Lichens are among the cryptogams such as algae, bryophytes and liverworts which are called hidden plants because of their small sizes in the realm of life, and they are included in the terrestrial fungi that reproduce via spores. Slowly growing lichens are very sensitive to air pollutants, although they are very durable and long-lasting in extreme conditions. Certain lichen species are indicative of the level of air pollution. Since air pollution affects lichens, their primary consumers and therefore their hunters are also negatively impacted. Thence much more extensive research on the effects of environmental pollutants is needed.

One of the characteristics of algae, mosses, fungi and lichens that can survive by adhering to man-made stone substrates is that they cause these stone surfaces to deteriorate in time. "Biodeterioration" (biological weathering) of stone monuments is one of the main interests of researchers working on the conservation of cultural heritage. The most particular biological agents of deterioration on stone surfaces in nature and also on stone monuments and works of art are lichens, mosses, algae, fungi, bacteria and other microorganisms. Some plants and animals may also participate. The term "biodeterioration" is defined as damage to materials that is caused by living organisms, meaning to the breakdown of materials by microbial action as a result of physical and/or chemical processes. Lichens and mosses capturing organic residues such as dust coming with the wind, plant fibres, seeds, dead insects and animal residues on rock contribute to the formation of soil. Changing of carbon dioxide (released from respiration of the organisms) into a very dilute carbonic acid dissolves rocks slowly and steadily and accelerates soil formation.

In biological perspective, biodeterioration (rock weathering) is the achievement stories of the organisms of algae, fungi and lichens that initiate life there. All they need is a substrate to attach and desirable environmental conditions such as temperature, moisture and light. The substrate refers to a special environment (rocks, stones, walls, glass, earth, crust, etc.) which lichens attach and live on, rather than a habitat. The nature of the substrate is efficient to some extent depending on the deterioration agents, for instance, in the case of nutritional requirements.

Degradation of organic materials is carried out especially by heterotrophic organisms, while the autotrophs are more capable for deterioration of inorganic materials. Therefore the ecological succession is owned by the autotrophs. Those photosynthetic organisms (algae, lichens and plants) demand a substrate for two purposes: a place of residence and beneficiation from minerals of it.

Limiting factors for biological growth include nature of the substrate; its pH, RH, aspect and orientation of the surface and its texture; patterns of water run-off; levels of nitrification (e.g. from bird droppings); light quality; and levels of atmospheric pollution that are consequently penetrative for biodeterioration of stones.

Carbon dioxide (CO_2) is released through respiration by all aerobic organisms. In the presence of water, it changes into a weak acid, carbonic acid (H_2CO_3) that reacts with the substrate. Carbonic acid can dissolve calcium and magnesium carbonates of limestone, marble, lime mortar, plaster, etc. and causes weathering of rocks (Caneva et al. 1991).

The most important form of biological degradation in the formation of cavities on the calcareous rocks, in terrestrial conditions, describes the impact of organisms such as fungi, blue-green algae, green algae and lichens growing on the surface of the rocks (Dannin 1992). The sphinxes and ruins covered by lichen populations in historical monuments in Alacahöyük in Turkey from the Hittite Empire Age (1450–1200 BC) was photographed by G. Özyiğitoğlu (Figs. 10.1 and 10.2) (Küçükkaya 2014).

In the case of colonization of biological organisms on monumental or historic stones, the degree of deterioration of whether it causes damage or not is a questionable phenomenon as well as determination of the methods for conservation.

The lichen *Dirina massiliensis* forma *sorediata* was mentioned as destructive agent on the monuments in Italy, Spain and Portugal over the last two decades (Seaward and Edwards 1995; Saiz-Jimenez 2001; Scheerer et al. 2009). As another study on biodeteriorative lichens, Uppadhyay et al. (2016) reported diversity and distribution of 28 lichen species from the monuments in Gwalior division in India. Sixteen species of lichens were identified growing on the surrounding walls of the Anadolu Fortress and the Rumelia Fortress in Istanbul which are exposed to anthropological impacts (Çobanoğlu et al. 2008a).

Recognizing biological deterioration and distinguishing it from other causes of destruction are possible with the understanding of the morphology of the

Fig. 10.1 Historical monuments in Alacahöyük in Çorum province (Turkey) are covered by the crustose lichen populations. The orange rosette-like crustose lichen is *Xanthoria elegans*; greyish rosettes are *Lecanora muralis*. (Photo by G. Özyiğitoğlu)

Fig. 10.2 Sphinxes and ruins in Alacahöyük, Çorum (Turkey), covered by orange crustose lichen – *Xanthoria elegans* – an example of stone that biological cavities have formed. Also *Lecanora muralis* (grey in rosette form) and other white crusts have been developed. (Photo by G. Özyiğitoğlu)

deterioration. Detailed taxonomical (position of organism's systematic level such as kingdom, division, class, order, genus, species and comparison with other groups) and biological (cell organization, tissue structure, physiology, growth forms, reproduction strategies, colouration, colonization patterns, habitat preferences, etc.) knowledge about organisms is required to be able to take precautions and/or be kept under control.

Biodeteriorative organisms, algal or fungal patinas, mosses and some lichens especially due to small sizes, are often confused with each other by nonbiologists. Individual species of the organisms that presumably attack monumental stones and derivatives can be best described by experienced specialists of each group.

10.2 Lichens as Ecological Values in Nature

The lichens in which members of 2–3 kingdoms live together are "self-sufficient miniature ecosystems" as Farrar (1976) describes in the lichen definition. From an ecological standpoint, they are extraordinary creatures that can be kept alive in very different ecosystems, ranging from the desert to the poles, adapting to extreme conditions in nature. With their exceptional abilities, they can develop in a wide geographic range in various habitats. Although they are durable to extreme conditions and live long, it is known that lichens grow very slowly and at the same time they show sensitivity to air pollution.

The natural habitat of lichens is mainly terrestrial. All lichens except the two aquatic species are continental life. These are one aquatic species *Peltigera hydrothyria* Miądl. and Lutzoni and one marine species *Verrucaria serpuloides* M. lamb. A few species of lichen live on the freshwater currents and on the coastline, which is affected by the tides of the seas. For example, there are many species such as *Caloplaca* and *Verrucaria* that live on the siliceous rocky shores of the sea, not in the sea. Some lichens grow on hard siliceous rocks in freshwaters, such as *Ephebe*, *Hymenelia*, etc. Apart from these, the majority of lichens are naturally distributed on substrata such as soil, rocks or trees in forest, hill or high mountainous terrains (alpine and tundra). Some species have even adapted to unconventional estates such as man-made buildings, walls, tiles and even concrete, plastic, glass and metal, belonging to natural urban and rural living environments.

There are two types of food sources for lichens. The "atmospheric sources" are precipitation, fog, dew, frost and air humidity. The second is "substrate sources". The nutrients of lichens living on soils and rocks are affected by the pH level of the environment in terms of solubility. Limestone contains more nutrients than acid rocks. The species of lichens that develop in these environments are also different. In addition, soil and rock species contain dust and soil particles flying around, where elements Al, Fe, Sc and Ti are present in high concentrations. They enter the intercellular spaces in lichen tissue. However, because the solubility of these substances is slow, lichens do not benefit as much as they need from dust. Epiphytic lichens are also affected by the characteristics of the tree bark and by the canopy. The nutrient composition of the bark also affects the pH level of the environment. The species of lichen on the neutral bark are different from those on the acid bark. Air pollution also affects the nutrient content of the tree bark and changes the lichen communities due to lowering pH with acid accumulation; calcium (Ca) accumulation causes the pH to increase, causing the lichen communities to change in the opposite direction (Nash 2008).

What are the environmental roles of the lichens in nature? The known ecological functions of the lichens in the nature, which will be elaborated in detail throughout this chapter, are summarized in the following items:

1. The lichens function as indicators for atmospheric pollution.
2. Lichens are pioneering organisms in succession and in soil formation.
3. Lichens help prevent erosion.
4. The role of lichens in the mineral cycle in ecosystems is great.
5. Lichens function as habitat for various fauna (birds, insects, invertebrates).
6. Lichens are a source of nutrients for some animals in the wild.
7. In the food pyramid in the ecology, the lichens are different from the other lichen-free fungi, not in the consumer's step, but in the producers' step by photobiont.

10.2.1 Lichen Biodiversity

The lichens among the terrestrial autotrophs on Earth are incredibly diverse in nature miniature. They have a fantastic range of colours: orange, yellow, red, green, grey, brown and black. Their size ranges from small 1 mm^2 dense lenses that are difficult to see to those with a length of 2 m, hanging from the branches. The largest foliose species is epiphytic *Lobaria pulmonaria* showing distribution in the old forests widespread in oceanic and montane Europe, and also in Macaronesia, North and South Africa, North America and Asia, but now extinct in the lowland plains of central Europe. The lichen species diversity is quite high in the old forests of mountainous areas with high altitudes, the rugged pebble ocean coastal cliffs and the tropics. For example, in Papua New Guinea, 173 lichen species have been reported on a single tree (Aptroot 2001). Species diversity grows with the diversity of ecosystems (Lohmus et al. 2007). The regions where the lichens develop best are tundra and high mountainous areas. Wherever the earth is – as slow-growing living creatures – they prefer robust rock surfaces with plenty of light. Oceanic coastal populations can have a rich lichen flora that is not seen elsewhere.

Lichens are colonies of bare soil and rock surfaces in addition to their presence on trees and other plants as corticolous (bark) or lignicolous (wood) epiphytic communities. The most prominent saxicolous communities on the rocks are epilithic on the surface, and others are endolithic in rock holes or cracks. Basic rocks such as limestone (high pH) and acid rocks (low pH) such as basalt often host different lichen species. Soil chemistry is also important for terrestrial communities living on the soil. In the tropics and subtropics, some fast-growing lichens colonize as epiphyllic communities on the surface of the leaves. In addition, some livestock lichens are colonizing some communities such as turtles and insects. In addition, there are microscopic aquatic invertebrate animals living on and between mosses and lichens.

Lichens live in most of the world's terrestrial ecosystems until they cover about 8% of the Earth's surface (Socthing 1999). However, biomass distributions vary widely. The majority of polar and subpolar ecosystems of lichens are dominant autotrophs. Lichens are a prominent element of many alpine, marine and forest ecosystems, such as the temperate rainforests of the Southern Hemisphere and the Northern Hemisphere. Because many lichens have relatively slow growth, their primary productivity distribution is quite small in most ecosystems. Ephemerals (annuals) are extremely rare among lichens. Lichens are "perennial" creatures that develop for many years. They grow very slowly and last very long. A crustose lichen species grows up to an average of 1 cm per year on average. By contrast, lichen varieties with leafy and flat thallus grow faster.

Another noteworthy point is that some lichens survive for 1000 years and are used to determine the age of rock surfaces. Growth can range from "invisible" to "several mm" per year. Faster-growing species can increase their biomass by 20–40% per year, and especially if they are the dominant species, they play an important role in the mineral cycle of the ecosystem they are in (Nash 2008).

10.2.2 Lichen Sociology

The various lichen communities separated by sociological analyses and other means also determine the significance of not only the diversity, frequency and biomass of different species but also their relation to the other components of the ecosystem or community, thus showing lichen-rich ecosystems.

Among the lichen species, various sociological units have been found to occur primarily within the broad vegetations that start with grouping in narrow areas due to substrate specificity and vary according to their geographical distribution. For these communities, sociological classifications are made with traditional phytosociological approaches or numerical approaches based on more recent statistical data analyses. In other words, associations determined by phytosociological approach and by floristic and intuitive methods can also be grouped as a result of numerical analysis of data obtained from random sampling techniques (James et al. 1977). The most appropriate is the comparative application of phytosociological and numerical approaches.

In the socioecological studies, epiphytic communities were uncovered, and even the keys were formed in accordance with the parameters such as canopy openness, tree type, crust feature (acid-basic, etc.) and tree diameter in the forest (Prigodina-Lukosiene and Naujalis 2001). There are also studies showing the distribution of lichen species associations with substrates such as natural or man-made stone residues, walls and rocks in habitats varying by the degree of exposure to haemerobic factors (human impact, urbanization, air pollution, etc.) (Lisci et al. 2002). Lichen species in a tree trunk may exhibit vertical propagation depending on microclimatic conditions. Çobanoğlu et al. (2008b) stated that the highest density of lichen species is between 16 and 18 m and that 11% of the species is above 6 m, with species density increasing between 4 and18 m in 27–37-m-long fir trees. The species distribution with 2 m intervals along the tree was observed, and some lichen species (*Bryoria fuscescens, Caloplaca herbidella, Cyphelium inquinans, Lecanora argentata, Ochrolechia androgyna, Pseudevernia furfuracea and Ramalina thrausta*) were reported to occur first 2 m above from ground, and about 47% of the species frequency occuring at above 4 m on the tree.

In some cases lichen species can also unite with mosses in the same environment (Sjögren 1988). In a study conducted by clustering analysis in Sweden (Bengtsson et al. 1988), it was observed that in the areas grouped by the habitat characteristic (siliceous, calcareous rocks or soils, limestone, coniferous or leaved forest types of forests, pastureland, etc.), algae and mosses formed by vegetation included in vegetation together with high plant communities.

Studies on lichen sociology are currently limited, and there is a need to increase these studies to better understand the ecology of lichens.

10.2.3 Ecological Factors Affecting Lichens

Lichens show susceptibility to climate changes (abiotic ecological factors) in general, as well as to changes in the chemistry of air, habitat and substrate (biotic ecological factors), as they feed on air.

In particular, the change in the concentration of elements and gases leading to atmospheric pollution negatively affects the likelihood of development. For this reason, the majority of lichen species are selective about habitat and substrate. In the case of contamination, there are differences in the colonization of lichen species in that region. The lichen composition of the region varies depending on the sensitivity of lichen species.

Environmental factors affecting the natural development of lichens are classified by Huckaby (1993) under the headings “macrohabitat” and “microhabitat” factors.

Macrohabitat factors:

1. Sunlight (the intensity and quality of the light is important, the light wavelength required for photosynthesis should be 460–640 nm)
2. Wind (speed and frequency)
3. Temperature (maximum, minimum, seasonal values)
4. Humidity (rain, snow, fog, annual average, minimum and maximum values)
5. The chemistry of atmospheric air (nutrients, toxins, acidity, and the type and proximity of pollution sources in the environment)

Microhabitat factors:

1. Substrate (topography, chemistry, stability, humidity and type such as rock, tree bark, moss, other plants, man-made materials)
2. Soil (structure and chemistry of soil is important, such as pH, toxins, nutrients, colour, particle size, water retention capacity, % rock content and % plant cover)
3. Atmospheric gases (concentration changes in, e.g. CO_2, ozone)
4. Forest cover (canopy). Percentage of openness of the top cover (% open area ratio) formed by tree branches and leaves that are shading in the forest

Most of the factors in this area are influenced not only in lichens but in different dimensions on many living beings around. Species choose their habitat according to whether these factors are suitable for their survival or to live there according to their ability to adapt to those conditions. In this context, ecological valences of lichens determine their tolerance limits. In addition, the impact ratings of ecological factors vary according to the lichen species.

10.3 The Environmental Roles of Lichens in Natural Ecosystems

10.3.1 Pioneers in Succession and in Soil Formation

Lichens living on bare rocks, which other creatures cannot hold, pioneer the formation of soil by slowly piercing and eroding the rocks with lichen acids they secrete. A thin soil layer formed over the rock will make possible growing of other lichens and mosses and so higher plants with the increase of organic matter.

The roles of the lichens in shaping the natural life are great. They can sustain life on bare rocks where no creature has ever existed before they can begin their first viability (primary succession). Saxicolous lichens provide soil formation by crumbling the rocks they hold with lichen acids they secrete, in a very long period of time. In this way, there they prepare suitable grounds for other living species such as mosses and higher plants. It enables the development of other species of lichens and mosses in the thin soil layer formed and higher plants with the continual increase of the organic matter. Likewise, in an environment that has previously been alive but has been damaged in some way, lichens can resume life (secondary succession). Thus, lichens are pioneer organisms that function both in primary succession and secondary succession.

10.3.2 Erosion Prevention Feature of Lichens

Terricolous (epigeic) lichens, such as tree roots, soil algae and mosses, are among the creatures that hold the earth and prevent it from slipping.

The foliose cyanolichen species such as *Collema*, *Leptogium* and *Peltigera*, as well as many other fruticose, crustose and squamulose soil lichen species such as *Cetraria* and *Cladonia*, catch and firmly grasp the soil particles by the hyphae of their mycobionts. Thus, lichens are among the erosion prevention organisms such as some soil algae, mosses and root crops.

10.3.3 Functions in the Mineral Cycles in Ecosystems

The organisms involved in the "nitrogen fixation" phenomenon, which means that nitrogen N_2 ($N \equiv N$) from the atmosphere is converted into ammonia (NH^{4+}), are only photosynthetic cyanobacteria and certain bacteria, so the nitrogen in the air becomes available for other plants as well (Sodhi and Ehrlich 2010). Cyanobacteria also maintain this function in the lichen. In this respect, cyanolichens also play an important role, especially in the atmospheric nitrogen cycle. For example, blackish colour *Collema* and *Leptogium* species, grey-brown *Peltigera* and green colour *Lobaria* species commonly found on the soil surface or on tree bark are among the cyanolichens in the foliose form, usually containing *Nostoc* as cyanobacterium. In ecosystems such as temperate rainforests and some subarctic ecosystems where cyanolichens are abundant, the nitrogen rate is remarkable.

The poikilohydric structure of lichens affects the hydrological cycle (water cycle) even in some systems where the biomass is small. In arctic and subarctic regions, lichens that constantly cover the ground can permanently saturate the soil (when not frozen) by preventing evaporation from the soil. Lichens, which are part of the cryptogamic crust commonly found in uncontaminated soils in arid and semiarid regions, facilitate the draining of water into soil in this layer. Even epiphytic lichens can change the hydrological cycle in ecosystems.

There is evidence that lichens may affect daily, monthly and seasonal mineral cycling. Changes in ecosystems affect N, P and S cycles (Sodhi and Ehrlich 2010). Al, As, Ca, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Sc, Ti, V, Zn, N, P, S, C, O and H elements retained by the lichens and the compounds containing them, the accumulation of macro- and microelements in the thallus and the effects on the balance of ecosystems are still the subject of many studies.

10.3.4 Nutrient Source and Habitat for Fauna

For some animals, lichens are a food source with a critical prescription because it is very difficult for them to find plants in the winter. The nutritional requirements of animals such as deer, roe and squirrel vary according to season, age, sex and location. In this case, the lichens play life-saving role until autumn.

Cladonia stellaris is the most abundant lichen species, and the filamentous *Bryoria* and *Alectoria* species are also eaten by deer in boreal forests. *Cetraria islandica* and *Cladonia rangiferina* are the nutrients of reindeer. Reindeer and caribou take their soil lichens out of snow. Lichen *Alectoria sarmentosa* known as the witch's hair is an important source of nutrients for the black-tailed reindeer. Especially these deers and the other animals fed with lichens have special enzymes called "lichenase" for the digestion of lichens (Svihus and Holand 2000; Jewell and Lewis 1918).

Lobaria linita, foliose tree lichen, is eaten by mountain goats in Alaska. Lichen *Bryoria fremontii* with filamentous morphology is a food and nesting material for squirrels. The predominant winter food of flying squirrels is composed of *Bryoria* species (Rosenireter et al. 1997). The raised-nosed monkeys, endangered in China, are also fed by two species of *Bryoria*. Snails are also among the living things that are usually fed with lichen. It was also noted that spruce forest poultry and wild turkeys were fed with lichen (Sharnoff 1997).

A wide variety of invertebrates and many kinds of insects such as moths, butterflies and caterpillars including springtails (Collembola), barklice (Psocoptera), lacewings (Neuroptera) and moths (Lepidoptera) among the lichen thalli for feeding (Nash 2008) can be called "lichenivorous" (fed with lichen).

It is known that many mammalian species feed on lichens. Diets of deer, elk, aquarium, musk oxen, mountain goat, arctic pole, field falcons, tree falcons, mountain rats, squirrels, apes and some domestic animals may contain lichens as supplement or winter feed for normal diets (Seaward 2008).

In the food pyramid in the ecology, the lichens different from the other non-lichenized fungi are not in the consumer's step, but in the producers' step by photobiont. For this reason, lichens, which produce their own food by alga/cyanobacteria partners who can make photosynthesis, are the producers in the food chain. The decrease in the number of species of lichen group by pollution or other reasons in vegetation will affect other living groups. The damage of one of the circles in the food chain will harm human beings both directly and indirectly, by affecting the animals that feed on, use as nest, and other animals fed with it.

The thalli of fruticose and foliose lichens that develop on the rocks or in the crevices have nesting and hatching environments for various invertebrates and insects. For example, *Ramalina* species are nesting environment for lady bugs (*Coccinella septempunctata*), photographed from Turkey (Fig. 10.3).

Some foliose and fruticose lichen species are birds' nesting material, for example, *Parmelia sulcata* as nest material of common finch bird *Fringilla coelebs* (Karabulut and John 2006), photographed in the province of Çanakkale in Turkey (Fig. 10.4), and humming birds that nest with the foliose *Lobaria pulmonaria* the so-called lung lichen. Some birds utilize the white lichen, *Thamnolia vermicularis*, which grows on

Fig. 10.3 *Ramalina* lichens on rock as nesting environment for lady bugs. (Photo by F. Atak)

Fig. 10.4 Bird nest made of foliose lichen *Parmelia sulcata.* (Photo by Ş.N. Karabulut)

the soil, for the construction of nests. The weaver's bird seems to have made its nest completely out of *Usnea* species.

Besides the fact that lichens are hatchlings for invertebrate animals, the loss of this important nutrient source also affects complex food webs where bird populations are dependent. Many bird species use lichens as nest materials, while others prefer certain lichen species with camouflage and decorative purposes at the same time. It is difficult for them to distinguish from the environment with entangled entities, but they become evident when they move. Flying squirrels (*Glaucomys sabrinus*) are highly selective in the selection of lichen material; they use in particular three species of *Bryoria* as nesting material (Rosenireter et al. 1997).

10.3.5 Bioindicators for Atmospheric Pollution

Since this is not a waterproof protective layer like chitin, lichens take directly all the pollutants in the air such as sulphur dioxide, metals, radioactive substances and so on and accumulate them in their thallus. For this reason, they exhibit susceptibility to atmospheric origin contaminants, especially at levels varying by species especially those with large surface areas. Except for some durable crustose species, susceptible lichen species exposed to haemerobic impacts in an area show biological deterioration and gradually begin to fade away. Thus the lichen of that zone shows the level of air pollution. The use of lichens as a biological indicator for air quality is a well-known approach for a long time.

10.3.6 Lichens in Biodegradation Events

Many living organisms in different biological structures, such as algae (blue-green, green, golden yellow, red, brown or black), bryophytes, lichens, bacteria and some fungi are among the organisms that develop on the rocks in general (Küçükkaya 2014). It is known that these organisms lead to the perforation, crumbling and disintegration of the rock over time, that is, they are worn out from the surface, which is called "biological destruction" or biodegradation, that is, "biodeterioration".

Appropriate climatic factors (temperature, humidity, rain, sun exposure or glare, inorganic and organic pollutants) and even optimal environmental conditions can be found on the surface of stone structures (aesthetic damage) and sometimes deeper (physical and chemical damage) for the development of organisms. Macroscopic organisms such as epilithic microorganisms (cyanobacteria, bacteria, various algae, mould fungi, etc.) and birds, some insects, plant roots, bryophytes and lichens are living groups responsible for biodeterioration (Scheerer et al. 2009). Each has different aesthetic, physical or chemical effects.

Lichens trigger physical and chemical damage because lichen acids can make the substrate soluble and break down (Caneva et al. 1991). One of the most obvious effects of lichens is the formation of pits or holes. In addition, lichens enrich the organic matter on the rock surface and form a thin layer of soil, allowing higher plants to develop here.

One of the important ecological features of lichens is their acidic properties, which they secrete, to form pits on the rocks and provide soil formation over time. For this reason, lichens are among the organisms causing biodegradation. As they are natural rocks, man-made stone structures (historical monuments, buildings, etc.) also cause consequent changes and deterioration of chemical and physical events (St Clair and Seaward 2004). By dissolving carbon dioxide released from lichenin respiration, holes are formed on the stone, and the crumbling occurs. When compared with this natural phenomenon occurring on the geological time scale, it can be considered that the effect of biodegradation is weak since the historical process is not very long. However, the role of biological destruction in architectural stones is important. It is an important issue to protect the historical rocks, sculptures, cultural and architectural value of stone works without biodeterioration. If these organisms are not required to colonize the organisms, techniques should be used to prevent them. Care should be taken to ensure that the surfaces covered by the biological organisms are cleaned so that no more species are destroyed as the stone is not damaged.

10.4 Biodeterioration and Biodeteriorative Organisms

From the definition of deterioration, which means loss of structural capacity over time due to external factors or material weakening, a description of "biodeterioration" was specified by Hueck (1968) as "any undesirable change in the properties of a material caused by the vital activities of organisms". In the same way, Rose (1981)

Table 10.1 Groups of biodeteriorative organisms growing on rocks

Prokaryotic organisms	Eukaryotic organisms
Bacteria	Algae
Cyanobacteria (blue-green algae)	Fungi
	Lichens
	Mosses
	Plants
	Animals

defines biodeterioration as the process by which biological agents are the cause of reduced structural quality or value.

Biodeterioration and biodegradation terms are often misused in place of each other. As stated by Allsopp et al. (2004), biodegradation relates to the use of microorganisms to modify materials according to a favourable or beneficial purpose, whereas "biodeterioration" is attributed to the negative effect of living organism activity. Biodegradation refers to the disintegration of materials by bacteria, fungi or other biological means. The term is often used in relation to sewage treatment, to environmental remediation (bioremediation) and to plastic materials.

Biodeterioration is classified into three categories (Gaylarde et al. 2003). These processes may occur separately or at the same time depending on the "biodeteriogens", the structure of the material and the environmental conditions.

1. Physical or mechanical
2. Aesthetic (fouling or soiling)
3. Chemical (assimilatory and dissimilatory)

The living organisms most commonly associated with biodeterioration of construction materials, biodeteriogens, are grouped as below (Sanchez-Silva et al. 2008):

1. Marine borers (e.g. gribble and shipworms)
2. Insects (e.g. termites and wood-boring beetles)
3. Fungi (moulds), algae, lichens
4. Microorganisms (bacteria, cyanobacteria)

The living organisms causing biological deterioration on rocks are indicated in Table 10.1. The general properties of each group were comparatively summarized under the following headings (Küçükkaya 2014).

10.4.1 Bacteria (*Bacteria, Cyanobacteria*)

Bacteria are single-celled organisms or are cells into colonies characteristically associated in chains or clusters. A bacterial cell in various shapes, small enough to be seen only under a microscope (1–10 microns), cannot be seen visually. Bacterial cells often form closely aggregated mats called biofilms to attach to surfaces. Bacteria within biofilms are more protected and it is much more difficult to eliminate.

Cyanobacteria known as blue-green algae are photosynthetic and aquatic organisms which also take place in the kingdom *Bacteria*.

Bacteria and blue-green algae (*Cyanobacteria*) are the most simple and small-celled organisms. Another important common feature of these two groups is they have prokaryotic cells. For this reason, bacteria are considered more primitive; all living things except this group are eukaryotes.

Cyanobacteria bear the name “blue-green algae” due to the blue pigment phycocyanin. Also, they contain the green pigment chlorophyll, like other algae, and so are photosynthetic bacteria with blue-green colours. Most of the other bacteria having no chlorophyll cannot make photosynthesis. They produce their own food through chemosynthesis using inorganic sources such as sulphur, methane and nitrogen. Most of the bacteria live in other cells as parasites and some are pathogenic causing disease.

A slippery greenish or blackish trace is formed on stone surfaces when colonized by cyanobacteria (e.g. *Gloeocapsa*, *Nostoc* and *Oscillatoria*).

There are three types of bacteria known to live on the stones (sulphate, nitrate, heterotrophic) (Fig. 10.5).

Sulphate bacteria (sulphur oxide bacteria), decomposing white lead $PbCO_3Pb(OH)_2$ often formed by a combination of lead carbonate and lead hydroxide by chemical way, cause to occur black-coloured PbS in the region. This way the surface colour turns to grey. Sulphate bacteria can be identified in this way. Gypsum,

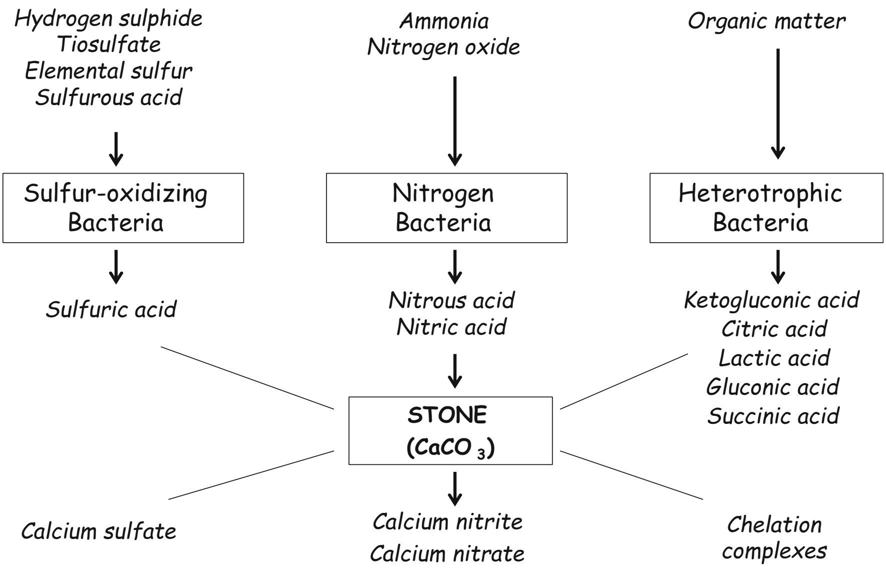

Fig. 10.5 The action scheme for bacteria living on stone (Caneva et al. 1991)

causing superficial and structural degradation of limestone, may be a typical reaction of sulphur oxide bacteria especially of "*Thiobacillus*" type in dirty air (Alexopoulos and Mims 1979).

10.4.2 Algae (Algae or Seaweeds)

Algae, commonly known as "seaweeds", single-celled or in colonies of microscopic forms or multicellular filamentous or leafy macroscopic forms up to several metres in size, are the photosynthetic organisms like plants, whose body is termed a thallus (no organs such as leaves, stems and roots but a whole body). Algae have green, golden yellow, red and brown colours due to consisting of different pigments, which is one of the most particular criteria for their classification. They are separated into various classes located in the kingdom Protista. There are thousands of algae species in sea or freshwater and on land, living in damp habitats such as rock faces, tree trunks and soil. A few even live endolithically within the pores of rocks in deserts, relying upon night-time dew for their source of moisture. Algae have a worldwide distribution and are prominent in bodies of water and common in terrestrial environments and are found in unusual environments, such as on snow and on ice. Some species of green algae "Chlorophyta" (*Trebouxia*) and blue-green algae "*Cyanobacteria*" (usually *Nostoc*) can establish a unique symbiotic life (common life of two or more species of organisms) with species of certain groups of fungi that participate in the internal structure of lichens. Organism of lichen is now not similar to the fungus or the alga consisted inside and is different in physiological structure as well as in the outer appearance. Since both groups of lichen-forming algae have green pigment "chlorophyll", this provides the necessary nutrients to lichen by photosynthesis.

The algae on land are often pioneer organisms as well as lichens growing on bare rock (if the moisture is enough to survive). The rock weathers and crumbles, the algae die, and the remains of both contribute to formation of soil. This leading activity opens the way for more demanding plants to invade.

Algae colonize ledges and projections, cracks and crevices and areas of water run-off. One key characteristic of algal colonization is that they rarely exhibit any sharp boundaries. A further distinguishing feature is that the most commonly encountered species group of algae are a distinctive yellow-green colour (sometimes orange).

According to a review on colonization of algae that causes deterioration of cultural heritage in European countries of the Mediterranean Basin, about 172 taxa of *Cyanobacteria* and Chlorophyta (green algae) were reported in 32 analysed papers. The most commonly mentioned taxa among the *Cyanobacteria* are *Gloeocapsa*, *Phormidium* and *Chroococcus*; and among Chlorophyta are *Chlorella*, *Stichococcus* and *Chlorococcum* (Macedo et al. 2009).

10.4.3 Fungi (*Fungi*)

Fungi having some characteristics in common with both plants and animals are examined under a separate kingdom (*Fungi*). They are made up of colourless cells called “hyphae” lacking chlorophyll and avoid carrying out photosynthesis. Some of the mushrooms (*Basidiomycota*) may contain coloured pigments. They have cell walls like plants but consisting of “chitin” as a main component instead of cellulose. Fungi having about 60,000 species live in water or on land saprophytic or parasitic on animals and plants. Members of the group of *Ascomycota* are mould-forming fungi (a mass of hyphae called mycelium) and the yeasts. The moulds occur in different coloured blots such as black, white or brownish on shaded surfaces of stones and other habitats with enough moisture.

Fungi may have a mutualistic association (life association in which both of the partner species benefit from each other) with plant roots forming mycorrhizae occurring on roots of about 95% of all seed plants. They are probably essential to the survival in nature of both partners. The plant derives an enhanced ability to absorb essential minerals and greater resistance to root diseases. The fungus obtains sugars directly from its partner, without competition from other microorganisms.

Specific groups of the fungi (frequently *Ascomycota* and some *Basidiomycota*) come together with green algae and/or blue-green algae in another mutualistic symbiotic association with the form of lichens. Fungi inside the lichen thallus can be observed only under the microscope. They are involved in sexual reproduction of lichens via their spores. In addition, surrounding algal cells with their hyphae, they participate in producing vegetative reproductive structures of lichens. By wrapping algal cells with their hyphae, fungi provide a humid environment for algae, and so external influences and likely desiccation of algae are preserved. When algal and fungal cells come together, they begin to produce lichen substances, and they create a variety of colours, and a new live view of both of them is different, in a lichenized fungi.

As well as bacteria, algae and lichens, fungal activity initiates pitting corrosion on reinforced concrete structures with time (Sanchez-Silva et al. 2008). Fungi may participate in biodeterioration process on stone monuments or works of art by either itself as a fungus species (such as *Cladosporium herbarum*, *Aspergillus niger* and *Penicillium* sp., frequently with dark spots) or involving in the thallus of a lichen species.

10.4.4 Lichens

Lichens are organisms that live on a variety of substrates such as rocks, stones, bricks, soil, tree bark and wood and are usually miscalled “mosses” among the people. Patterns of many lichen species come together to form different coloured and shaped spots on rocks. Biological structure consists of the algae (*Cyanobacteria* and Chlorophyta) which is located together often with the fungi of an *Ascomycete* (or rarely a *Basidiomycete*, especially in tropical regions) in one body “thallus”.

Lichens unlike mosses have white, black, orange, green, red, yellow, brown and a variety of colours and hard and brittle structure. They sometimes thrive together with mosses side by side or on. General appearances are mainly separated into the thallus types: crustose (appears crust-like and attaches to substrate very tightly), foliose (a leaf-like thallus that attaches to substrate by rhizines, root-like extensions underside of the thallus), fruticose (attaches to substrate at one point and appears shrub-like or filament-like), squamulose (scale-like thallus that appears in between crustose and foliose, attaches to substrate in one or more points underside) and leprose (a granular or powdery form of the crustose thallus) (Figs. 10.6, 10.7, and 10.8). Leprose lichens are sometimes difficult to be distinguished by the naked eye from algae on rocks or on tree trunks. Algae have more powdery (fine) structure, while leprose lichens have more granular appearance.

The poikilohydric (being able to live in environments with variable water levels) characteristic of lichens makes them survive in extraordinary habitats (Hashton 2000). Since they are resistant to water stress, there are species capable of living in environments ranging from deserts to the poles.

The lichens represented with about 20,000 species on earth grow very slowly. Development of lichens to a visible diameter of up to several centimetres in the form of a rosette takes more than 50 years. The slow development among lichens is probably due to their ability to continue respiration but stop photosynthesis and keep themselves in a kind of dormancy state under drought conditions (Nash 2008). Therefore they can stay alive on old stones for many centuries. Moreover, it is possible to establish the date of elements of historic buildings, by following the annual rates of growth of lichen species and the ones on undated substrata colonized by the same species (Fig. 10.9).

Lichens have an important ability on colonizing a life union (symbiosis) together with at least two species (sometimes triple symbiosis in one thallus). One of the partners is an alga belonging to Chlorophyta and/or *Cyanobacteria*, and the other is a fungus often from *Ascomycetes*. They usually colonize on a substrate in a few years. Lichens which grow on rocks and stones, including man-made rock derivatives such as wall, concrete, marble, stone monuments and works of art, are called "saxicolous". They usually prefer stable stones for colonization. The growth forms of thalli that colonize stone may be epilithic (on the outer surface of rock) or endolithic (inside the rock, within holes or cracks) (Lisci et al. 2002). Epilithic ones may occur

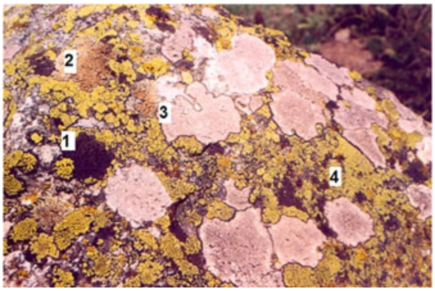

Fig. 10.6 Various lichens on a siliceous rock; *1. Xanthoparmelia* (very dark brown foliose), *2. Lecanora muralis*, *3. Pertusaria* sp. (grey crustose) and *4. Rhizocarpon geographicum* (yellow-black crustose). (Photo by G. Özyiğitoğlu)

Fig. 10.7 A magnified photograph (under stereomicroscope) of the crustose lichen *Rhizocarpon geographicum* (yellow thallus with black spore-producing parts) on a siliceous rock (Photo by G. Özyiğitoğlu)

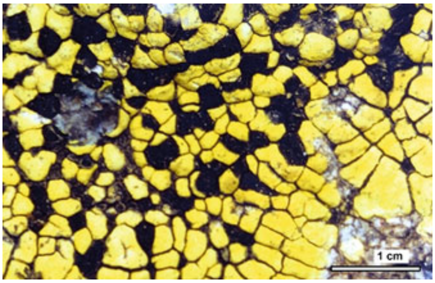

Fig. 10.8 An example of foliose lichen, *Parmelia* attach to substrate tightly by rhizines. (Photo by G. Özyiğitoğlu)

Fig. 10.9 A quite large (60-cm-diameter) and old lichen *Lobothallia radiosa*, growing radially on siliceous rocks. (Photo by G. Özyiğitoğlu)

in several morphological forms of crustose, leprose, squamulose, foliose and fruticose. On lower surfaces, the crustose lichens penetrate into the rock with their fungal hyphae. It is almost impossible to leave it from the surface otherwise scraping. The foliose lichens are also effective with their root-like extensions called rhizines under the thallus to attach to the substrate into the depth of about a few millimetres (Fig. 10.10).

The squamulose lichens attach to rock usually with hapter-like organs in one or more points. The fruticose lichens attach to the substrate on one point and usually hang down. Endolithic lichens, on the other hand, grow inside the rock totally or in part and often appear like a hole (Caneva et al. 1991) (Fig. 10.11). Observation of thin sections from lichen-invaded rocks under stereo microscope indicates size of penetration of fungal hyphae or rhizines. Species such as *Caloplaca crenularia*, *Candelariella vitellina* and endolithic *Verrucaria* spp. have shorter hyphae up to

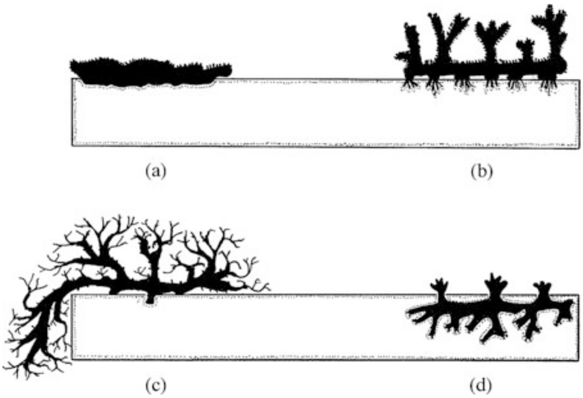

Fig. 10.10 Different forms of lichen growth on stone: (**a**) crust-like lichen; (**b**) foliose lichen; (**c**) fruticose lichen; (**d**) endolithic lichen (Lisci et al. 2002)

Fig. 10.11 An example of endolithic crustose lichen – *Verrucaria muralis* – growing on limestone. (Photo by G. Özyiğitoğlu)

1.5–2 mm in sandstones than *Lecidea fuscoatra* with 4–5 mm in volcanic clastites (St Clair and Seaward 2004).

Lichens produce lichen acids (more than 1000 secondary metabolites unique to lichens) all of which are of fungal origin (Nash 2008). Most of the lichen acids have a relatively low solubility, but they are effective chelators (that can form metal complexes effective in chemical biodeterioration), forming metal complexes with silicates, etc., derived from the substratum (Seaward 2003). Oxalic acid is a strong chelating agent and produced by fungi, lichens and higher plants (Caneva et al. 1991).

As a result of metabolic activity of mycobiont component (fungi), calcium oxalate (CaC_2O_4) crystals are deposited in some lichen species. Oxalic acid ($H_2C_2O_4$) which is extremely soluble in water and acts as a chelator of metal ions forming oxalates (Mg-oxalate, Ca-oxalate or Cu-oxalate) at the thallus/substrate interface is more active than the organic acids (Seaward 2003). Ca-oxalate is more common in lichens; however, all lichens cannot be generalized that produce oxalic acid. Products of lichens generally increase with age and are higher on calcareous rocks than on siliceous rocks.

The saxicolous lichens releasing carbonic acid (H_2CO_3) in considerable amounts cause fine detritions of rocks (Dannin 1992). Intensive cavities are formed on the surfaces covered by lichens as two types: mesopits and micropits (5–10 μm in diameter). Lichen penetrates into depths of 4–5 mm by their hyphae within mortar.

Depending on microclimatic conditions, species of lichens differ on the walls (Arino and Cesareo 1996). A different chemical composition occurs on weathered rocks compared to lichen-free substrates. Additionally, nature of weathered substrate differs according to biodeteriogen species. For instance, Erginal and Öztürk (2009) report more amounts of Fe and S and lesser K and Ca beneath *Xanthoria calcicola* compared to *Diploschistes scruposus* on the same rock.

Chemical mechanism of lichen weathering can be summarized by the following reactions:

1. Deterioration of $CaCO_3$ and $MgCO_3$ through carbonic acid from respiration in two steps
   (1) $CO_2 + H_20 \rightarrow H_2CO_3$ (carbonic acid)
   (2) $CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$
   or $MgCO_3 + H_2CO_3 \rightarrow Mg(HCO_3)_2$
2. Acidic polysaccharides extracting metal ions
3. Oxalic acid, formation of two mineral forms of calcium oxalate (CO), the monohydrated whewellite (COM) and the dihydrated weddellite (COD) (Giordani et al. 2003)
   $Ca(C_2O_4) \bullet H_2O$ (whewellite = monohydrated form of oxalic acid)
   $Ca(C_2O_4) \bullet 2(H_2O)$ (weddellite = dihydrated form of oxalic acid)
4. Organic acids (lichen acids), chelating agents forming mineral complexes.

Effects of climatic change on lichens colonizing cultural heritage stone materials have been overtaken by their adaptive strategies (Arino et al. 2010). Some lichens benefiting from various adaptation strategies such as endolithic thalli development and thick and strong pigmented thalli are well adapted to dry areas with abundant sunlight; on the contrary they develop leprose or microfruticulose thalli by disabling the unnecessary cortex layer when growing on damp and shaded walls.

Lichens are pioneer organisms in ecological succession initiating life on a bare rock. Secreting their specific lichen acids, lichens attach to the rock and crumble it slowly and play a primer role in the soil formation. A thin layer of soil formed on rock allows the development of other lichens and mosses, and continually growing organic matter on rock enables continuous increase in the development of higher plants over time (Nash 2008). One of the most prominent effects of lichens is the formation of pits or crater-shaped holes especially on limestone and calcareous rocks, due to the lichen acids that have solubilizing and disintegrative action on the constituents (Prieto et al. 1997).

Lichens cause direct and indirect weathering of masonry, including gravestones, and often interfere with the legibility of inscriptions. On the other hand, in many countries, lichens are protected by the government and recognized as having equal status to monument conservation.

In the past, attention was drawn to the possible effect of dissolved carbon dioxide, derived from lichen respiration, attacking the substratum to produce pits and channels for easier penetration of hyphae. This is important on a geological time-scale, however, have so far been considered to be minimal in terms of the life of stone buildings and monuments. Seaward (2003) reports that many lichen species create microclimatic effects at the thallus/substratum interface, particularly in terms of water retention, which lead to mechanical damage to stonework on a short timescale of 10 or so years. Furthermore, forces generated by climatic wetting and drying of lichen thalli cause them to expand and contract in conjunction with the chemical breakdown of substrata by lichen acids.

Another well-known ecological feature of lichens is the bioindicator roles of certain species for level of air pollution (SO_2 and other pollutants). They accumulate heavy metals and radioactive materials from the atmosphere by their thallus surfaces (Garty 2001). According to the degree of their sensitivity to air pollution in a region while certain species are eliminated other species are colonized.

The lichen floras vary considerably according to the spatial differences in the chemical properties of stone surfaces, the microenvironmental conditions and the overall influence of air pollution. Changes in air pollution levels cause rapid disappearance of other more sensitive species and alternation in the composition of organisms with less sensitive lichens and other microorganisms. There is a direct correlation between the composition of the flora and the passage of time (Fig. 10.12). The diversity of the lichen flora can be a reliable indication of the level of air pollution which in itself is one of the most serious factors in the deterioration of ancient monuments (Seaward 2003).

Examples of lichen species on ancient monuments in the literature include *Tephromela atra* and *Ochrolechia parella* that are reported among the most abundant lichens colonizing granitic monuments in the region of Galicia (northwest Spain) (Prieto et al. 1997). Sixteen species of lichens were reported growing on the surrounding walls of the Anadolu Fortress and the Rumelia Fortress in Istanbul which are exposed to anthropological impacts by Çobanoğlu et al. (2008a) (Fig. 10.13).

The lichen diversity reported by Uppadhyay et al. (2016) from the monuments in Gwalior division in India are members of the lichen families *Physciaceae*, *Teloschistaceae*, *Verrucariaceae*, *Peltulaceae* and *Lecanoraceae*, respectively, according to species majority. According to morphological types, the most dominant lichen species are crustose species, which are followed by squamulose and foliose ones. The substrata types in various monuments are sandstone, concrete, igneous granite, calcareous and clay.

10.4.5 Mosses (Bryophytes)

Mosses (bryophytes) including liverworts, hornworts and true mosses (95%) are positioned systematically in the plant kingdom. From primitive to advanced order, they are more developed than fungi and lichens but more primitive than the ferns and the vascular plants. Since they contain chlorophyll they are able to make photosynthesis.

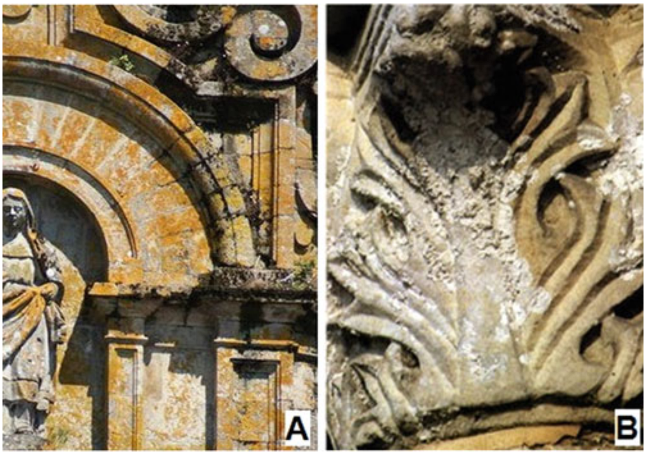

Fig. 10.12 Yellow *Caloplaca* species and diversity of other crustose lichens on the walls of Santiago cathedral in Spain (**a**), photo by H. Sengun. White crusts are *Dirina massiliensis* f. *sorediata* with large amounts of calcium oxalates (**b**) (Nimis et al. 1992)

Fig. 10.13 *Caloplaca flavescens* – one of the lichens on the bottom walls of the Anadolu Fortress in Istanbul (Çobanoğlu et al. 2008a)

Bryophytes, in most recent analyses, are classified into the Marchantiophyta (liverworts), Anthocerotophyta (hornworts) and Bryophyta (mosses). The mosses, unlike the liverworts and hornworts, are present in more terrestrial habitats.

Bryophytes carry all of the organs: leaf, stem and root-like (rhizoids) structures similar to higher plants. They (represented with approximately 26,000 species) live on moist and shady rock, soil and tree trunk appearing green to brown in colour. They can easily be removed from the substrate and so differ from some lichens that stick tight to the substrate with their entire lower surface.

Mosses as biodeteriogens form a green to brown layer depending upon species, much thicker than algal or fungal traces and softer than do crustose lichens on stones; they appear like lowered plants when moist but patches more crusty and darker when dry. They can be easily identified from the presence of leaves and stems with a magnifying glass or even by the naked eye (Fig. 10.14).

Fig. 10.14 Lichens (white-grey patches), mosses (green) and higher plants which are more apparent in winter with the increasing humidity on the calcareous garden walls in Edirne Beyazit Camii (mosque). (Photo by G. Küçükkaya)

Mosses and lichens are macroscopically evident because they cover the material surfaces with visible films of growth. Consequently, an aesthetic alteration is initially noticed (Prieto et al. 1997).

Concisely, algae, lichens and mosses are spore-reproducing multicelled photosynthetic land crops that form a visible microflora on similar habitats. On the other hand, traces or biofilms of bacteria, fungi and some microscopic algae are more difficult to be identified by the naked eye.

10.4.6 Higher Plants and Animals

The roots of trees can grow toward the water they need to live. If necessary, cracking the building blocks can reach water sources (Hashton 2000). Shrubs and trees, especially beech tree with its thick roots, are very dangerous for ancient stones. Even if damages are discussed, the vines, to some researchers, climbing plants were said harmless (Kieslinger 1968).

Lichens and mosses led the process of soil formation on the rock; organic matter gradually increases (Owen and Chiras 1990). Plant seeds coming with wind cling to this environment and develop roots. As roots enter into rock and thickens slowly, deformation increases (Fig. 10.15).

Higher vegetation growing on historical buildings and ruins includes plants such as herbaceous annual *Sonchus tenerrimus* and perennials *Centranthus ruber*, *Parietaria diffusa* and *Sedum pachyphyllum* and trees *Ailanthus altissima* (Lisci et al. 2002). Among the most frequent plants which cause mechanical force and/or chemical damage to stones are *Antirrhinum* spp. (herbaceous), *Capparis spinosa* (shrub), *Ficus carica* (shrub) and *Hedera helix* (shrub) (Caneva et al. 1991).

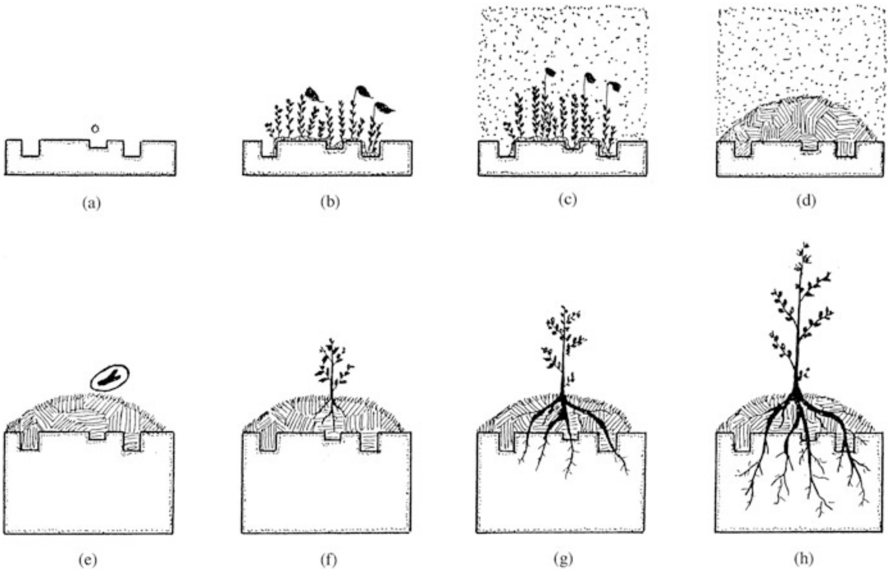

Fig. 10.15 The stages of a second mode of wall colonization. A moss spore (**a**) falls on porous stone, such as travertine, and develops (**b**). Atmospheric dust collects on the moss (**c**) forming a small amount of substrate (**d**). A seed falls on the substrate (**e**), germinates (**f**), grows (**g**) and flowers (**h**). The moss does not damage the substrate but the plant roots penetrate it. (Lisci et al. 2002)

Fig. 10.16 Plants growing on a bridge in Vatican. (Photo by L. Coşan)

Abandoned archaeological sites, particularly in warm tropical or semi-tropical regions, are occupied by plants quickly and are subjected to irreparable damage in a very short time. Small quantities of fragments of earth, moved with the wind, are stored over the archaeological remains. Lack of care is sufficient for the growth of the plants there (Fig. 10.16).

Removing plants and trees at first is the logical solution. Grass should be cleaned regularly throughout the year. If delayed (e.g. if plants established or roots developed well), intended to be difficult and hard to remove plants may cause damage on structures through mechanical cleaning. Especially when thick roots of woody plants penetrate into the walls, taking into account plants uprooted would damage the stone, the plants can be cleaned by cutting. But the growth occurs again. Therefore, the solution is not to cut or remove the roots, rather they should be eliminated by injecting poison.

Herbicides for wild plants are not toxic to human and animals, will not damage agricultural products, do not kill plants in and around the historic surroundings and do not cause chemical or physical damage to the stones. There is a wide field of use of this kind of products. These are neutral triazine compounds and are used as two types, absorbing only roots (chlorotriazines) and absorbing roots and leaves (methoxytriazines). The first type of plant killers is well adapted to both fine-leaved and broad-leaved herbaceous plants. None of triazines penetrate easily into the soil so that reduces the risk of contamination. Effects on plants starts 60 days after the application, and the application is made, in appropriate seasons, especially in spring and autumn periods (Lazzarini and Tabasso 1990).

As for the animals, pigeons living in large masses in the cities should be mentioned. Pigeon droppings with 2% phosphoric acid cover the architectural details in a bad way. Coverings of cornices made of forged metal, copper and zinc are disrupted and pierced. The rain from these goes into the stone walls and wets out and thereby indirectly causes destruction. Even seemingly harmless flies cause destruction, both with their waste left and with holes created by taking some chemical substances on the stone to be fed (Fig. 10.17).

In the case of historical monuments, molluscs (snails), insects and spiders, mussels, clams and sea urchins may be also deteriorative by chemical action of secreted acids and mechanical stress (Caneva et al. 1991). Reactions of all the mentioned biological organisms on different works of art are indicated comprehensively in the Table 10.2.

10.5 Management and Conservation Strategies

When physico-chemical and environmental conditions of a work of art accommodate with the character of the organism's genetics, biological damage can occur (Caneva et al. 1991). If the formation of conditions is prevented, the protection of the material is possible. Conservation methods are indirect methods. The aim is to

Fig. 10.17 Istanbul New Mosque (Yeni Camii)-Hünkar Kasrı, destruction and pollution caused by pigeons. (Photo by G. Küçükkaya (2014))

Table 10.2 Reactions of biological organisms on different works of art

	Stone	Glass	Metal
Autotrophic bacteria	Black crust, black-brown patinas, exfoliation, powdering	Pitting, opacification, black spots, blackened water-logged material	Corrosions
Heterotrophic bacteria	Black crust, black patinas, exfoliation, colour change	Pitting, opacification, black spots, blackened water-logged material	Corrosion
Actinomycetes	Whitish grey powder, patinas, white efflorescence	ND	ND
Fungi	Coloured stains and patches, exfoliation, pitting	Opacification, black spots	ND
Algae	Patinas and sheets of various colours and consistency	ND	ND
Lichens	Crusts, patches, pitting	ND	ND
Mosses	Green-grey covering surface layers	ND	ND
Higher plants	Grass, shrubs and woody species induce cracks, collapse, detachment of materials	ND	ND
Animals			
Marine borers and snails	Holes of typical shape	ND	ND
Birds	Deposition of excrement with corrosive effects, holes, scratches		

ND not described because they do not play an active role on these materials (Caneva et al. 1991)

prevent the development or slow down the surviving conditions for the organism by changing the values of the physico-chemical and biological environmental conditions of work of art if possible (Figs. 10.18 and 10.19).

Among the approaches, Tiano (2016) suggested the biogeomorphology theory as one factor to remove and prevent biological settlements. They proposed a model "Management of Dynamic Durability Model" describing the stone durability concept involving the biodeterioration process.

A close relationship and dependence of biological activity with the environment describes the limiting factors for the most effective method of preventing undesirable developments. Environmental factors cannot be changed all the time but can be changed only in the controlled areas such as museums. Biological destruction at the archaeological sites and the external surfaces of buildings is much more difficult to control. The parameters that can be changed in theory are humidity (Rh and the amount of water contained in the work), temperature and light. It is not possible to change inherent factors supplying these values without disturbing the structure of the work. However, nutritive factors that are not associated with the structure can be reduced (dust, pigeon manure, organic-based, improper restoration materials, etc.).

Fig. 10.18 Dissolution of the superficial surface and exfoliation (detachment) likely to be caused by microorganisms coating on (LRMH 2000)

Fig. 10.19 Chemical dissolution and regional contamination caused probably by the microorganisms viable on shady parts (LRMH 2000)

In places such as museums, libraries, warehouses and churches, factors that led to the development of biological organisms are:

- High relative humidity
- High temperature
- Poor ventilation
- Strong light
- Work containing organic material
- Dust, dirt and materials subsequently added to the restoration

All of these factors can be checked by a continuous care with simple or complex methods such as a complete air conditioning system.

High humidity is the main factor of biological attack that causes increase in development of microorganisms creating biological degradation. Temperature should be kept below 20 °C, 20–16 °C, but should not be forgotten that low heat slows down biological development, not completely avoids. Heat is not a limiting factor. The following measures can be taken, depending on the source of intense humidity: isolation against rising moisture, roof repair, proper water drainage system against leakage of water from the ceiling and the air conditioning to control excess heat. In tropical areas, thick protective walls and roofs or exterior corridors in parallel to artefacts rooms are additional solutions for new buildings. In cold climate regions, heating is essential. Materials can be placed in display cases in small ethnographic museum artefacts. Excess moisture can be absorbed with hygroscopic materials. The silica gel can be used for protection but has a limited capacity and should be replaced when frayed.

To control microclimate is very difficult in indoor places with a high Rh such as caves, tombs or outdoor spaces for public use. The visitors increase heat and humidity. Another indirect adverse effect is due to closing and opening the doors and turning on and off the lights by the visitors. In this case, average values are examined, and the protection requirements are created. If humidity conditions are appropriate, light and inorganic materials also help the development of microorganisms with photosynthesis. For example, in the burial chambers, mosses are numerous, and wall Rh and water levels are high. Since it is difficult to control the temperature and humidity in such places, a single factor to control and reduce the occurrence of the biological destruction is light. The light adjustments vary depending on the type of organisms, lightening quality, quantity and duration. In the dark, it should be considered that some insects and microorganisms (fungus and actinomycete) ceased their developments (Caneva et al. 1991).

Choosing the proper cleaning methods may be useful for the biological control and prevention of the destruction. These are indirect methods. They purify the organic and inorganic materials deposited on the surface of the work of art (actually these materials are often nourishing factors for many organisms) and thus prevent the biological deterioration. The use of some biocides, effective types for microflora on stones such as aqueous TBTO (bis(tri-*N*-butyltin)oxide), CTMQ (cetyltrimethylammonium chloride), copper and silver nitrate and polybor (complex cyclic borates), are suggested by Ginell and Kumar (2004).

Cleaning process prevents deposits in the form of biological diffusion (spores, insect eggs, etc.) which cause infection. Maintaining the control of outside temperature and humidity may be helpful in reducing the biological development. In highly humid environment, a protective cover reduces intense moisture and water absorption. For example, archaeological sites may be retained in the rain. The stone is to be preserved, reduces the permeability and increases the resistance to the water. A complete control of temperature in the outdoor areas is often impossible. Simple shade panels and other shading methods can be used.

Protection of monuments and historic buildings from birds, particularly swallows and pigeons, is another problem. Wires and black nylon nets are the most commonly used methods to avoid them to roost and nest but may result in aesthetic problems if not be given attention to appropriate details. In recent years, new protective gels effective on pigeons have been developed, based on the principle of annoying birds by creating a soft ground. This gel is not sticky and do not stain stone. High-voltage wires are a solution, but there is the short-circuit problem. Avoiding biological growth will help in the protection of archaeological sites and external environment.

In terms of the relationship between environmental factors and plants, planting may be a solution to the problem of stone building protection. For instance, a suitable plantation provides the following effects:

- The water level is reduced by using plants like a biological pump.
- Creating solar panel, microclimate is regulated with plants by minimizing evaporation and radiation.
- Tree planting blocks the wind and wind erosion is reduced.
- Reduce air pollution. Plant selection is important. The roots must not give damage to the buildings.
- In the sun-effective west aspects, plantation is made to form barrier, and so the extreme UV damage to building materials (melting, colour change, etc.) can be kept under control.

10.6 Conclusions

The environment is a broad concept in which all living ecosystems, from microorganisms to plants and animals, interact as a whole. It changes locally or globally as a result of human activities in many directions. These are changes such as temperature, carbon dioxide, rainfall, UV radiation, ozone, acidification and nitrification, and they have direct negative effects on ecosystems and lichen communities. Natural and human-induced adverse factors (such as air pollutants) and various external factors pose a threat to the continuity of the equilibrium. Haemerobic events, such as a rapid climate change, should be taken into account when environmental protection strategies are being developed and protection areas are being selected, so that taxa and ecosystems are being protected.

The long evolutionary history of lichens has seen many catastrophic events in the planet's terrestrial environment, and they will probably succeed in getting rid of it in the future with their unique microbial symbiotic systems.

In addition to a number of significant ecological roles in the environment, biodeteriorative organisms as well as lichens cause weathering of stone substrates. In the case of ancient monuments, biodeterioration of cultural heritage seems a complicated problem, and rational measures should be taken for conservation of these artefacts. For the preservation of historical and artistic stone works, it is necessary to struggle with lichens and similar organisms. The application of preventive approaches to the formation of living organisms is the best way to both avoid harming species and protect these artefacts.

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11 Reclamation of Saline and Sodic Soil Through Phytoremediation

Neerja Srivastava

Abstract

Agricultural productivity is threatened worldwide because of salt-affected soils. Various remediation techniques have been successfully developed and are being utilized, but still there is no proper technical method under different conditions. In different situations, phytoremediation technically as well as economically is the best available option. More focussed efforts are required to measure the contribution of phytoextraction to the remedial procedure because the main mechanism behind salt phytoremediation is still not known. To improve the effectiveness and quality of the treatment of salt-affected soils, many new methods are used like mixing of treatment types, mixed plant cultures, biostimulation, etc. which can be extended to new methods like co-treatment and salt flow control measures. The new methods are in preliminary stages that require further research.

Keywords

Phytoremediation · Saline soil · Sodic soil · Saline-sodic soil

11.1 Introduction

The main environmental limitation in arid and semiarid area of the world for agricultural productivity and sustainability which degrades soil is salinity and/or sodicity (Pitman and Läuchli 2002; Qadir et al. 2006; Suarez 2001; Tanji 1990). In salt-affected soils, there is higher concentration of soluble salts (salinity) and/or Na^+ in the solution phase as well as on cation exchange complex (sodicity). There is production of salts and Na^+ either by the degradation of parent minerals

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_11

which causes primary salinity/sodicity or from human actions because of the mismanagement of land and water bodies which gives rise to secondary salinity/sodicity (Qadir et al. 2007).

About 800 million ha of land in more than 100 countries of the world is contaminated by salt (Rengasamy 2006; Munns and Tester 2008). Saline soils also occur in subhumid and humid landscapes besides arid and semiarid climate (Fageria et al. 2011). It was reported by the United Nations Environment Program that about half of the cropland and 20% of agricultural land worldwide is salt-afflicted (Ghassemi et al. 1995; Cheraghi 2001). It is predicted that by 2050 there will be 50% loss of productive land due to higher salinization of arable lands (Wang et al. 2003). It has been observed that presently sodicity covers almost 4 million km^2 area. According to the US scientific convention, in sodicity, Na^+ represents >15% of the exchangeable sodium percentage (ESP).

In the past few decades, throughout the world, various irrigation schemes have increased soil degradation in different areas such as Indo-Gangetic Basin of India (Gupta and Abrol 2000), Indus Basin of Pakistan (Aslam and Prathapar 2006), Yellow River Basin in China (Chengrui and Dregne 2001), Euphrates Basin in Syria and Iraq (Sarraf 2004), Murray-Darling Basin in Australia (Herczeg et al. 2001; Rengasamy 2006) and San Joaquin Valley in the USA (Oster and Wichelns 2003). Different changes in the environment of Aral Sea Basin of Central Asia by soil damage through salt and irrigation are considered the largest one caused by humanity (Cai et al. 2003). In the different parts of the world, some other examples of salt-prone soil degradation also exist (Ghassemi et al. 1995; Szabolcs 1994).

Saline-sodic and sodic soils become infertile because of low physical properties like slaking, swelling, clay dispersal, surface crusting and hardsetting that severely damage the productivity of crops (Shainberg and Letey 1984; Naidu and Rengasamy 1993; Sumner 1993; Qadir and Schubert 2002). In such soil, osmotic and specific ion stress with disturbances in plant-available nutrients affects plant growth (Suarez 2001; Barrett-Lennard 2002). It has been estimated that all over the world, sodic and saline-sodic soils cover about 560 million ha (Tanji 1990). All over the world, an increase in saline area about 10% per year has been observed (Saboora et al. 2006). To increase crop yield and the varieties of crop species that can be grown in these soils, efficient, cheap and environment-friendly management approaches are required.

Phytoremediation is a plant-assisted approach which can be utilized for ameliorating sodic and saline-sodic soils (Kumar and Abrol 1984; Mishra et al. 2002; Qadir et al. 2002). The phytoremediation of sodic and saline-sodic soils can be done through the ability of plant roots to enhance the dissolution rate of native calcite and removal of Na^+ in plants (Oster et al. 1999). As it is an efficient approach, in saline-sodic soils, it can replace costly chemical amelioration (Qadir and Oster 2002). Many agriculturally important plant species effectively ameliorate calcareous and moderately sodic and saline-sodic soils.

Crops have significant variation in their effectiveness of utilization (Batra et al. 1997; Dagar et al. 2004). Generally the species which produce more biomass and have more ability of tolerating soil salinity, sodicity and periodic inundation can ameliorate soil better (Qadir et al. 2001). Phytoremediation of saline-sodic soils can be done by cultivating those plant species that can tolerate ambient soil salinity and sodicity. Several agriculturally important plant species are very effective in phytoremediation of these soils (Ghaly 2002; Qadir et al. 2002). Some forage species withstand salinity which restricts the growth of conventional crops and are very easy to handle (Aydemir and Akıl 2012).

11.2 Saline, Sodic and Saline-Sodic Soils

11.2.1 Saline Soils

About 40% salt-stressed area of the world is covered by salty soil (Tanji 1990). Non-sodic soil with sufficient soluble salts has negative impact on the productivity of most crop plants. Lower limit of saturation extract, i.e. electrical conductivity of a saturated soil extract (ECe), in these soils is conventionally set at 4 dSm^{-1} at 25 °C, because sensitive plants are affected at 2 dSm^{-1} and highly tolerant ones at about 8 dSm^{-1} (Soil Science Society of America 2006). EC give estimates of total soluble salts (CTSS).

CTSS is calculated from EC by Eq. 11.1:

$$\mathrm{CTSS} \approx 10(\mathrm{EC}) \tag{11.1}$$

CTSS is given in $mmol_c\ L^{-1}$ and EC in dSm^{-1}. An EC of 4 dS m^{-1} is considered good for this relationship (U.S. Salinity Laboratory Staff 1954). Some other approximate relationships between CTSS and EC are also derived (Marion and Babcock 1976).

11.2.2 Sodic Soils

Sodic soils cover around 60% salt-stressed area of the world (Tanji 1990). They are nonsaline soils having sufficient exchangeable Na^+ which under most conditions of soil and plant type severely damages crop production and soil structure. In some countries, these soils are also known as black alkali, alkali, solonetz and slick-spot. A different type of salt-affected soils, saline-sodic soils, is grouped with sodic soils as various characters and the management strategies needed for both are similar. Generally, sodic and saline-sodic soils can be explained on the basis of the relative amounts of Na^+ on the cation exchange complex, or in the soil solution, and by the presence of associating salt concentration.

Actually, soil sodicity results from the joint effects of soil salinity (which can be estimated through electrical conductivity or by soil-to-water suspensions in various proportions) and either the sodium adsorption ratio (SAR) which gives the soluble sodium ion concentration in relation to the soluble divalent cation concentrations in the soil solution or the exchangeable sodium fraction (ESF) which is the percentage of the cation exchange capacity (CEC) meaning the exchangeable sodium percentage (ESP).

The soils are categorized as non-sodic below the value of 15 ESP ((SAR~13). Above this, due to water application, soils become diffusive and have severe physical damages (Soil Science Society of America 2006). If EC is lower than 4 dSm^{-1}, soil may become sodic at ESP values of less than 5 (Sumner et al. 1998). The principal reason which decides the amount of the harmful effects of Na^+ on soil properties is the ambient electrolyte level in the soil solution. Low levels worsen the deadly effects of exchangeable Na^+. ESP is substituted by the SAR within the limit of 0–40 which is the most common one in agricultural soils (Qadir et al. 2008).

11.2.3 Saline-Sodic Soils

These soils contain high level of total soluble salts and have more than 15% exchangeable sodium. Their pH is generally below 8.5. At high concentration of salts, these soils have better physical properties (Diaz and Presley 2017).

11.3 Remediation Strategies

In most of the arid and semiarid regions of the world, salt-affected soils are widely found to reduce agriculture yield and extension. These soils can be reclaimed through effective, economical remediation approaches and better management practices. Sodic and saline-sodic soils generally have many structural problems like slaking, swelling, dispersion of clay and surface crusting which may restrict water and air movement; reduce plant-available water, nutrient availability, root penetration and seedling emergence; and enhance runoff and erosion potential (Suarez 2001; Qadir and Schubert 2002).

These soils can be remediated either by using chemical amendments or by growing high salt- and sodicity-tolerant crops. Gypsums contain calcium (Ca^{2+}) and substitute high amount of sodium ion from the cation exchange sites. This is a well-known method for ameliorating the soil with chemical amendments (Oster 1982; Shainberg et al. 1989), while dissolving of calcite in calcareous saline-sodic soils increased by using sulphuric and phosphoric acid (Mace et al. 1999; Gharaibeh et al. 2010). This replaced Na^+ is either taken up by crops and/or removed from the root zone by surplus irrigation (Qadir and Oster 2002). Chemical amendments are more expensive because of their demand in industry and deduction in government subsidy to farmers. Salt-tolerant varieties can be used for ameliorating calcareous soil, if sufficient amount of water for irrigation and drainage is available. These varieties dissolve more calcite by their roots which results in sufficient amount of calcium in soil solution to substitute exchangeable sodium. Phytoremediation can be done only through the salt removal by crop parts, if they are not supplied again to the same soil (Robbins 1986a; Qadir and Oster 2002; Qadir et al. 2005). The mechanism of phytoremediation is driven by various methods like increase in the PCO_2 in the root zone, proton release in the rhizosphere of some of the legume crops and sodium and salt uptake by harvested shoots (Qadir et al. 2005). Phytoremediation increases the depth of remediation zone and also increases the strength of soil aggregates and soil hydraulic properties as it is a less expensive technology that increases plant nutrient availability (Ilyas et al. 1993; Robbins 1986b; Qadir and Schubert 2002; Gharaibeh et al. 2011).

11.4 Soil Reclamation

To recover any salt-affected soil, the initial step would be testing of the soil and its profile. A salt-alkali soil test can be done to know the condition of the soil characteristics. Through examination of the soil profile with soil inspection, soil permeability characteristics are determined which are significant in removing salts. In certain situations, for successful reclamation, removal by tile drains or open ditches is needed. Before doing any alteration of the affected area, it should be confirmed that the changes (drainage, etc.) do not break the conservation rules. Due to low soil permeability, absence of enough drainage or lack of good-quality irrigation, water amelioration may not be economical. Sometimes reclamation will not be possible or not permanent if the source of the salt problem cannot be resolved or decreased.

11.4.1 Reclamation of Saline Soils

If sufficient amount of irrigation water with less salt or rainfall are available and internal drainage of the soil is also good, then reclamation of saline soil for producing crop is very simple to do. These soils can be remediated through use of sufficient amount of high-quality water to remove extra salts and not by chemical amendment, conditioner or fertilizer. Water should be added in sequential applications for giving sufficient time for the soil to leach after each application. Water needed for reclamation differs in starting salt concentration, preferred salt concentration, quality of irrigation water and the method of water application. There is need of 8–10 inches of leaching water to eliminate 70% of total salt in each 12 inches of soil by sequential applications leaching.

11.4.1.1 Leaching

Those saline soils which are irrigated with large amount of water having less salts can be remediated because salts percolate below the root zone. In the start, the quantity of water running through the profile and away from the root zone (the leaching fraction) decides reclamation rate. Therefore, sufficient drainage should be done in the soil to adjust sufficient leaching fraction. Before the reclamation can be done, drainage should be provided to lower the water table when salts come from shallow water table. In certain conditions, another crop or land should be used because reducing the water table might be a costly affair. Irrigation of soil with water that contains medium to high salt concentration results in different types of saline soil. Salt accumulation is minimized by leaching, but the whole problem will be resolved only by securing alternate irrigatioon source to mix with or changing the low category water. Even by using the finest management methods, salt reduced only 1.5 times the EC of the irrigation water.

Sandy soils are coarser and needs less efforts to filter salts because it has higher infilteration rates and use extra water over less period of time. While clays are fine-textured and require more efforts to take salts out of the soil due to lower infiltration rate and addition of less water only once which creates trouble with ponding and runoff.

11.4.1.2 Other Management Practices

In the absence of high-quality water and/or sufficient drainage, crops tolerant to salinity should be selected. Though at germination plants are more sensitive to salt, they become more tolerant at maturity. If germination is the primary concern, it is not essential to remove all salts out of the root zone but only move salts far from the germinating seed. Even when complete reclamation is not possible, soils can remain productive. Careful management and continual monitoring is required in these situations so that productivity remains acceptable. Tolerant crops (such as alfalfa and barley) can be irrigated with more salty waste water which is generated by a coal-fired power plant and mixed with sufficient land water to use slightly above of evapotranspiration. Crop produce can be utilized in eliminating salt, improving water infiltration and supplying organic material. Therefore, vegetation management is a very significant portion of remediation. Plants have great difficulty in absorption of water under saline conditions as salts increase osmotic potential of water present in soil. Therefore, for a crop to get sufficient water, level of moisture must be kept high in saline soil than nonsaline soil as it requires lesser volume of irrigations very often. To keep higher soil moisture in saline soils, drip irrigation can be effective. Elemental sulphur, gypsum, other calcium materials and other soil amendments add salts in soil that worsen the problem instead of remediation. All soil amendments including manures and composts should be studied to know the type and level of salts present as any material dissolved in water will increase salt burden and raise electrical conductivity of soil. Elimination of salts from the root zone is the only way to remediate saline soils by having good drainage and using high category irrigation water.

11.4.2 Reclamation of Sodic and Saline-Sodic Soils

In most of the conditions, it is not cost-effective to reclaim sodic soil since it is very expensive. To fully remediate sodic soil, excellent soil and crop management for a very long time is needed, although it can be improved by many reclamation procedures.

To remediate sodic soils, extra sodium must first be substituted by other cations and then should be removed. To treat sodic soils, the sodium is replaced by calcium from a soluble source. The most cost-effective source of soluble calcium for treating sodic soils is gypsum ($CaSO_4 \cdot 2H_2O$). To supply calcium indirectly in calcium-rich soils (soils with extra $CaCO_3$), elemental sulphur (S) can be applied. The oxidation of sulphur which is oxidized in soil forms sulphuric acid that combines with the calcium carbonate to make gypsum. But this procedure has restricted use because elemental sulphur is slowly oxidized. For reclamation of 1 foot deep sodic soil on 1 acre, approximately 1.7 tons gypsum is needed for every milliequivalent of replaceable sodium per 100 g of soil. Sodium which is moved past the root zone is leached upon application of gypsum and addition of sufficient high-quality water. Sodic soil is remediated very slowly because damaged soil structure also improves slowly. A salt-tolerant crop can be grown, and manure or crop residues can be incorporated in early stages of reclamation to add up organic material, due to which water infiltration and permeability rise and fasten the remediation. To remediate saline-sodic soils, extra salts should be leached, and exchangeable sodium should be substituted by calcium. If the extra salts are removed and exchangeable sodium is not substituted by calcium, soil will change into sodic one (Diaz and Presley 2017).

The top three methods used for reclamation of saline and alkali soils are as follows.

11.4.2.1 Eradication

The most common methods generally used to reclaim saline soils are:

1. Drainage
2. Leaching or flushing

Flooding after tile drains is the combination of the two and is the most effective method. The method of leaching is very much effective in remediating those saline soils which possess neutral soluble salts and rich in Ca^{2+} and Mg^{2+} with very little exchangeable Na^+. Water having more soluble salt but less exchangeable Na^+ may be effective for leaching saline-alkali or sodic soils.

Leaching Requirement (LR)

The leaching requirement is that portion of the irrigation water which should percolate through the root zone to restrict soil salinity at any particular point. It may be expressed as a fraction or as per cent and is just the ratio of the equivalent depth of the drainage water with the depth of irrigation water.

This ratio is equal to inverse ratio of the matching electrical conductivities under the conditions of consistent aerial use of irrigation water, no rainfall, no salt removal in the crop produce and no precipitation of soluble content in the soil, which can be given as:~

$$LR = D_{\mathrm{dw}}\tilde{A}—100/D_{\mathrm{iw}} = EC_{\mathrm{iw}}\tilde{A}—100/EC_{\mathrm{dw}}$$

where LR is leaching requirement expressed in percentage, D_{dw} is drainage water depth given in inches, D_{iW} is irrigation water depth given in inches, EC_{iw} is electrical conductivity of the irrigation water in dSm^{-1} and EC_{dw} is electrical conductivity of the drainage water in dSm^{-1}.

To apply this equation, a value is usually assumed for EC_{dw} (8 dSm^{-1} for most of the field crops) to represent the maximum soil salinity that can be tolerated. The leaching requirement is 13, 25 and 38% (taking the value of EC_{dW} as 8 dSm^{-1}) for irrigation waters having 1, 2 and 3 dSm^{-1} conductivities, respectively.

11.4.2.2 Conversion

In this conversion method different chemical amendments are used for varying portion of the caustic alkali carbonates into sulphates and ultimately lost by leaching. All chemical amendments are not suitable for all soil conditions. The amendments suitable for different soil conditions are the following.

Amendments	Soil Conditions
Gypsum	Saline and alkali soil having pH range upto 9
Sulphur	Alkaline and saline-alkali
Iron sulphates oils having pH range	
Iron pyrite	8.0-9.0
Limestone	Saline soils having pH less than 8.0

Chemical reactions involving reactions of salt-affected soils

Chemical Reactions Involving Reclamation of Salt-Affected Soils

1. Gypsum ($CaSO_4.2H_2O$) To ameliorate salt-affected soils, when gypsum is applied, the loss of exchangeable sodium (Na^+) will occur, while calcium will take the place of sodium on the exchange complex. Reaction of gypsum with both Na_2CO_3 and the adsorbed sodium is given below:

$$Na_2CO_3 + CaSO_4 \leftrightarrow CaCO_3 + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

$$\mathrm{Clay}]^{Na}_{Na} + CaSO_4 \leftrightarrow Ca\,[\mathrm{Clay} + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

2. Sulphur The following reaction takes place when sulphur is applied to salt-affected alkaline as well as saline-alkali soil.

$$2S + 3O_2 = 2SO_3 \quad \text{(By the action of sulphur oxidizing bacteria in soil)}$$

$$SO_3 + H_2O = H_2SO_4$$

$$H_2SO_4 + Na_2CO_3 \leftrightarrow CO_2 + H_2O + \underset{\text{Leachable}}{Na_2SO_4 \downarrow}$$

On Calcareous Alkali Soil

The production of H_2SO_4 is common for all soils as mentioned above.

a) $$H_2SO_4 + CaCO_3 \leftrightarrow CO_2 + H_2O + \underset{\text{leachable}}{CaSO_4 \downarrow}$$

$$CaSO_4 + {}^{Na}_{Na}[Clay \leftrightarrow Ca\,[Clay + \underset{\text{leachable}}{Na_2SO_4}$$

b) $$H_2SO_4 + 2CaCO_3 \leftrightarrow CaSO_4 + Ca(HCO_3)_2$$

$$CaSO_4 + {}^{Na}_{Na}[Clay \leftrightarrow Ca\,[Clay + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

$$Ca(HCO_3)_2 + {}^{Na}_{Na}[Clay \leftrightarrow Ca\,[Clay + 2NaHCO_3$$

c) On non-calcareous alkali soil

$$H_2SO_4 + {}^{Na}_{Na}[Clay \leftrightarrow {}^{H}_{H}[Clay + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

3. Iron Pyrite (FeS_2)

The following reaction takes place when iron pyrite is applied to sodic soils.

$$FeS_2 + 3^{1/2}O_2 + H2O \leftrightarrow FeO_4 + H_2SO_4$$

$$FeSO_4 + 2H_2O \leftrightarrow H_2SO_4 + Fe(OH)_2$$

$$H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + H_2O + CO_2$$

$$CaSO_4 + {}^{Na}_{Na}[Clay \leftrightarrow Ca\,[Clay + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

4. Iron Sulphate ($FeSO_4$)

The following chemical reaction will occur when iron sulphate is applied to the soil.

$$FeS_2 + 3^{1/2}O_2 + H2O \leftrightarrow FeO_4 + H_2SO_4$$

$$FeSO_4 + 2H_2O \leftrightarrow H_2SO_4 + Fe(OH)_2$$

$$H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + H_2O + CO_2$$

$$CaSO_4 + {}^{Na}_{Na}[Clay \leftrightarrow Ca\,[Clay + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

5. Lime Sulphur (CaS_5)

The following reaction takes place when lime sulphur is applied to soils

$$CaS_5 + O_2 + 4H_2ODCaSO_4 + H_2SO_4.$$

The production of gypsum will take place from H_2SO_4 in the calcareous soil as follows.

$$H_2SO_4 + CaCO_3 \leftrightarrow CO_2 + H_2O + \underset{\text{leachable}}{CaSO_4 \downarrow}$$

$$CaSO_4 + {}^{Na}_{Na}[Clay \leftrightarrow Ca[Clay + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

In noncalcareous soil, the following reaction will take place.

$$10Na\text{-}Clay + H_2SO_4 + CaSO_4 \leftrightarrow 8H\text{-}Clay + Ca\text{-}Clay + \underset{\text{leachable}}{5Na_2SO_4 \downarrow}$$

Control

The slowdown of evaporation is a significant property for controlling salty soils. Due to this, not only there is a decrease in the upward movement of soluble salts into the root zone, but moisture is also conserved. Salt-free irrigation water should be used. Salt-resistant crops can also be used for successful management of salty and alkali soils.

Highly salt-resistant crops – barley, sugar beet, cotton, etc.
Moderately salt-resistant crops – wheat, rice, maize, etc.
Low salt-resistant crops – beans, radish, etc.

11.4.2.3 Other Methods (Salt Precipitation Theory)

For remediating sodic soils, use of salt precipitation theory is satisfactory. Leaching can be used for removing salts and exchangeable sodium from soils, but removed salts are added in the underground water or streams. They now will carry extra salt when used for irrigation purpose. The soils will now face more salt problems due to the use of these water. Therefore, a new concept of precipitation of salts is given in management of salty soils where salts can be moved away to only 0.9–1.8 m deep (3–6 ft) instead of leaching them completely away. Slightly soluble gypsum ($CaSO_4.2H_2O$) or carbonates ($CaCO_3$, $MgCO_3$) which were soluble only to some extent earlier will be produced in dry periods and no longer will act as soluble salts.

The amount of precipitated salt will vary with composition of the cation and anion present in these salts. Mostly calcium, magnesium, carbonate, bicarbonate and sulphate ions are precipitated. It is estimated that about 30% of the total salts may eventually precipitate. The rest two-thirds of salts will have very little effect on the yields of corn and tomatoes. In this management technique, less water should be added, and wetting should be done very carefully in uniform depth.

11.4.2.4 Irrigation Water Management

Irrigation water which is taken from deep wells consists of high level of bicarbonate and high SAR (high level of sodium in relation of calcium + magnesium). Sodic soils will be formed over time by using this water. The electrical conductivity and the SAR of the irrigation water decide water application impact on soil structure and the possibility of water infiltration problems.

Irrigation water rich in bicarbonate or carbonate can mix with calcium present in soil solution to produce calcium carbonate and removes calcium from it. When calcium is reduced in the soil solution, soil SAR as well as sodium risk increases. Those soils which are not tilled have reduction in water infiltration and percolation by precipitation of calcium carbonate in pore spaces. The most effective means of resolving this problem is the acidification of irrigation water just before using it. Water and carbon dioxide are produced from the reaction of bicarbonates with sulphuric acid which is added in irrigation water (Horneck et al. 2007).

11.5 Phytoextraction (Phytoaccumulation)

In this process contaminants are extracted by plants and accumulated in their harvestable parts. It is the most widely used method to reclaim saline soils (US-EPA 2000). Halophytes and salt-tolerant non-halophytes have the ability to accumulate more salt especially Na^+ and Cl^- in their shoots and are ideal to fix salinity-affected landscapes (Manousaki and Kalogerakis 2011). Salt-tolerant *C. dactylon* stores sodium and chloride in glands of its leaves (Marcum and Murdoch 1994; Parthasarathy et al. 2015), while *T. pergranulata* stores salts in cell vacuoles (Flowers and Colmer 2008). If harvesting has to be done, then the less salt-tolerant plants which can store salts like *Brassica juncea* (Brassicaceae) can be used (Susarla et al. 2002).

11.6 Phytopumping and Water Balance Control

In phytopumping plants are used as a hydraulic barrier to create an upward movement of water in roots which will prevent contaminants either percolating down or diffusing horizontally (Pilon-Smits 2005). In this method, plants behave like ‘organic pumps’ to extract contaminated water in high amount by transpiration (Susarla et al. 2002). Various species of *Salix* (Salicaceae) utilize up to 200 L of water per day (Gatliff, 1994), while perennial forage plants, like *Medicago sativa* (Fabaceae), which are deep-rooted utilize high quantities of soil moisture which prevent extra water from moving in the water table (Ridley et al. 2001). Such plants are probable candidates in these kinds of management process.

11.7 Phytostabilization

Phytostabilization has two steps: the first one is salt immobilization (Gaskin 2008), and the second one is the storage of salts in roots instead of shoots (Huang and Chen 2005). Plants selected for phytostabilization can withstand salt but do not transfer it to the aerial parts, like in *Populus alba* (Salicaceae) 90% of sodium are stored in its roots, while its level in shoots remains less (Imada et al. 2009). This is a very competent salt management mechanism as most of the absorbed salts are stored in roots (Tester and Davenport 2003). Plant roots have significant role in changing the pH and soil moisture content around roots thus coagulating the salt ions and decreasing their ready availability to others.

11.8 Phytotransformation (Phytodegradation)

In this process, salt ions that occur at high levels in the soil are absorbed and passed to plant tissues, where they are degraded to less toxic forms or non-toxic compounds through various metabolic stages (Singh and Jain 2003). Various enzymes like dehalogenase, peroxidase, nitroreductase, nitrilase and phosphatase are synthesized by plants which break down toxic compounds (Susarla et al. 2002; Gaskin 2008). Recently people have become more curious to know the role of symbiotic endophytic microorganisms in phytodegradation method (Zhuang et al. 2007). The endophytic fungi are very crucial for the biosynthesis of gibberellins which have significant role in mitigating abiotic stresses. During examination of the function of the endophyte *Penicillium minioluteum* LHL09 (*Eurotiales*: *Trichocomaceae*), Khan et al. (2011) explained that the stress mitigation capacity of *P. minioluteum* is due to low level of endogenous abscisic acid and high salicylic acid accumulation. There is a rise in the daidzein and genistein concentration in *Glycine max* (Fabaceae) in salt stress by *Penicillium minioluteum*. Khan et al. (2011) concluded that *P. minioluteum* empowered *G. max* to mitigate bad effects of salinity stress by influencing biosynthesis of hormones and flavonoids (Bhuiyan et al. 2017).

11.9 Phytoremediation

11.9.1 Phytoremediation of Sodic and Saline-Sodic Soils

Chemical amelioration of sodic soils in developing countries has several limitations due to lesser quality of amendments with more impurities, limited availability of amendments at the time of need of the farmers for amelioration because of more demands for them in the industrial sector and large decrease or stoppage of government subsidies for agricultural utilization of the amendments. Chemical remediation is very expensive for survival of farmers since the early 1980s as last factor being most dominant one. It has been proved by various sources that phytoremediation can be used for remediation of sodic and saline-sodic soils (Kumar and Abrol 1984;

Mishra et al. 2002; Qadir et al. 2002; Robbins 1986b). In typical plant-based amelioration approaches, certain plant species can be grown in the soils rich in metals and metalloids which hyperaccumulate targeted ions in the shoots and remove them from soil (Baker et al. 1994; McGrath et al. 2002; Salt et al. 1998). The capability of plant roots to increase the calcite dissolution rate, which increases Ca^{2+} ion concentration in soil solution for efficient substitution of sodium on the cation exchange complex, is exploited in phytoremediation of sodic and saline-sodic soil. During phytoremediation, salt concentration in soil solution provides adequate soil structure which adds stability to assist water passage in soil profile and increases remediation (Oster et al. 1999). Phytoremediation is also termed as vegetative bioremediation, phytomelioration and biological reclamation (Qadir et al. 2007).

Phytoremediation is the utilization of the plants to eliminate contaminants from environment and to make them risk free (Salt et al. 1998). They not only treat the soil which is having salt but also give food, fodder, fuel wood and raw materials for industry. This also raises the farmers' earnings in these salt-contaminated lands. Many halophytes were examined for reclaiming salt-affected soils in the past (Ravindran et al. 2007; De Villiers et al. 1995; Gul et al. 2000; Jithesh et al. 2006). Through various experiments many workers have shown that phytoremediation is a valuable amelioration method for calcium-rich saline-sodic and sodic soils. Their performance is similar to chemical remediation (Singh et al. 1989; Ahmad et al. 1990; Qadir et al. 1996a, b). Not only these halophytes have positive effect on salt-contaminated soils, but they can also be utilized like forage and oil seed crops (Glenn et al. 1999). Qadir et al. (2007) have shown that phytoremediation is useful in many aspects as there is no economic burden to buy chemicals. Not only there are monetary and other gains from crops used for remediation, but there is also an increase in soil aggregate strength, macropore formation for betterment of soil hydraulic features, root propagation, higher plant nutrient availability in soil following phytoremediation, more consistent and higher remediation in deeper zones of soil and environmental benefits like carbon sequestration in the post-amelioration soil (Hasanuzzaman et al. 2014).

11.9.2 Phytoremediation of Saline Soil

In phytoremediation, plants are used to remove salts like NaCl, KCl, $CaCO_3$, $MgCl_2$, Na_2SO_4, etc. from soil by storing them in the tissues (Kömives and Gullner 2000; US-EPA 2000). In this method, either plants are intentionally grown into the salt-contaminated area or those already present transport and accumulate salts in their tissues. Their roots also help in removing the salts from the area. This is known as phytoreclamation or biological reclamation (Qadir et al. 2007), biodesalination (Graifenberg et al. 2003) and soil desalinization using halophytes (Rabhi et al. 2009). The final aim of any soil remediation method is to either absorb the contamination or decrease it to safe level to restore the physical, chemical and biological property of the contaminated soil and to maintain its natural, innate fertility (Amer et al. 2013). For this, phytoremediation is a suitable method because not only it enhances the physico-chemical and biological properties of contaminated soil (Arienzo et al. 2004), but once a plant is placed in the designated area, it also helps in decreasing the movement and spreading of pollutants via water and air. Phytoremediation is a rising technology to purify and/or restore major areas of affected soil (Garbisu and Alkorta 2001). The previous testings with plants were done on stabilizing pesticides (Siciliano and Germida 1998), polyaromatic hydrocarbons (PAHs) and aliphatic petroleum hydrocarbon soil pollutants (Hutchinson et al. 2003) and heavy metals (Adams et al. 2013a, b). But, recently, phytoremediation is used for managing and reclaiming salt-contaminated soils (Qadir et al. 2007; Wu 2009). The generic strengths of helpful plants are due to their capability of storing different metallic ions present in salts. Illustrative datasets are supplied by Bhuiyan et al. (2017) from the experiments performed from 2014 to 2016 by utilizing plants in salinity-affected soil of central-western New South Wales.

11.9.3 Phytoremediation of Sodic Soil

Kelley and co-workers have performed experiments in series in California during the 1920s and 1930s (Kelley and Brown 1934; Kelley 1937) for phytoremediating sodic soil. In this experiment, barley (*Hordeum vulgare* L.) was grown for 2 years; the 1-year green manuring was done by Indian sweet clover (*Melilotus indicus* L.) and white sweet clover (*Melilotus albus Medik.*) followed by farming of alfalfa (*Medicago sativa* L.) for 5 years. The plots were not cropped until 1 year followed by cotton (*Gossypium hirsutum* L.) farming after the final alfalfa crop. The first post-reclamation crop cotton has produced 2.10 Mg per hectare after the phytoremediation. In upper 0.3 m layer of soil, exchangeable sodium percentage declined from 65 to 6 in the phytoremediated area. When the first crop was still in the second stage, a phytoremediation treatment was started in 1930 with Bermuda grass (*Cynodon dactylon* L. Pers.) (Kelley 1937). Barley was grown for 1 year after the cultivation of grass for 2 years and then alfalfa for 4 years followed by oats (*Avena sativa* L.) for 1 year. After 8 years of Bermuda grass cultivation in the starting of the cropping, there was reduction of ESP in the upper 0.3 m layer of soil from 57 to 1 and decline of average profile (0–1.2 m) ESP from 73 to 6. It was even higher than gypsum treatment of the previous experiment. Kelley and co-workers have used a phytoremediation method on the basis of the same principles and techniques as employed in the irrigated meadow treatment of Békéscsaba, Hungary (deSigmond 1924). In this test, different grasses and legumes were cultivated in combination with success on a heavy black-alkali soil which gradually remediated. Same procedures were employed efficiently at Fallon, Nevada (Knight 1935), and at Vale, Oregon (Wursten and Powers 1934). For remediating soil, various cropping systems were utilized by the farmers of the USA as well as of Indian subcontinent. These remediation attempts have been made in new lands at west side of San Joaquin Valley of California which was irrigated in between 1950s and 1960s and has calcium-rich soils with a broad spectrum of salinity, sodicity, gypsum and boron levels. Cropping was done commonly in the area during reclamation. Chemical remediation was not utilized much because many soils can be reclaimed without them also (Kelley 1951; Overstreet et al. 1955). Gypsum, sulphur and sulphuric acid were employed for higher rate of reclamation. Barley a winter crop was the first crop cultivated on new ground during remediation in between 1950s and 1960s where border irrigation is utilized to complement annual rainfall. Cotton crop was usually used after one or more barley crops. Before plantation, ripping is done in cotton fields and if needed treated with gypsum, channels were made, and preirrigation was also done. During preirrigation, huge quantity of water (0.25–0.35 m) penetrates due to which substantial leaching and remediation take place. It was shown by farming history of Indian subcontinent that farmers usually begin reclamation of soil contaminated with soil during the period of high rainfall (0.6–0.9 m) from July to September (Gupta and Abrol 1990; Oster et al. 1999). The various options for remediation on the basis of economic condition of farmers are:

1. Gypsum application in the range of 10–15 Mg per hectare on the basis of personal knowledge without examining the soil for gypsum requirement (GR)
2. Before transplantation of rice seedlings, extra irrigations for about 15–20 days to leach out contamination
3. Setting up of tube wells in elevated water table regions with the help of government subsidy and utilizing the pumped water in irrigation and remediation
4. Cultivation of some salt-tolerant crops usually Kallar or Karnal grass like *Leptochloa fusca* (L.) Kunth or *Sesbania bispinosa* (Jacq.) W. Wight or *Sesbania aculeata* Pers. without applying amendment
5. Using farm manure with extended leaching
6. Green manuring before rice cultivation, mostly with *Sesbania* species

Gypsum has become more costly in different regions of the world due to the industrial utilization and decrease in governmental discounts to farmers in the early 1980s (Kumar and Abrol 1984; Ahmad et al. 1990). Therefore, people have started searching the other methods of cheaper remediation. Robbins (1986a) has obtained promising results in remediating calcium-rich sodic soil which resulted due to cropping and irrigation with no gypsum. This inspired a lot of research on phytoremediation (Singh and Singh 1989; Ahmad et al. 1990; Ilyas et al. 1993; Qadir et al. 1996a, b; Batra et al. 1997; Qadir and Oster, 2002).

11.10 Mechanisms and Processes Driving Phytoremediation

There are vast effects on soil properties due to the mechanisms of salt removal from the soil by plants. The complete strategy of effects of plant and its coupled rhizosphere microorganisms in the soil system is not fully probed yet, although the main mechanisms behind the actions are properly known and identified. In reclamation of soils contaminated with salt, plants not only raise leaching conditions but also play its part through two main mechanisms (Qadir et al. 2000, 2005). During the first mechanism, decline in pH is observed due to which more $CaCO_3$ is dissolved that ultimately raises the available Ca^{2+} for replacing cation with sodium (Qadir et al. 2000, 2005; Rasouli et al. 2013; Walker et al. 2013). In the second mechanism, plants take up generally dissolved salts and/or specifically sodium (Rabhi et al. 2009; Shelef et al. 2012; Walker et al. 2013; Manousaki and Kalogerakis 2011). The significance of these two mechanisms is still debatable (Qadir et al. 2006; Rabhi et al. 2009), but some valuable opportunities such as bioenergy crops and cellulose production exist due to the plant biomass production during this process (Abideen et al. 2011; Suer and Andersson-Sköld 2011; Wang et al. 2011; Wicke et al. 2011; Glenn et al. 2013). Various workers (Minhas et al. 2007; Shekhawat et al. 2006; Gharaibeh et al. 2011) have reported that $CaCO_3$ dissolution is likely the main mechanism of remediation as in a salinized soil, but salt uptake by plant is less in comparison to salt intake or salt concentration. It was reported by Qadir et al. (2000) that *Leptochloa fusca* removed only 90% of the salt added by the water applied during remediation process even at best possible conditions like high yield and high-quality irrigation water, and therefore soil salinity increased rather than reduced. Other workers (Rabhi et al. 2010; Ammari et al. 2011; Shelef et al. 2012) have demonstrated the scope of salt and more particularly sodium intake. According to Rabhi et al. (2009), Qadir et al. (2000) have not considered salt deposition in plant shoots. They observed up to 70% reduction in sodium concentration and in salinity of polluted soils on the whole in greenhouse experiments and under non-leaching conditions. Although both mechanisms for salt exclusion are valid, maybe the different outlook resulted from employing different plant species or from different experimental setup like leaching (Qadir et al. 2000) or non-leaching environment (Rabhi et al. 2009), which affects plant intake and storage in the shoots. But, it has to be clarified that significant mechanism of salt removal is due to plant uptake or not, as this can restrict the phytoremediation strategy to calcareous soils, to those conditions where water for leaching is available.

For phytoremediation of soil for salt, either those plants which can withstand salt or halophytes are used. In halophytes, salt uptake is decided by plant species (Tipirdamaz et al. 2006). Classification of halophytes into three categories, i.e. excluder, accumulator and conductor, by Yensen and Biel (2006) is based on their different behaviours in salt remediation processes as conductor plants are relatively new category while excluder and accumulator plants are already well established (Ammari et al. 2008; Gamalero et al. 2009; Shelef et al. 2012; Guittonny-Philippe et al. 2014). In excluders, salts are prevented from entering into tissues due to salinity tolerance mechanism, while accumulators absorb and deposit salts in their tissues. But, in the conductor plants, salts are absorbed and discharged by salt glands moving them from the soil into the air. This classification and mechanisms behind phytoremediation actions are the principal factors for selection of plant species and efficiency of related remediation process. Therefore, if the principal mechanism behind remediating saline soil is dissolution of $CaCO_3$, the best adequate plants will be those which have higher capacity to increase pCO_2 and have stronger and bigger root systems. If plants can tolerate high salinity, then it is immaterial which kind of salt tolerance mechanism is operating. Utilization of accumulator plants is more suitable, if plant uptake is the main factor for successful remediation as they can have greater amount of total salts (more specifically sodium) and have greater aerial biomass yield. For longer active period of remediation during the whole year, perennial plants are more useful. Knowledge of those plants which have salt glands or bladders or in situ visualization of discharged salt for conductor-type plants would be helpful in screening. More work is needed to verify the hypothesis that by sufficient dispersion of salts, the soil recontamination can be avoided (Yensen and Biel 2006).

The function of salt intake in aerial biomass by plants in remediation process is needed to be clarified. If this is significant, it can be extended to those soils which are not calcium-rich soil and/or in non-leaching settings (Rabhi et al. 2009). These noncalcareous soils which are contaminated by soil still pose a major problem. In salt-contaminated soil of France and Hungary, this type of soils occupies almost 30% (75,000 ha) and 23.1% (294,000 ha) area, respectively (Van-Camp et al. 2004). It is very important to develop efficient remediation techniques for these types of soils (Jesus et al. 2015).

11.11 Plants Used for Phytoremediation

There are certain limitations in the plants which are grown in a saline-sodic or sodic soil. Saline soils decrease crop yields (Maas and Hoffman 1977; Maas and Grattan 1999), but sodicity damages physical condition of the soil and disturbs plant nutrition due to higher Na^+ levels which affects plant growth. High Na^+ levels in the root medium decrease Ca^{2+} concentration present for plant intake. Although there is considerable variability among crops, germination and seedling stages are specifically prone to low level of Ca^{2+}. There should be field trials to know local crops which are suitable to saline-sodic or sodic conditions as there is variability among many crop genotypes (Shannon 1997). Due to diversity in salt tolerance, sodicity and need of water between crop species, significant variation in the degree of soil reclamation is found (Robbins 1986b; Ahmad et al. 1990; Qadir et al. 1996b; Ilyas et al. 1997; Maas and Grattan 1999; Gupta and Abrol 1990). Generally, remediation of soils having better infiltration rates and greater hydraulic conductivities by those crops which have more water necessity benefitted from the extra leaching due to larger volume of applied irrigation water. The rate of bioremediation is increased by high salt- and sodicity-tolerant crops which have better growth to produce higher biomass. For soil reclamation, plants capable of growing in salt-contaminated soils are important. To speed up soil reclamation, many workers favour Kallar grass (Kumar and Abrol 1984; Malik et al. 1986; Qadir et al. 1996a), *Sesbania* (Ahmad et al. 1990; Qadir et al. 1996b; Ilyas et al. 1997), alfalfa (Ilyas et al. 1993) or sordan (Robbins 1986b) as the first crop. In soils treated with gypsum, rice has been used as the first crop (Chhabra and Abrol 1977). During reclamation due to purposeful application of extra water, crops employed for bioremediation may have oxygen deficiency. Among others Kallar grass, Bermuda grass, and rice are the one that withstand longer waterlogging or greater soil water contents. It is particularly very important to choose crops which can withstand these conditions in the soils with less hydraulic conductivities which means soils having more clay contents or soils which have layers to limit flow of water. Through proper rotations of the tolerant crops during soil remediation, reduction in water table, removal of salts and replaceable sodium ions and soil compaction can be promoted.

11.12 Factors Influencing Phytoremediation of Salt-Affected Soils

An interaction among different environmental factors like type of soil, pH, organic material, temperature and water and oxygen availability affects phytoremediation. Some factors have direct influence on phytoremediation, while others affect it by altering the salt ion accessibility to plants in working condition (Gaskin 2008). Overall various environmental and biological factors control the availability and absorption of extra salt ions in plant rhizosphere.

11.12.1 Soil Texture

Soils which have greater amount of clay show more water retention in comparison to sandy soils and when it is with slower drainage have more salt retention particularly during time of greater soil evaporation (Setia et al. 2011). Plants adjusted for a specific soil type in salt contaminated sites will be more successful in phytoremediation than those which are adapted for living in different types of soils. For example *Sebania bispinosa* (Fabaceae) is highly adapted for the reclamation of coarse, calcium- rich saline-sodic soil and not only provide better quality forage but also assist in symbiotic N_2 fixation (Qadir et al. 1997). *Leptochloa fusca* (Poaceae) is more suitable for fine, calcareous soils having more salinity and sodicity (Oster et al. 1999).

11.12.2 Soil Organic Matter

Soil organic material affects efforts of salt remediation as addition of organic matter (OM) to saline soil can reduce EC and ESP and enhance water-holding capacity, water percolation and soil bulk density and thus increase stability (El-Shakweer et al. 1998). In addition, OM also affects microbial population buildup (Paul and Clark, 1996). Microorganisms which act like osmolytes store salts balancing their intracellular osmotic potential (Oren 1999), thereby reducing environmental salinity. Okeke et al. (2002) tested the experimental brine solution and found that *Haloferax denitrificans* (*Halobacteriales*: *Halobacteriaceae*), *Paracoccus denitrificans* (*Rhodobacterales*: *Rhodobacteraceae*) and a species of *Citrobacter*

(*Enterobacteriales*: *Enterobacteriaceae*) significantly reduced perchlorates as well as nitrates.

11.12.3 Soil pH

Soil alkalinity and acidity significantly determines species distribution (Allen et al. 1997) as pH affects nutrient availability for plants. The level of macronutrients like nitrogen, phosphorus, potassium, calcium, magnesium and sulphur reduces when pH is >6 (Larcher 1980), while aluminium and manganese are easily available at pH <6 but reach toxic levels with more drop in pH (Barbour et al. 1987). In alkaline soils (pH >8), manganese, iron and phosphates are fixed as comparatively insoluble compounds and therefore become less accessible to plants (Larcher 1980). Most bacteria operate at optimum near neutral to alkaline pH and fungi found abundantly in acidic conditions (Leahy and Colwell 1990). Vascular plants have specific pH tolerance, but many of them perform optimally between 5.5 and 7.5 pH range (Barbour et al. 1987). At pH levels of <3 and > 9, vascular plant protoplasts coagulate (Larcher 1980) disabling plant performance.

11.12.4 Soil Temperature

Temperature of soil affects phytoremediation (Frick et al. 1999) and rate of evaporation of soil resulting in salt accumulation. Temperature influences ion movement conducting electrical charges. Under these circumstances, the carrier velocity (= the electrical conductivity, EC) of an aqueous solution becomes directly proportional to temperature. The electrical conductivity of water and temperature are linearly related between 0 and 25 °C range, with alteration in EC of about 1.8%/°C (Hayley et al. 2009). Vascular plants have different reactions to temperature and various levels of salinity (Wright and Wellbourn 2002). For instance, germination in *Phragmites australis* (Poaceae) enhanced through mixture of low mean temperature (10–25 °C) and midrange (15 ppt) of salinity (Greenwood and MacFarlane 2006). *Cynodon dactylon* demonstrates a wide range of variation in growth to different soil temperatures and salinity levels (Grattan et al. 2004; Wu et al. 2006).

11.12.5 Water and Oxygen Availability

Growth of plant is influenced by waterlogging and high levels of sodium and chloride ions. Groundwater-induced salinization is very common in valley floors where waterlogging also occurs. Hypoxia or anoxia is caused by waterlogging in soils. However, in waterlogging situation more Na^+ and Cl^- are phytoaccumulated in shoot tissues. Generally waterlogging enhances the level of sodium ion by 228% and raises 135% chloride ion level in shoot tissues (Barrett-Lennard 1986, 2002). In some case, the results are surprising like a study examining the salt accumulation capacity of Eucalyptus camaldulensis (Myrtaceae) demonstrated about 850% and 590% more Na^+ and Cl^- accumulation in shoots respectively after about 80 days of 'waterlogging+salinity' treatment (van der Moezel et al. 1988), while Liu et al. (2008) have reported enhanced phytoaccumulation of Na^+ and Cl^- in *Suaeda salsa* (Amaranthaceae: Chenopodioideae) with reduction in moisture levels of examined saline soil.

11.12.6 Plant and Plant-Associated Factors

Some of the important plant factors which influence phytoremediation are plant architecture, nature and amount of root discharges and mechanical properties of roots. Root architecture is one of the main factors in phytoremediation efforts. Plants like those of Poaceae, bearing fibrous root systems, are more effective phytoremediators as they spread over a wider volume of soil in comparison to annuals bearing taproots (Aprill and Sims 1990). Plants having herringbone root morphology are more effective in comparison to those with dichotomous morphology (Fitter et al. 1988). Poaceae efficiently remediate superficial and transient salinity, but tap-root plants are more effective in remediating deep groundwater generated salinity (Robson 2003). Deep-rooted plants have greater capacity for better performance in salt-affected landscapes in comparison to shallow-rooted plants (Brady and Weil 1996) because the first type of plants can efficiently use water present in deeper locations, particularly during the time of less rainfall. In fact, deep-rooted plants reduce the groundwater table level and hence the salinity. In Australia, perennial deep-rooted plants, like *Medicago sativa* (Fabaceae), reduce water table and thus salinity (Ridley et al. 2001). *Cynodon dactylon* (Poaceae) and *Melilotus siculus* (Fabaceae) (Hameed and Ashraf 2008; Teakle et al. 2012) possess relatively long and extending root systems and thus are found to be helpful class in decreasing the water table height in saline soils. *Tecticornia pergranulata* tolerates salinity and waterlogging, due to its robust adventitious root system (Rich et al. 2008). *Thinopyrum ponticum* (Poaceae) also possesses an extensive root system which extends approximately 5 m deep and is useful in reducing the water table in salty soils (Bleby et al. 1997). Roots have another important role in moving sodium ions below to deeper soil layers in saline-sodic soils. The inorganic carbon generally occurs in calcite ($CaCO_3$) and dolomite ($Ca.Mg(CO_3)_2$) forms in such soils (Wong et al. 2010). However, the minimal dissolution capability of calcite and dolomite (several fold lower than calcite) inhibits the release of sufficient Ca^{2+} to substitute the extra sodium ion in the soil (Qadir et al. 2007). During revegetating the salinity-affected areas, plants increase the dissolution of inorganic carbon like $CaCO_3$ by the discharge of CO_2 through root respiration which dissolves in soil water and forms H_2CO_3. In addition, roots of legumes usually release protons (Mubarak and Nortcliff 2010). H_2CO_3 and the proton (H^+) facilitate the dissolution of inorganic carbon, which discharge Ca^{2+} in the soil solution. The Ca^{2+} thus concentrated displaces replaceable Na^{+} from cation exchange complex areas, and ultimately sodium ions move down with water (Naidu and Rengasamy 1993; Qadir et al. 2005). In certain phytoremediation studies in both sodic and saline-sodic soils, release of CO_2 through plants in soil has been quantified. For example, Robbins (1986b) has estimated the root zone CO_2 in *Hordeum vulgare* and *Agropyron elongatum* (Poaceae), *M. sativa* (Fabaceae) and *G. hirsutum* (Malvaceae) during reclamation of calcium-rich sodic soil and reported that the two tested Poaceae produced considerable amount of soil-atmospheric CO_2 that facilitated removal of Na^{+}. Since different plant species provide different amount of CO_2, plant species, producing more CO_2, will be an effective candidate to increase leaching of sodium ion (Qadir et al. 2007). In northern Egypt, after 2 years, physical treatment like ponding and chemical treatment like application of gypsum were less efficient in reducing salinity in comparison to utilization of native grasses like *Phragmites communis* and *Panicum repens* (Poaceae) (Ghaly 2002). Sodium ion removal through leaching because of root-zone CO_2 is a more efficient mechanism than chemical restoration like gypsum use (Qadir et al. 2005; Bhuiyan et al. 2017).

11.13 Conclusion

The two main methods, i.e. phytoextraction and leaching enhanced by plant roots, should be improved through which plants can remediate a salt-contaminated soil for increasing salt phytoremediation. This can be achieved through enhancing salt intake per unit of mass by many biological procedures or through enhancing tolerance to salt stress and thus raising yield or by leaching by bigger and stronger roots to increase salt uptake on whole. Through various management techniques, efficiency of the process can be enhanced. Knowledge of future research trends and co-treatment possibilities can be obtained to manage the complex soil contaminations through the investigation of the potential applicability of different enhancement processes for phytoremediation of salt-contaminated soils.

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Soil Pollution by Fluoride in India: Distribution, Chemistry and Analytical Methods

12

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Abstract

Fluoride is an essential element required for normal development and growth of the body at trace level but is highly toxic at concentration above 1.5 μg ml^{-1}. Pollution of soil by fluoride in India is an old problem but least given the attention. In India, the problem of F^{-} contamination was first reported in groundwater from Andhra Pradesh in 1937. Since then, the cases of fluoride contamination of soil and water are increasing day by day. Presently, in India, 19 states are highly affected from the pollution of fluoride in groundwater and soil. Major source of fluoride in India is mainly from the fluoride-containing rocks, use of phosphate fertilizers, and emission of smelters.

To estimate the fluoride in the samples, numbers of methods are available. Some of the methods are electrochemical method, like potentiometry, voltametry and polarography, chromatography, micro-fluid analysis, capillary zone electrophoresis, sensors, spectroscopy and titrimetry.

Keywords

Fluoride · Soil · Analytical methods · Fluoride source · Fluoride distribution

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_12

Abbreviations

CDTA	Diaminocyclohexanetetraacetic acid
DTPA	Diethylenetriaminepentacetate
EDTA	Ethylenediaminetetraacetic acid
TTHA	Triethylenetetranitrilohexaacetic acid

12.1 Introduction

The first member of the halogen group in the periodic table is fluorine, denoted by the symbol F with atomic number 9 and atomic weight of 18.998 U. It is the lightest halogen and exists as a highly toxic pale yellow diatomic gas at standard conditions. Fluorine has the highest electronegativity; it has a strong tendency to acquire a negative charge and in solution forms F^- ions. Fluoride is an essential element required for normal development and growth of the body at levels below 1.5 μg ml^{-1}; however, at higher doses of fluoride, it is lethal to humans, animals and plants (Khairnar et al. 2015; Choubisa 2010; Fornasiero 2001). In the early 1960s, the green revolution in Indian agricultural sector was adopted with use of modern methods and technology such as high-yielding variety seeds, tractors, irrigation facilities, pesticides, fertilizers, etc. The prolonged applications of fertilizers lead to increasing concern about acidification of agricultural soils and its effects on soil pollutants. Fluoride contamination in soil is attributed to the use of phosphate fertilizers which contain 1–4% F^- as an impurity (Loganathan et al. 2001).The total phosphate fertilizer consumption in India in the year 2003–2004 stands at 4124 tonnes. At this rate of consumption, the probability of F introduction to the soil from phosphate fertilizers would be 82.48 tonnes at median value of impurities.

The contamination of soil by fluoride also depends on the constituents of the natural parent rocks. Fluoride accounts for about 0.06–0.09% of the Earth's crust (Koritnig, 1951). Minerals containing F^- are fluorspar or fluorite (CaF_2), cryolite (Na_3ALF_6), fluorapatite ($Ca_5(PO_4)_3F$), villiaumite (NaF) and topaz ($Al_2(SiO_4)F_2$). Weathering of the primary mineral fluorite releases F^- to the soil. Volcanic and hydro-geothermal activities also release F^- into the environment and contaminate the soil with fluorides; released gases which contain HF also contaminate the air with F^-, which then falls to the surface of the soil along with particulate matter (CEPA 1996; Vithanage and Bhattacharya 2015) (Fig. 12.1). The third major natural source of F^- is from marine aerosol, which contributes globally about 20,000 kg of inorganic F^- annually (CEPA, 1996). Soil pollution by fluoride is basically because of utilization of phosphorous fertilizers, accidental spillage of fluoride-containing chemicals and atmospheric particulate deposition from natural (volcanic eruption) and anthropogenic source (Bhat et al. 2015). The level of fluoride contamination in the soil depends on soil pH and soil types. The average fluoride content of soil ranges from 150 to 400 mg kg^{-1} (Bhat et al. 2015). The impact from fluoride-polluted soil

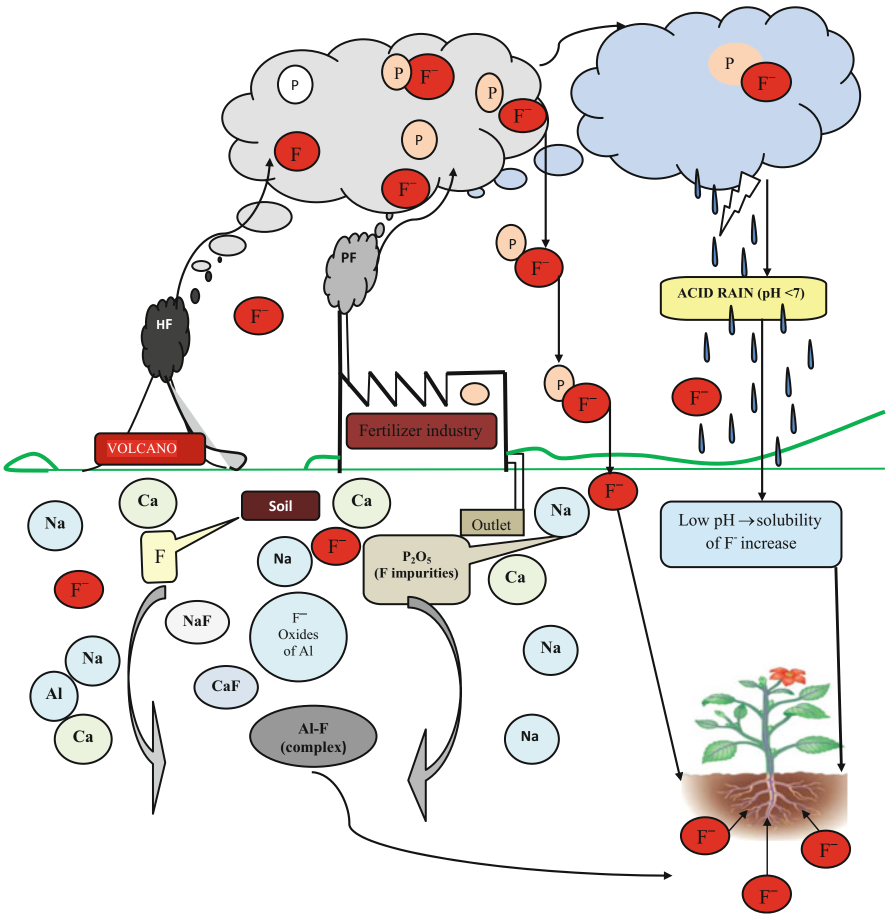

Fig. 12.1 Different routes of fluoride contamination in to the soil

in India is still in its nascent stage, as most of the works are on groundwater. Soil/sediment is the only medium in which all life forms sustain its life from. Understanding the origin and the chemistry of fluoride in soil would provide insight to remediate in an efficient manner.

12.2 Fluoride-Affected States of India

In India, the problem of F^- contamination was first reported in groundwater from Andhra Pradesh in 1937. According to the Indian ministry report, Rajasthan is on the top for F^--affected area having highest number of 7670 habitations with 48,84,613 people. The second state is Telangana with 1174 habitations of 19,22,783 affected people followed by Karnataka with 1122 habitations. The major fluoride-affected districts in India are Kamrup, Karbi, Golaghat, Karimganj (eastern India), Naugaon, Gaya, Jamui, Kaimur, Munger, Bhatinda, Unnao, Sonbhadra (northern India), Ajmer, Bundi, Dholpur, Chhitorgarh, Jalgoan, Mehsana, Udaipur (western India), Salem and Nalgonda (southern India) (Table. 12.1) (Singh et al. 2018).

The major source of fluoride in India is mainly from fluoride-containing rocks. According to physiographic divisions, the northern and western part of the state largely falls within the Great Plain of North India, while southern, middle and the eastern parts are classified under the Peninsular Plateau. This geographical belt is associated with (a) sediments of marine origin in mountainous areas, (b) volcanic rocks and (c) granitic and gneissic rocks; the groundwater in this zone is extensively laden with high fluoride content. High groundwater fluoride concentrations associated with igneous and metamorphic rocks such as granites and gneisses have been reported from India.

Rajasthan has the maximum number of fluoride-affected areas in the country. Fluoride contamination in the range of 98–189 mg kg^{-1} in the soil of Debari, a small town located in Udaipur, Rajasthan, has also been reported. The level of fluoride in soil was found to be correlated to the distance from the smelters plant present in that town and also with depth of the soil (Bhat et al. 2015). The state of Gujarat has some of the oldest fluoride-affected places, where this problem has been reported from Mehsana and Amreli. Maharashtra with Basalt rocks presents a unique fluoride situation, where contamination of soil and groundwater has been reported from Jalgoan district (Naik et al. 2017). The problem from fluoride is also prevalent in the state of Haryana; it has a moderate to high fluoride problem very close to Delhi. Punjab like Haryana has a moderate range of high fluoride problem.

Andhra Pradesh-Telangana state has highly fluoride-affected places such as Nalgonda and Prakasam. The granitic rocks in Nalgonda district contain fluoride ranging from 325 to 3200 mg kg^{-1} (Brindha and Elango 2011). Karnataka with increasing borewells is rising as a highly fluoride-affected state. The state of Tamil Nadu contains dark mineral fraction of gneisses having 180–2600 mg kg^{-1} of fluoride (Jacks et al. 2005). The rapid rise in the use of borewells in Karnataka has also started receiving reports on fluoride contamination in certain pockets of the state. Kerala with Alappuzha and Palakkad has two areas with high fluoride.

The number of fluoride-affected places in Bihar is rising; some of the affected places are Jamui, Gaya and Munger. Chhattisgarh has high fluoride-affected districts such as Korba and Durg. Fluoride-affected West Bengal areas are mostly in the eastern regions bordering Jharkhand. Soil contamination by fluoride was first reported in 1997, in the village of Nasipur (24°17′33.7″N and 87°45′13.6″E) in Nalhati I block of Birbhum District, West Bengal, India, soil contamination by fluoride was first reported in 1997. The town of Unnao, Uttar Pradesh, is also facing the plaque of fluoride contamination of its soil. From Agra to Unnao to Sonbhadra, Uttar Pradesh has hundreds of human population affected with high fluoride. In a project by this same author to assess the level of fluoride contamination of different blocks of Unnao district, it was observed that many blocks were infested with it (unpublished data).

Table 12.1 Districts/area of different states in India having fluoride content more than 1.5 mg L^{-1}

Zone	Fluoride-affected states	Affected district/area	Range (mg L^{-1})	References
East	Assam	Goalpara, Kamrup, Karbi Anglong, Naugaon, Golaghat, Karimganj	1.6–29.0	Chakraborti et al. (2000) and Dutta (2013)
	Bihar	Aurangabad, Banka, Bhagalpur, Gaya, Jamui, Kaimur (Bhabua), Munger, Nawada, Rohtas, Sheikhpura, Nalanda, Lakhisarai	0.2–8.32	Ray et al. (2000), Yasmin et al. (2014), and Singh et al. (2009)
	Chhattisgarh	Bastar, Bilaspur, Dantewada, Dhamtari, Janjgir-Champa, Jashpur, Kanker, Korba, Koriya, Mahasamund, Raipur, Rajnandgaon, Surguja, Durg	–	Gitte et al. (2015)
	Jharkhand	Bokaro, Giridih, Godda, Gumla, Palamu, Ramgarh, Ranchi	0.5–14.32	Srikanth et al. (2008)
	Manipur	Imphal	0.7–0.84	Devi and Kamble (2006)
	Orissa	Angul, Balasore, Bargarh, Bhadrak, Baudh, Cuttack, Deogarh, Dhenkanal, Jajpur, Keonjhar, Khurda, Mayurbhanj, Nayagarh, Nawapara, Sonpur	0.6–9.2	Das et al. (2003), Kundu et al. (2001), and Mishra et al. (2009)
	West Bengal	Bankura, Bardhaman, Birbhum, Dakshin Dinajpur, Malda, Nadia, Purulia, Uttar Dinajpur, South 24 Parganas	1.1–14.47	Sharma (2003), Chakrabarti and Bhattacharya (2013)
North	Delhi	East Delhi, New Delhi, North West Delhi, South Delhi, South West Delhi, North Delhi, West Delhi	0.2–32.0	Susheela et al. (1996) and Singh et al. (2009)
	Haryana	Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendergarh, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonepat, Yamuna Nagar	0.23–18.0	Gupta and Mishra (2014), Meenakshi et al. (2004), and Bishnoi and Malik (2009)
	Jammu and Kashmir	Rajaori, Udhampur	0.5–4.21	Shah et al. (2014), CGWB report (2013), and Sharma (2003)

(continued)

Table 12.1 (continued)

Zone	Fluoride-affected states	Affected district/area	Range (mg L^{-1})	References
	Madhya Pradesh	Chandidogri, Shivpuri	1.5–4.2	Chatterjee and Mohabey (1998) and Nawlakhe et al. (1995)
	Rajasthan	Ajmer, Alwar, Banswara, Barmer, Bharatpur, Bhilwara, Bikaner, Bundi, Chittaurgarh, Churu, Dausa, Dhaulpur, Dungarpur, Sri Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jhunjhunu, Jodhpur, Karauli, Kota, Nagaur, Pali, Rajsamand, Sirohi, Sikar, Sawai Madhopur, Tonk, Udaipur	0.1–10.0	Muralidharan et al. (2002) and Choubisa (1997)
	Uttar Pradesh	Agra, Aligarh, Etah, Kanshiram Nagar, Firozabad, Jaunpur, Mahamaya Nagar, Mainpuri, Mathura, Mau, Sonbhadra, Varanasi and Unnao	0.2–25.0	Ray et al. (1983), Chadha and Tamta (1999), Gupta et al. (1999), and Misra et al. (2006)
	Himachal Pradesh	Una, Solan, Hamirpur, Kangra, Mandi, Kullu	–	Sharma (2003)
	Punjab	Amritsar, Barnala, Bhatinda, Faridkot, Fatehgarh Sahib, Firozpur, Gurdaspur, Jalandhar, Ludhiana, Mansa, Moga, Muktsar, Patiala, Ropar, Sangrur, Tarn Taran	0.4–42.0	Shashi and Bhardwaj (2011)
	Uttarakhand	Dehradun, Haridwar, Udham Singh Nagar	0.1–0.66	Jain et al. (2010) and Seth et al. (2016)
West	Gujarat	Ahmedabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dahod, Junagadh, Kachchh, Mehsana, Narmada, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar, Vadodara	1.5–18.0	Chinoy et al. (1992) and Kotecha et al. (2012)
	Maharashtra	Chandrapur, Raigad	0.11–10.0	Deshmukh et al. (1995)

(continued)

Table 12.1 (continued)

Zone	Fluoride-affected states	Affected district/area	Range (mg L^{-1})	References
South	Tamil Nadu	Coimbatore, Dharmapuri, Dindigul, Erode, Karur, Krishnagiri, Namakkal, Perambalur, Pudukkottai, Ramanathapuram, Salem, Sivagangai, Theni, Thiruvannamalai, Tiruchirapally, Tirunelveli, Vellore, Virudhunagar	0.1–7.0	Handa (1975) and Sarvanan et al. (2008)
	Kerala	Palakkad, Alappuzha, Idukki, Ernakulum, Thiruvananthapuram, Palghat	0.2–5.40	Shaji et al. (2007)
	Andhra Pradesh	Adilabad, Anantapur, Chittoor, Guntur, Hyderabad, Kadapa, Karimnagar, Khammam, Krishna, Kurnool, Mahabubnagar, Medak, Nalgonda, Nellore, Prakasam, Rangareddy, Visakhapatnam, Vizianagaram, Warangal, West Godavari	0.4–29.0	Rao (2003), Rao and Devdas (2003), Sreedevi et al. (2006), and Sujatha (2003)
	Karnataka	Bagalkot, Bangalore, Belgaum, Bellary, Bidar, Bijapur, Chamarajanagar, Chikmagalur, Chitradurga, Davanagere, Dharwad, Gadag, Gulbarga, Hassan, Haveri, Kolar, Koppal, Mandya, Mysore, Raichur, Tumkur	0.2–7.79	Latha et al. (1999) and Wodeyar and Sreenivasan (1996)

Source: Singh et al. (2018)

12.3 Phenomenon of Fluoride Contamination

Soil contamination of fluoride is fundamentally because of three activities: dissolution from fluoride-containing rocks, utilization of phosphorous fertilizers and irrigation of agricultural fields with fluoride-contaminated water. Soil can also be contaminated by fluoride from accidental spillage of chemicals and atmospheric particulates originating from volcanic eruption (Fig. 12.2).

The mean average value of fluoride in soil of India varies greatly from zone to zone. The levels of fluoride were observed to influence by soil pH and content of

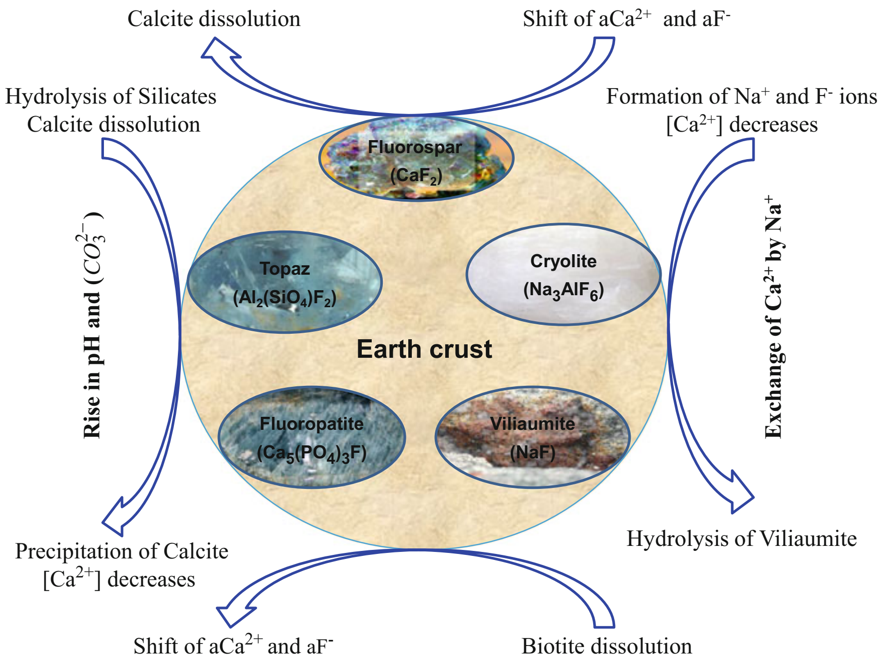

Fig. 12.2 Chemistry of fluoride in soil

clay minerals in the soil (Bombik et al. 2011). Fluoride concentration in the soil usually originates from the parent material, and therefore its distribution pattern in the soil is related to underlying parent rocks. The average fluoride concentration in the soil in India ranges from 90 to 500 mg kg^{-1} (Bhattacharya and Samal 2018). The pH of the soil, soil type and organic carbon content are the prime factors determining the level of soil fluoride concentration (Kumar et al. 2016). Clayey soil is usually associated with high level of fluoride, whereas sandy soil is usually found to have lower level of fluoride in their soil. Weathering of mafic rocks (biotite, pyroxene, amphibole) can also lead to releasing of fluoride in the soil. Fluoride deposition in the soil can occur through many different ways such as dry deposition, precipitation and with contaminated water where it is absorbed readily by the cations present in the soil. The absorbed fluoride originating from different sources increases the total fluoride concentration in the soil; depending upon the pH of the soil, the availability or solubility of fluoride increases and can form complexes with toxic elements such as aluminium and heavy metals. In soil, fluoride can exist as a free fluoride ion (F^-) or form complexes with elements such as iron (Fe), boron (B), calcium (Ca), sodium (Na) and aluminium (Al); the predominant complex found in the soil is that of Al and F (Domingos et al. 2003).

In India, most of the research work on fluoride is on water, particularly on groundwater (Misra et al. 2006; Sreedevi et al. 2006). The loading of fluoride to the groundwater is due to the surrounding geology of the parental rocks. Once the fluoride from its mineral rocks is solubilized to the water system, it can be transported to the surface and has the potential to contaminate the soil with fluoride. Agricultural fields using this fluoride-contaminated water then further contaminate the soil over a period of time.

Fluoride pollution of the soil can also be from fallout of atmospheric suspended particulate matter.

The inorganic fluorides present in the atmosphere consist of hydrogen fluoride and inorganic fluoride particulates, which account for approximately 75% and 25%, respectively. Fluorine and silicon fluorides present in the atmosphere are hydrolysed to form hydrogen fluoride. Hydrogen fluoride then combines with water vapour to produce an aerosol or fog of aqueous hydrofluoric acid. The atmosphere fluorides adsorbed on the surface of particulate matter are stable and are not easily hydrolysed, though it may be degraded by radiation if they persist in the atmosphere (US NAS 1971). Atmospheric fluorides are then transported to soils and surface waters through both wet and dry deposition processes (US NAS 1971).

12.4 Chemistry of Fluoride in Soil

Fluoride is an essential constituent in minerals such as fluorite, apatite, cryolite and topaz. Minerals like biotite, muscovite and hornblende may contain considerable per cent of fluoride. Of the 85 million tonnes of fluoride deposits in the Earth's crust worldwide, 12 million is found in India (Teotia and Teotia 1994). It has a very damaging effect on human beings, plants, animals, aquatic organisms as well as vegetation. The soil receives fluoride-contaminated minerals from the environment. Generally fluoride enters the soil through precipitation, through dry deposition and through contaminated litter. Soil pollution can be a source of fluoride for plants as it can be taken up by the roots (Braen and Weinstein 1985; Hani 1978; Hurd-Karrer 1950; Singh 1990). Fluoride contained in the soil is taken up by the roots of plants and transported to their aboveground parts, where it is accumulated (Singh and Verma 2013).

Bioavailability of fluoride to plants depends on, inter alia, the type and pH of the soil and the content of other elements, e.g. calcium, aluminium and phosphorus, in the substrate. According to Romar et al. (2009) in soils rich in calcium, fluoride occurs in the bound form as insoluble compounds such as CaF_2 or apatite compounds with a similar composition, thus reducing its bioavailability. The formation of CaF_2 may represent a way of detoxification of fluoride, but it may also disrupt the normal Ca^{++} metabolism (Weinstein and Alscher-Herman 1982). It has also been found that fluoride exhibits considerable affinity towards aluminium present in loam and binds easily via anion exchange. Thus, fluoride pollution of soil can lead to increased solubility of aluminium (Polomski et al. 1982), and Hani (1978) has reported increased uptake of Al in plants with increased fluoride pollution of soil. Aluminium in certain forms is toxic to roots, but the availability and toxicity depend on speciation and plant species (Cameron et al. 1986; Care 1995; Grauer 1993). Aluminium may influence the uptake of cations due to competition at absorption and adsorption sites in the roots (Fig. 12.2).

Fluoride is relatively immobile in soil, since most of the fluoride is not readily soluble or exchangeable (Gilpin and Johnson 1980). The solubility of fluoride depends on pH, with maximum sorption in soil usually occurring at pH 5–6 (Barrow and Ellis 1986; Omueti and Jones 1977). However, pH and formation of stable aluminium and calcium complexes are key factors affecting mobility of inorganic fluorides in soil (Pickering 1985). Concentration of inorganic fluoride is considerably higher in the deeper horizons of acidic soils. This may be due to the low affinity of fluoride for organic material resulting in leaching from the more acidic surface horizon and also due to increased retention by clay and silts in the alkaline soil (Davison 1983; Kabata-Pendias and Pendias 1992). But this distribution profile is not observed for exclusively either alkaline or saline soils (Gilpin and Johnson 1980; Davison 1983).

The fate of inorganic fluoride released into the soil also depends on the chemical form, rate of deposition, soil chemistry and climate (Davison 1983). Increased amounts of fluoride are released from fluoride salts and fluoride-rich wastes when solids capable of exchanging cations are present. This effect is more when there are more exchange sites available and also when the fluoride compound cation possesses greater affinity for the exchange material. In sandy acidic soils, fluoride tends to be present in water-soluble forms. According to a study by Street and Elwali (1983) on the activity of fluoride ion in limed acidic sandy soils, fluorite was found to be the solid phase controlling fluoride ion activity between pH 5.5 and 7.0. However, at pH values below 5.0, the fluoride ion activity indicated supersaturation with respect to fluorite. Based on the data, it was concluded that liming of acid soils may precipitate fluorite, with a subsequent reduction in the concentration of fluoride ion in solution.

Apart from pH and exchange with cation, fluoride concentration in soil may also be a result of leaching of its water-soluble form. Murray (1983) reported low amounts of fluoride leaching from a highly disturbed sandy Podzol soil of no distinct structure. However at high fluoride application rate (3.2–80 g per soil column of diameter 0.1 m with a depth of 2 m), only 2.6–4.6% of the fluoride applied could leach in the water-soluble form. But the pH of the elute increased with increasing fluoride application, and this was probably due to adsorption of fluoride, releasing hydroxide ions from the soil metal hydroxides. Also, with the passage of time, the concentration of water-soluble fluoride decreased due to increased adsorption on soil particles.

12.5 Fluoride Estimation Techniques

Fluoride (F^-) is found in every component of the environment, i.e. soil, water, plants and human beings. Analysis of fluoride is necessary to monitor the current status of F^- contamination and also to devise strategies while planning for fluoride mitigation. It can be determined through various methods like chromatography, electrochemical method, micro-fluid analysis, capillary zone electrophoresis, sensors, spectroscopy and titrimetry (Yahyavi et al. 2016) (Table. 12.2).

Table 12.2 Efficiency of different mitigations techniques of defluoridation

Methods/techniques		Efficiency	References
Physical	Adsorption		
	Activated alumina	1.78 mg g^{-1} for 6 h	Ghorai and Pant (2005)
	Aluminium hydroxide	23.7 mg g^{-1} for 6 h	Beneberu et al. (2006)
	Nano aluminium hydroxide	20.7 mg g^{-1} for 0.5 h	Beneberu et al. (2006)
	Precipitation		
	Nalgonda techniques	5.5 to 7.5 mg L^{-1}.	Waghmare and Arfin (2015)
	Membrane process		
	Reverse osmosis	98% (load <15 mg L^{-1})	Sahli et al. (2006)
		<90% (load >15 mg L^{-1})	
	Electrodialysis	1.5–15 mg l^{-1}	
Chemical	Ion exchange		
	Modified polyacrylamide	2290 mg kg^{-1}	Sundaram and Meenakshi (2009)
Biological	Biosorbent		
	Peels of *Citrus limetta*	94.3%	Pandey et al. (2016)
	Fusarium moniliforme	36%	Merugu et al. (2012)
	Phyllanthus emblica	82.1% (contact time 75 min)	Veeraputhiran and Alagumuthu (2011)
	Zirconium-doped *Aspergillus* spp.	94%	Hiremath and Theodore (2017)
	Phytoremediation		
	Tea bush	4000 mg kg^{-1}	Polonskij and Polonskaya (2013)
	P. juliflora	2222.83 mg kg^{-1}	Baunthiyal and Sharma (2012)
	Bioremediation		
	Acinetobacter RH5	25.7% (after 8 days)	Mukherjee et al. (2017)

In electrochemical method, fluoride may be estimated through potentiometry, voltametry and polarography. First fluoride ion-selective electrode (F-ISE) was built in 1966 (Frant and Ross 1966). Using ISE, F^- concentration can be estimated by potentiometric titration (Weinreich et al. 2007), direct potentiometry (Borjigin et al. 2009) and flow injection (Wada et al. 1985). To overcome the problem of formation of complex of ion with F^- in this method, different masking agents are being used like CDTA (1,2-cyclohexanedinitrilo-tetraacetic acid), citrate, TISAB (total ionic strength adjustment buffer), DTPA, TTHA, EDTA, etc.

Fluoride can also be determined in the presence of La (III) and alizarin complex on ALC (alizarin complexone) through polarographic method (Li and Shang 1986). Mao et al. (2013) has proposed an indirect strategy for sensitive F^- ion detection using $K_3Fe(CN)_6$.

Using the chromatography method F^- ion can be analysed through IC (ion chromatography), GC (gas chromatography) and HPLC (high-performance liquid chromatography). Nowadays FID (flame ionization detector) and MS (mass spectrophotometry) are commonly used with GC for fluoride detection. However, GC is less preferred since it's time-consuming and requires high skill. Haldimann and Zimmerli (1993) analysed fluoride ion in the form of fluoro dimethylphenyl silane through GC-FID by extracting with chloro(dimethyl)phenylsilane in cyclohexane. In HPLC, fluoride is detected as the product of reaction of fluoride with triphenylhydroxysilane using UV detector (Musijowski et al. 2010). Compared to the other available chromatographic methods, IC is widely used (Quintana et al. 2003) because it provides the required sensitivity to detect trace level concentration of this ion and other negatively charged F^--containing compounds such as monofluorophosphate (Gunnlaugsson et al. 2006). The use of IC is preferred as the method is simple and highly stable and gives good reproducibility. Another advantage is IC can be used with different detectors like conductimetry, spectrophotometric fluorescence (Jones 1992) and UV-vis detector (Michigami et al. 1993).

In the spectrophotometric method, F^- can form a coloured complex of metal ion like zirconium and thorium (Parham and Rahbar 2009). ICP-MS can be used to detect F^- below the level of ngL^{-1} (Montes Bayon et al. 1999). In 2002, Garrido et al. (2002) proposed simple flow injection fluorometric method in which F^- is detected through fluorescence of quercetin complex with fluorine. NMR spectroscopy method is considered as highly specific for absolute quantification of F^- and its metabolites present in drug or in the biological media. Hull et al. (1988) used NMR spectroscopy at 470 MHz to measure the level of 5 fluorouracil and other catabolites in plasma and urine of colon cancer patients. The best part of NMR is to provide resonance of fluorine nuclei without the problem of interfering with background signals.

Electronic, optical sensor and biosensors are also applied for F^- detection (Prodi et al. 2000; Asav et al. 2009). Biosensor technique has good reproducibility, excellent sensitivity and short response time. An inhibition type amperometric biosensor based on tyrosinase enzyme was reported for estimation of F^- by Asav et al. (2009). In titrimetric method, F^- ion is first titrated with $LaNO_3$ or thorium nitrate followed by the detection either through F-ISE (Abramović et al. 1992) or by a chain of pH value using HF resistant glass electrode (Weinreich et al. 2007).

Capillary zone electrophoresis (CZE) technique has short separation time, high separation efficiency and low consumption of samples and reagents (Li 1992). Wang et al. (1997) have reported new CE method with CTAB as electro-osmotic flow modifier and tungstate as internal standard for the simultaneous determination of MFP (sodium monofluorophosphate) and fluoride.

Flow injection analysis is another method which is also known for simplicity, cost efficiency and less volume sample required on-site real-time measurement, and it may be an alternative method to IC and CE (Farrell et al. 1999).

12.6 Conclusion

The pollution of fluoride is a worldwide problem. In India, 19 states are highly affected from the pollution of fluoride in groundwater and soil. Fluoride is an essential element required for normal development and growth of the body at levels below 1.5 μg ml^{-1}; however, at higher doses of fluoride, it is lethal to humans, animals and plants. Contamination of the soil by fluoride depends on the constituents of the natural parent rocks; weathering of the primary mineral fluorite releases the F^{-} to the soil. Fluoride contamination in the soil is also attributed to the use of phosphate fertilizers and from the use of fluoride-contaminated water for irrigation. With decrease in water table of the country, the numbers of fluoride-affected areas are increasing with passing years. As the source of fluoride pollution in India is due to the geological factor, the only solution for its mitigation is to have an efficient removal technology for water, so that the contaminated water does not cause any serious threat to organism.

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Multielement Analysis Using ED-XRF and ICP-MS from *Couroupita guianensis* for Sustainable Agriculture by Soil Reclamation

13

Kalpna D. Rakholiya and Mital J. Kaneria

Abstract

Various plant residues used for a number of different purposes and huge quantities of different plant materials are also available. Different parts of some plants are rich in nutrients, elements and minerals, yields are readily decomposable, and there is good scope for their further utilization. The fulfilment of improved technology for recycling is much needed. Organic waste recycling can bring tremendous benefits to crop management and soil conservation with clean environmental development. From this point of view, the study aimed for the elemental and mineral composition of the leaf, stem and flower of *Couroupita guianensis* by energy-dispersive X-ray fluorescence (ED-XRF) and inductively coupled plasma mass spectrometry (ICP-MS). X-ray fluorescence is one of the most reliable and accurate methods, it is also a consistent and nondestructive method for analysis of major and trace elements. During the study, it was found that potassium, calcium, phosphorus, magnesium and chlorine detected in significant amount. The exhibited amount of numerous elements and minerals from the different parts of *C. guianensis* suggest a good source for the supplementation of nutrients, elements and minerals for the soil fertility improvement, mineral enrichments and sustaining soil health.

Keywords

ED-XRF · ICP-MS · Sustainable agriculture · Soil fertility · Soil conservation · Soil reclamation

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_13

13.1 Introduction

The multielemental study is much needed in order to study the role of different elements in plant growth. The multielemental analysis of samples has been carried out with energy-dispersive X-ray fluorescence (ED-XRF) technique and inductively coupled plasma mass spectrometry (ICP-MS). Both of these techniques has many advantages over other techniques, like AAS, and other chemical methods, and it is multielemental, is nondestructive, and has better sensitivity and precision.

In ED-XRF, the atoms in the sample material are excited by X-rays, emitted from an X-ray tube. All element-specific X-ray fluorescence signals, the intensities of which are proportional to concentration of respective elements, emitted by the atoms after the photoelectric ionization are measured simultaneously by detector. ED-XRF spectroscopy offers an alternative to digestive methods, in the determination of total elements such as key nutrients, trace elements and heavy metals across a range of sample types. This technique allows simultaneous analysis of all elements nondestructively in minutes, eliminating the time spent using different digestive reagents for different elements (Valkovic 1980; Daly and Fenelon 2017). For elemental analysis, early workers used whole plants. But workers now generally prefer plant parts such as leaves, roots and fruits sampled at specific growth stages, thereby determining the nutrient concentration ranges in these plant parts associated with nutrient deficiency, sufficiency and excess.

Elements contained under natural conditions in soil may differ widely and might be characterized by a variety of parent material; chemical processes; difference in the extraction agent, concentration and time of extraction; and other factors. Mainly parent material, its mineralogical composition and intensity of pedogenetic and weathering processes influence elemental composition of soil (Kabata-Pendias and Pendias 2001). According to Tessier et al. (1979), different elements and their speciation in soil could be defined as exchangeable, bound to the carbonates, bound to the manganese and iron oxides and bound to soil organic matter and residual.

Application of intensive agriculture and modern technique of farming, along with high-yielding varieties and agricultural crop, has increased by manifold. However, with the increased use of chemical fertilizer alone, particularly in an unbalanced manner, problems such as soil productivity and physical and biological degradation are created. In fact, the awareness regarding detrimental effect of chemical fertilizer is lacking in farmers. Among various crop residues such as leaves, bark, stem, twigs are rich in nutrients, used as fuel, remaining are burnt in situ or lie as waste material, which can be readily decomposed, and there is a good scope for their utilization and recycle. The fulfilment of improved technology for recycling of waste in agriculture is much needed. Waste recycling can bring tremendous benefits to crop and land management and clear environment. Hence, the main purpose was to characterize recyclable resource, and potentiality of enhancing the availability of natural resources to augment the plant nutrient is necessary to understand its application. Soil nutrients are important for better plant growth and development. Therefore, the chemical composition, particularly concentration of elemental contents, is very important.

13.2 Elemental Analysis by Energy-Dispersive X-Ray Fluorescence Technique

Plant materials for elemental analysis from the dried crude powder of flower, leaf and stem of *C. guianensis* (Family: Lecythidaceae) (Fig. 13.1) were collected in August 2015 from Motibaug, Junagadh, Gujarat, India. The plant parts were washed thoroughly with tap water, shade dried and homogenized to fine powder and stored in airtight bottles. The processed sample was then subjected to energy-dispersive X-ray fluorescence (ED-XRF) technique for elemental analysis. Sample pellets from the dried crude powder of the plant parts were prepared by hydraulic pressure (Technosearch 30) at 500 psi and used for further elemental analysis in X-ray fluorescence instrument (Panalytical 203137). Benchtop energy-dispersive X-ray fluorescence (ED-XRF) spectrometers used for elemental analysis, X-ray tube with high performance SDD detector with the use of Epsilon 3 software.

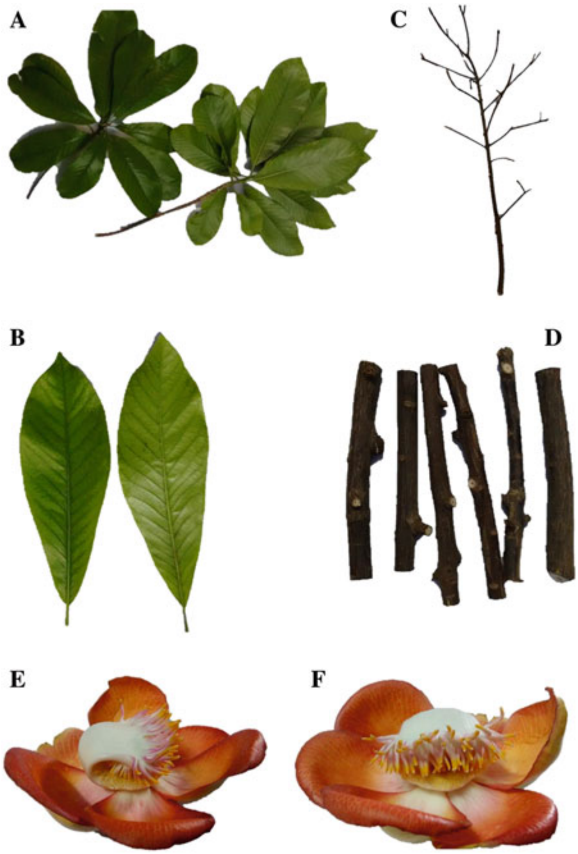

Fig. 13.1 Photo plates of the selected parts for the present study of *Couroupita guianensis*. (**a**) Twig (Leaf + Stem); (**b**) leaf; (**c** and **d**) stem; (**e** and **f**) flower

13.2.1 Extraction

The dried powder of the leaf of *C. guianensis* was extracted individually by cold percolation method (Rakholiya et al., 2015) using petroleum ether followed by aqueous. Ten grammes of dried powder was taken in 150 ml petroleum ether in a conical flask, plugged with cotton wool and then kept on shaker at 120 rpm for 24 h. After 24 h, it was filtrated through eight layers of muslin cloth and centrifuged at 5000 rpm for 15 min, and the supernatant was collected, and the solvent was evaporated using a rotary vacuum evaporator to dryness. This dry powder was then taken in 150 ml of deionized water and was kept on a shaker at 120 rpm for 24 h. Then the procedure followed same as above, and the residues were weighed to obtain the extractive yield and were stored in airtight bottles at 4 °C.

13.2.2 Elemental Ion Analysis by Inductively Coupled Plasma Mass Spectrometry Technique

Elemental ion analysis in aqueous extract of *C. guianensis* leaf was employed by using inductively coupled plasma mass spectrometry (ICP-MS). The ICP-MS system of Perkin Elmer-Sciex (Model – Elan 9000). Sample nebulization was performed for leaf aqueous extract obtained by cold percolation method. The detection modes for isotopes were 'scanning' or 'peak jumping'. The following are the ICP-MS operating conditions: nebulizer gas flow l/min, 0.92; ICP RF power, 1000; pulse stage voltage, 950; lens voltage, 6; dwell time, 50 ms; acquisition modes, scan (peak hopping); sweeps/reading, 1; reading/replicate, 3; replicate, 3; sample flush, 30 s; read delay, 15 s; wash, 30 s; wash solution, 1% nitric acid; and nebulizer gas, argon.

13.3 Interpretation of ED-XRF Data

Flowers, leaves and stem of *C. guianensis* were subjected to energy-dispersive X-ray fluorescence spectrometer (ED-XRF) for elemental analysis. Qualitative analysis charts and spectra acquired by ED-XRF in flowers, leaves and stem are presented in Figs. 13.2, 13.3, 13.4, 13.5, 13.6 and 13.7. The mean concentrations (%) obtained for three samples, namely, flower, leaves and stem, using ED-XRF are shown in Tables 13.1, 13.2 and 13.3. The following elements were found to be present in the samples: K, S, P, Cl, Mg, Ca, Si, Al, Fe, Ag, Cd, Ti, Zn, Cu, Sr, Mn, Ni, Sc and Br. The major components in the flowers constituted CHO (percent wise) which was found to be 94.537%, whereas potassium (K) content was noted to be 3.408% (Table 13.3). The concentration of sulphur (S) (0.498%) and phosphorus (P) (0.414%) were found to be in near range. Content of chlorine (Cl) (0.378%) and magnesium (Mg) (0.332%) were found to be in near range. Calcium (Ca) concentration was noted to be 0.216%, whereas silicon (Si) and aluminium (Al) were found to be 0.088% and 0.066%, respectively. Iron (Fe) concentration was

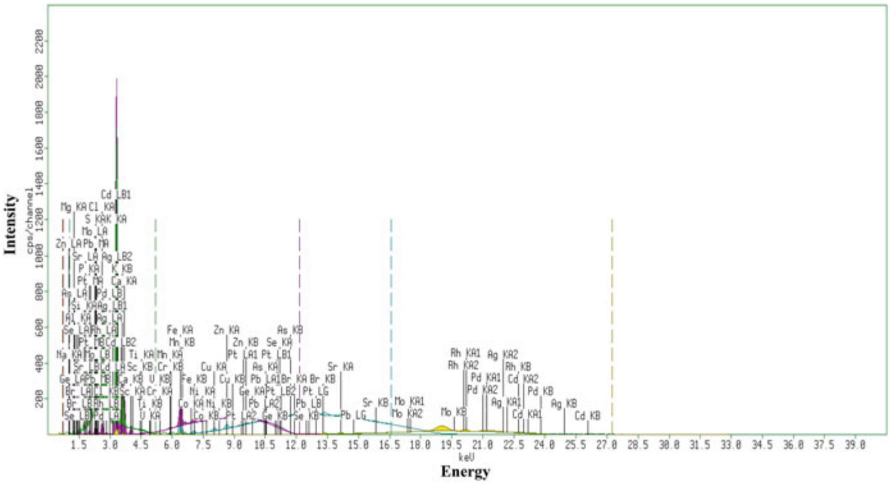

Fig. 13.2 Spectra of XRF for mineral ions in the flower of *Couroupita guianensis*

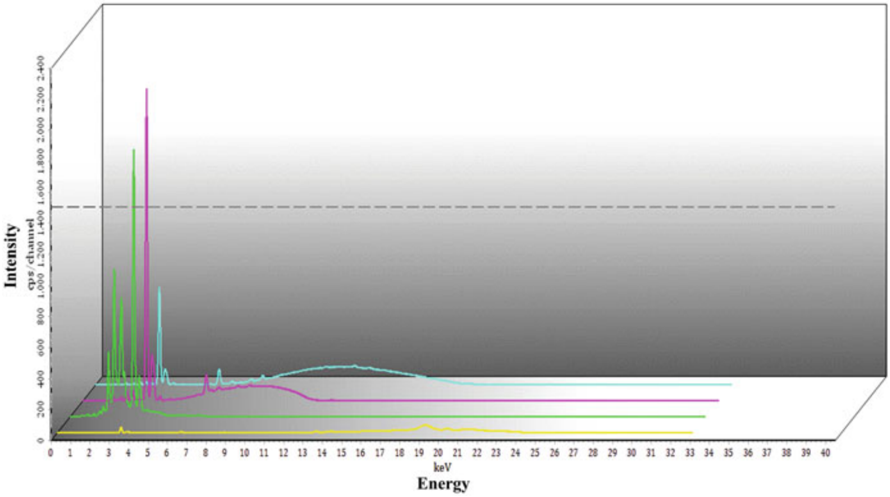

Fig. 13.3 Graph of XRF for mineral ions in the flower of *Couroupita guianensis*

noted to be 0.029%, whereas silver (Ag) and cadmium (Cd) were found to be 0.014% and 0.007%, respectively (Table 13.1). Content of titanium (Ti) and zinc (Zn) were found to be in similar range (0.003%). The concentration of copper (Cu) and strontium (Sr) were found to be in similar range (0.002%). Content of manganese (Mn) and nickel (Ni) were found to be in similar range (0.001%). However the elements which were undetected were bromine (Br), arsenic (As), cobalt (Co), vanadium (V), chromium (Cr), germanium (Ge), molybdenum (Mo), sodium (Na), lead (Pb), platinum (Pt), palladium (Pd), rhodium (Rh), scandium

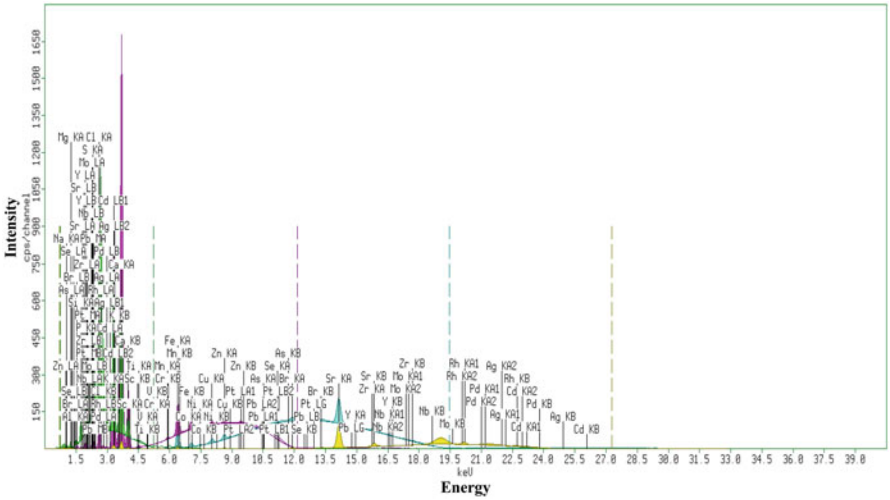

Fig. 13.4 Spectra of XRF for mineral ions in the leaf of *Couroupita guianensis*

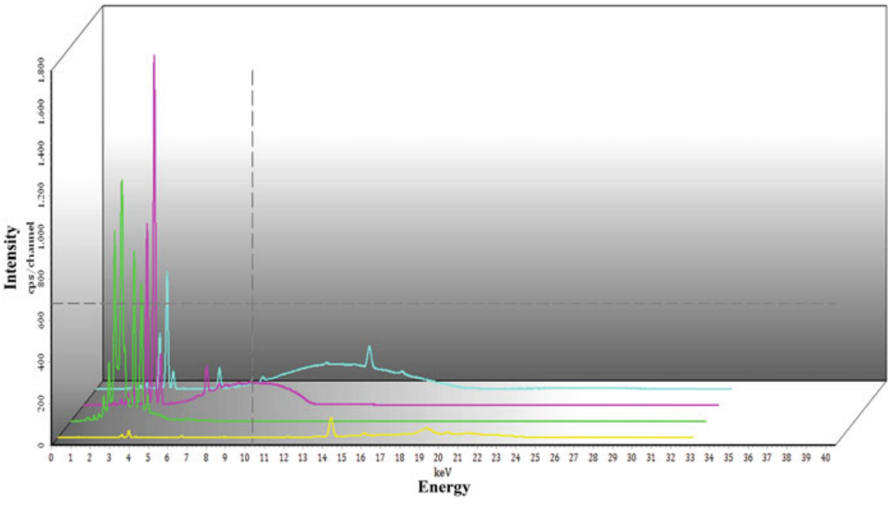

Fig. 13.5 Graph of XRF for mineral ions in the leaf of *Couroupita guianensis*

(Sc) and selenium (Se) in the flowers (Table 13.1).The major components in the leaves constituted CHO (percent wise) which was found to be 94.599%, whereas calcium (Ca) and potassium (K) were noted to be 1.68% and 1.45%, respectively (Table 13.4). Chlorine (Cl) and magnesium (Mg) contents were found to be in similar range (0.571%). Sulphur (S) content was found to be 0.461%, whereas phosphorus (P) and silicon (Si) were found to be 0.236% and 0.205%, respectively. The concentration of aluminium (Al) was found to be 0.131%, whereas strontium

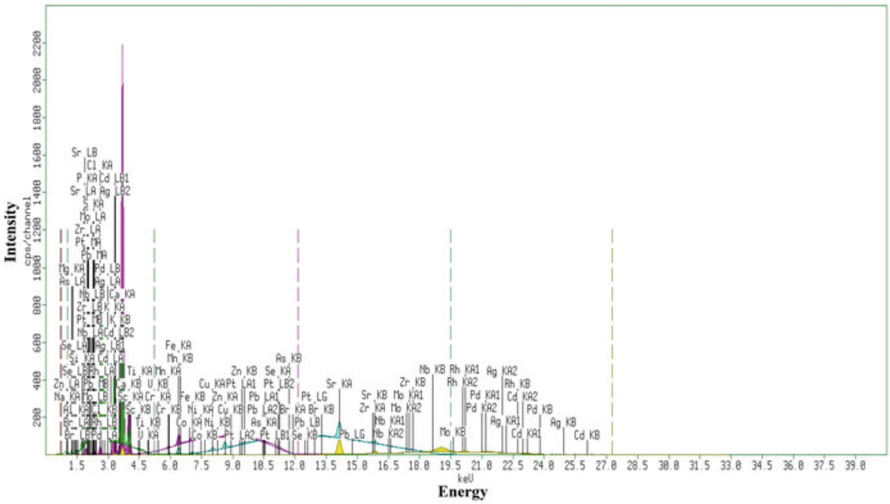

Fig. 13.6 Spectra of XRF for mineral ions in the stem of *Couroupita guianensis*

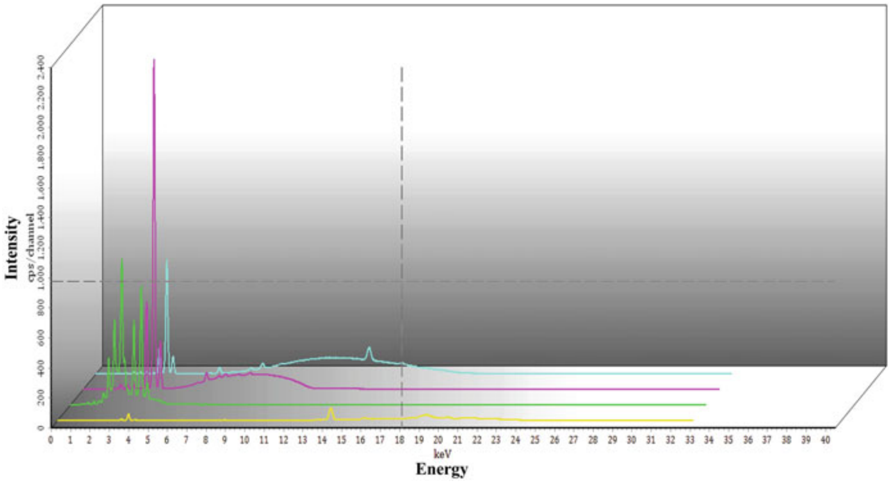

Fig. 13.7 Graph of XRF for mineral ions in the stem of *Couroupita guianensis*

(Sr) and iron (Fe) were noted nearly to be 0.03% and 0.029%, respectively. Important findings were to note the presence of silver (Ag) 0.022%, whereas titanium (Ti) was found to be 0.003% (Table 13.2). The concentration of copper (Cu), manganese (Mn) and zinc (Zn) were found to be in similar range (0.002%). Content of bromine (Br) and scandium (Sc) were found to be in similar range (0.001%). Whereas the elements which were undetected were arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), molybdenum (Mo), sodium (Na), niobium (Nb), nickel (Ni), lead (Pb), palladium (Pd), platinum (Pt), rhodium (Rh), selenium (Se),

Table 13.1 Elemental composition analysed by energy-dispersive X-ray fluorescence (ED-XRF) technique in *Couroupita guianensis* flower

Sr. no.	Element	% mass	Oxide	Mass %
1.	CHO	94.537	K_2O	54.844
2.	K	3.408	$CaCO_3$	14.101
3.	S	0.498	SO_3	9.978
4.	P	0.414	$MgCO_3$	6.878
5.	Cl	0.378	P_2O_5	6.74
6.	Mg	0.332	SiO_2	1.251
7.	Ca	0.216	Fe_2O_3	1.178
8.	Si	0.088	Al_2O_3	0.796
9.	Al	0.066	Ag_2O	0.167
10.	Fe	0.029	TiO_2	0.124
11.	Ag	0.014	CdO	0.098
12.	Cd	0.007	ZnO	0.094
13.	Ti	0.003	CuO	0.073
14.	Zn	0.003	SrO	0.072
15.	Cu	0.002	MnO	0.048
16.	Sr	0.002	PdO	0.037
17.	Mn	0.001	NiO	0.021
18.	Ni	0.001	Cr_2O_3	0.019
19.	As	0	Co_3O_4	0.004
20.	Br	0	MoO_3	0.003
21.	Co	0	SeO_2	0.002
22.	Cr	0	V_2O_5	0.001
23.	Ge	0	GeO_2	0.001
24.	Mo	0	PbO	0.001
25.	Na	0	Na_2O	0
26.	Pb	0	Sc_2O_3	0
27.	Pd	0	As_2O_3	0
28.	Pt	0	BaO	0
29.	Rh	0		
30.	Sc	0		
31.	Se	0		
32.	V	0		

vanadium (V), yttrium (Y) and zirconium (Zr) in the leaves (Table 13.2). The major components in the stem constituted CHO (percent wise) which was found to be 95.592%, whereas calcium (Ca) and potassium (K) were noted to be 2.006% and 0.914%, respectively (Table 13.3). The concentration of magnesium (Mg) was found to be 0.529%, whereas phosphorus (P), chlorine (Cl) and sulphur (S) were noted nearly to be 0.267%, 0.231 and 0.204, respectively (Table 13.3). Silicon (Si) content was found to be 0.115%. Aluminium (Al) concentration was noted to be 0.074%, whereas strontium (Sr) and silver (Ag) were noted nearly to be 0.024% and 0.022%, respectively (Table 13.3). The content of iron (Fe) and zinc (Zn) were found to be 0.011% and 0.003%, respectively (Table 13.3). The concentration of copper (Cu) and manganese (Mn) were found to be in similar range (0.002%), whereas

Table 13.2 Elemental composition analysed by energy-dispersive X-ray fluorescence (ED-XRF) technique in *Couroupita guianensis* leaf

Sr. no.	Element	% mass	Oxide	Mass %
1.	CHO	94.599	$CaCO_3$	54.732
2.	Ca	1.680	K_2O	15.79
3.	K	1.450	$MgCO_3$	9.567
4.	Cl	0.571	SO_3	7.214
5.	Mg	0.571	P_2O_5	3.155
6.	S	0.461	SiO_2	2.352
7.	P	0.239	Al_2O_3	1.268
8.	Si	0.205	Fe_2O_3	0.761
9.	Al	0.131	SrO	0.618
10.	Sr	0.030	Ag_2O	0.199
11.	Fe	0.029	TiO_2	0.087
12.	Ag	0.022	ZnO	0.051
13.	Ti	0.003	Sc_2O_3	0.050
14.	Cu	0.002	CuO	0.040
15.	Mn	0.002	MnO	0.039
16.	Zn	0.002	NiO	0.009
17.	Br	0.001	Cr_2O_3	0.004
18.	Sc	0.001	Y_2O_3	0.004
19.	As	0	CdO	0.003
20.	Cd	0	V_2O_5	0.002
21.	Co	0	SeO_2	0.002
22.	Cr	0	Nb_2O_5	0.002
23.	Mo	0	MoO_3	0.002
24.	Na	0	Na_2O	0
25.	Nb	0	Co_3O_4	0
26.	Ni	0	As_2O_3	0
27.	Pb	0	ZrO_2	0
28.	Pd	0	PdO	0
29.	Pt	0	PtO_2	0
30.	Rh	0	PbO	0
31.	Se	0		
32.	V	0		
33.	Y	0		
34.	Zr	0		

titanium (Ti) and scandium (Sc) contents were also found to be in similar range (0.001%). Whereas the elements which were undetected were sodium (Na), vanadium (V), chromium (Cr), cobalt (Co), nickel (Ni), arsenic (As), selenium (Se), bromine (Br), zirconium (Zr), niobium (Nb), molybdenum (Mo), cadmium (Cd), lead (Pb), rhodium (Rh), palladium (Pd) and platinum (Pt) in the stem (Table 13.3). Samples presented for XRF measurement are treated with an X-ray radiation source to excite the inner orbital electrons within the sample, to an excited state. When electrons relax to the ground state, fluorescent energy is emitted, and the

Table 13.3 Elemental composition analysed by energy-dispersive X-ray fluorescence (ED-XRF) technique in *Couroupita guianensis* stem

Sr. no.	Element	% mass	Oxide	Mass %
1.	CHO	95.592	$CaCO_3$	66.953
2.	Ca	2.006	K_2O	10.201
3.	K	0.914	$MgCO_3$	9.987
4.	Mg	0.529	P_2O_5	3.899
5.	P	0.267	SO_3	3.486
6.	Cl	0.231	SiO_2	1.479
7.	S	0.204	Al_2O_3	0.814
8.	Si	0.115	SrO	0.563
9.	Al	0.074	Fe_2O_3	0.348
10.	Sr	0.024	Ag_2O	0.209
11.	Ag	0.022	ZnO	0.086
12.	Fe	0.011	Sc_2O_3	0.069
13.	Zn	0.003	MnO	0.047
14.	Mn	0.002	CuO	0.043
15.	Cu	0.002	TiO_2	0.040
16.	Ti	0.001	Cr_2O_3	0.005
17.	Sc	0.001	V_2O_5	0.003
18.	Na	0	Nb_2O_5	0.003
19.	V	0	NiO	0.002
20.	Cr	0	SeO_2	0.001
21.	Co	0	PtO_2	0.001
22.	Ni	0	PbO	0.001
23.	As	0	Na_2O	0
24.	Se	0	Co_3O_4	0
25.	Br	0	As_2O_3	0
26.	Zr	0	ZrO_2	0
27.	Nb	0	MoO_3	0
28.	Mo	0	PdO	0
29.	Cd	0	CdO	0
30.	Pb	0		
31.	Rh	0		
32.	Pd	0		
33.	Pt	0		

process results in measurable intensities and spectral lines, specific to each element (Daly and Fenelon 2017).

Elementals analysed by inductively coupled plasma mass spectrometry (ICP-MS) technique in *C. guianensis* leaf aqueous extract is shown in Table 13.4. The major components in the leaf extract constituted calcium (Ca) which was found to be 237.591 ppm, whereas silver (Ag) and iron (Fe) were noted to be 12.043 ppm and 8.843 ppm, respectively. Zinc (Zn) content was found to be 7.560 ppm, whereas boron (B) and copper (Cu) were found to be 4.141 ppm and 1.2 ppm, respectively. The concentration of lithium (Li) was found to be 0.0215 ppm, and cobalt (Co) was

Table 13.4 Elemental analysed by inductively coupled plasma mass spectrometry (ICP-MS) technique in *Couroupita guianensis* leaf aqueous extract obtained by cold percolation method

Sr. no.	Element	Value (ppm)
1.	Ca	237.591
2.	Ag	12.0435
3.	Fe	8.843
4.	Zn	7.560
5.	B	4.141
6.	Cu	1.200
7.	Li	0.0215
8.	Co	0.012
9.	Cd	Absent
10.	Pb	Absent
11.	Mg	Absent

to be 0.012 ppm. The elements which were undetected were magnesium (Mg), cadmium (Cd) and lead (Pb).

13.4 Conclusion

In this work, we have performed rapid, simple and reliable methodology for multielemental analysis from flowers, leaves and stem of *C. guianensis* by using ED-XRF and ICP-MS. During the study, amongst the detected elements, i.e. K, S, P, Cl, Mg, Ca, Si, Al, Fe, Ag, Cd, Ti, Zn, Cu, Sr, Mn, Ni, Sc and Br, potassium and calcium were detected in maximum amounts in all the different parts of *C. guianensis*. Apart from these elements, Ca, Ag, Fe, Zn, B, Cu, Li and Co were also detected by ICP-MS technique from aqueous extract of *C. guianensis* leaves obtained through cold percolation method. The exhibited amount of numerous elements and minerals from the different parts of *C. guianensis* suggest a good source for the supplementation of nutrients, elements and minerals for the improvement of soil fertility, mineral enrichments and sustaining soil health.

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Waste Management: A Paradigm Shift

14

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Abstract

According to the available data worldwide, more than 4 billion tons of waste is generated annually. This includes municipal, industrial, biomedical, hazardous, and e-waste. Generation of solid waste is directly proportional to the size of economy and population. Management of waste is a responsibility of every human being living on this earth. Recent report of World Health Organization (WHO) states that about 25% diseases in developing countries are due to improper waste management, leading to environmental pollution and ultimately to diseases. Waste can be classified into five broad categories including solid, industrial, plastic, e-waste, and biomedical wastes. Policy guidelines at national and international level were drafted and implemented for management of wastes, environmental protection, and sustainable development. Converting waste into energy like biogas, biofuels, and novozymes (an enzyme-based solution that converts low-grade oils and cooking oils into biodiesel) is a smart approach. Another important aspect is the recyclability of certain products like plastics. Identification of one plastic polymer from another is very challenging and hence their recyclability. All the developing countries need to ratchet up the recyclability procedures. Further, the attitude of people needs to change drastically for waste generation, e.g., people being charged for the amount of food wasted by them, enforcing them to change their attitude. In addition to that, process like *bioremediation* is playing a significant role in environmental cleanup and to

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_14

remove toxins. It is the emerging green technology of environment conservation which explores the potential of microbes for degradation of xenobiotic compounds as well as eradication, transformation, and infringement of various other contaminants.

Keywords
Waste · Management · Biomedical · E-waste · Hazardous

14.1 Overview

Waste can be defined as substances or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law (UNEP 2003). Daily activities of all living creatures generates huge amount of wastes. Management of waste is one of the biggest problems that many developing and underdeveloped countries are facing. According to the available data worldwide, more than 4 billion tons of waste is generated annually. This includes municipal, industrial, biomedical, hazardous, and e-waste. Generation of solid waste is directly proportional to size of economy and population. Management of waste is a responsibility of every human being living on this earth. The cost of solid waste management is increasing annually, thus causing impact at global level. Cleaning and management of waste are less cost-effective as compared to reduction of generation at source. Management of waste is a herculean task that every country is facing. Management of waste is a wholesome process involving many steps including collection segregation, transportation, reprocessing, recycling, and disposal.

According to World Health Organization (WHO), about 25% diseases in developing countries are due to improper waste management, leading to environmental pollution and ultimately to diseases. One of the main cause of pollution is population and fast pace of urbanization particularly in developing countries, like India. India with 1.33 billion people is the second largest country in the world in terms of population after China. The population growth in India has been high with average rate of increase approx. 2% per annum. With a fast pace of urbanization, it is estimated that by next decade, more than 500 million people will start living in urban areas of the country. Not only big and small cities but small towns are facing problem of urban waste management, as piles of garbage left in open areas to rot. This problem is due to difference in requirement and availability of services (Mavropoulos et al. 2012).

Waste management in urban area is one of the critical issues as these cities are dumped with piles of garbage. The waste is lying in open land area to rot. This mismanagement or partial management of garbage is leading to soil, air, and water pollution and causing health impacts.

14.2 Waste Identification and Management

Proper waste identification is essential for its correct and effective treatment and management of it. Is it a solid waste, a liquid waste, hazardous waste, etc.? If the waste identified is hazardous, it has to be properly managed, or else it will cause a severe risk to the environment as well as human well-being. The Resource Conservation and Recovery Act (RCRA) has streamline a structure for proper management of hazardous wastes. All the waste generators must settle on the types of waste generated by them and must watch over the ultimate fate of those wastes. Additionally the generators must ensure and fully document that the waste generated by them is correctly identified, transported, and treated before recycling and disposal process. The waste generated is transported further to facilitate its treatment, disposal, or recycling process; since the transportation would be carried out on public roads, railways, and waterways, various guidelines come in action, for example, the US Department of Transportation Hazardous Materials Regulations and US Environmental Protection Agency (EPA). There are also proper guidelines for temporary storage and final treatment and disposal of hazardous wastes, failing which could lead to unmanageable results.

14.2.1 Identification of Waste Factors in Various Manufacturing Processes

There are many factors during the manufacturing process that leads to waste generation, which needs to be resolved before implementation. The following are some practical examples to review the uncover possible waste factors:

1. Transportation could be minimized by having multiple production sites for the complete production targeted.
2. Don’t go for inventory stock of perishable materials (fruits and vegetables). Aim for just in time production.
3. Always analyze and aim for the correct production number of any product. Dumping the overproduced materials not loved by the consumers may lead to waste generation. (Overproduced bike models which do not sell).
4. Production with zero defects will also reduce the waste production. Always target for zero-error production.
5. Minimize the processing stage; excess processing may lead to undue waste generation.

14.2.2 Managing Wastes: Generation to Final Disposal

Waste management refers to the combination of transporting, recycling, and proper disposal of waste generated by any organization. Waste management provides various ways to efficiently use garbage that do not belongs to trash. There are many methods for waste disposals, among which the most commonly used method by the developing countries is using landfills for disposal. Landfill means burying the waste in land. This method of disposal comes with two major constrains, namely, the requirement of space and air and water pollution. The gases produced by the degradation of dumped materials (mainly methane) cause a lot of air pollution and successively water pollution too. Incineration or burning (also known as thermal treatment) is another disposal system in which municipal solid waste is burn at elevated temperature in order to switch them into remains and vaporized stuff. The principal benefit of this kind of process is that it can condense the amount of solid waste to 25–35% of their initial volume.

Recycling is the practice of converting waste stuff into innovative and new products via expenditure of new raw materials. Recycle is the third component of reduce, reuse, and recycle waste ladder. The thought at the back recycling is to diminish energy consumption, trim down dimensions of landfills, condense water and pollution, condense gas emissions from greenhouse, and hence safeguard our natural assets for upcoming employ.

Plasma gasification is a further variety of waste administration. Plasma is principally an electrically charge and extremely ionize gas. By means of this process of waste clearance, a container uses distinctive plasma torch functioning at 10,000°F and above, which creates a gasification sector of 3000°F for the renovation of solid or liquid waste into syngas.

Composting is a trouble-free and widely accepted biodegradation procedure that takes organic wastes and turns them into nutrient loaded foodstuff for plants. Usually composting is used for organic agriculture and happens by allowing organic supplies to stay at one place for long duration till microbes act upon and decompose them. It is among the most excellent system of waste clearance as it can spin hazardous organic commodities into secure compost. This method is accompanied by two lacunas, space and time constraints.

14.3 Classification of Waste

Waste can be classified in various ways, viz., on the basis of its processing, e.g., recyclable and nonrecyclable, and on the basis of source of origin, e.g., urban wastes, industrial wastes, domestic wastes, e-waste, etc. (Fig. 14.1). Generally health care is a broad area in terms of the types of facilities which can be public or private or semigovernment and government installation. It can be a service industry or research installation in health-care sector, sometimes small home health care for the incurable and long-term disease which produces waste as dialysis, insulin, etc. (Table 14.1) (Hoornweg and Bhada-Tata 2012).

Household waste also called general domestic waste coming from kitchen and housekeeping activities contribute 3/4 of the total solid waste generation. Remaining 1/4 waste is considered to be harmful and commonly called hazardous. Hazardous waste can be responsible for variety of environment and health issues which can lead to health hazards.

Fig. 14.1 Classification of waste

Table 14.1 List of waste generated from health-care facilities

Waste category	Descriptions and examples
Sharps	Injection needle; transfusion sets; scalpel; surgical knives and blades; glass pieces
Infectious	Contaminated body fluids, blood; cultures and microbial stocks; waste including human feces
Pathological	Operated tissues and organs or body fluids; amputated body parts; aborted fetuses
Pharmaceutical, cytotoxic	Expired drugs, cytotoxic, cancer therapy chemicals; genotoxic chemicals
Chemical waste	Laboratory reagents; film developer; disinfectants, heavy metals like lead and cadmium; mercury of thermometers and blood pressure gauges
Radioactive waste	Liquid chemicals from radiotherapy including film development liquid, dyes, etc.
Nonhazardous or general health-care waste	Waste that does not pose any type of hazard for human and environment

14.3.1 Solid Waste Management: Especially Municipal Waste

Municipal waste is part of urban wastes. From year to year municipal solid waste (MSW) has been on the increase across the world. Municipal solid wastes comprise of biodegradable, recyclable, and inert wastes. Such recyclable waste reduces production of raw material for production of these items. The biodegradable waste basically comprises of wastes generated in kitchen which chiefly includes waste food, besides that vegetable and garden wastes are also part of biodegradable waste. Recyclable waste comprises of plastic and paper wastes, glass, metal, and tin can. Recycling is the process where the waste material is used for processing to produce a new product. Other wastes, viz., sand, pebbles, and gravels that are part of building material and generated due to construction or demolition, comprise inert waste.

Management of solid wastes is done on the principle of reduce, reuse, recycle, and reduce (Kasturirangan et al. 2014).

According to recent data, more than 50% waste generated in India is biodegradable. The remaining less than 50% comprises of inert and recyclable wastes. Recyclable waste is less than 20% (approx. 17.5%) and inert includes 31%. Annual municipal solid waste generation in India is about 62 million tons; for dumping, its 340,000 cubic meters of landfills is required. In a decade, we will be short of land to dump this amount of solid wastes without treatment. Dumping solid waste in landfills also has serious health hazards (Kasturirangan et al. 2014).

14.3.1.1 Sewage

Sewage comprises of waste suspended in water, and more than 90% of sewage is water. Management of sewage/wastewater is essential to protect environment general health and well-being. The treatment of wastewater or sewage produces sludge, a semisolid waste material produced during wastewater treatment. Sludge is rich in nitrogen and phosphorus. The treatment process includes various physical and chemical treatments. It contains various hazardous chemicals and also heavy metals and organic matters. It also contains many pathogenic as well as nonpathogenic microorganisms.

14.3.1.2 Construction and Demolition Waste

It is again a solid waste generated during to destruction of old buildings or renovation of private industrial commercial or governmental properties or infrastructure. The waste generated due to these activities can be recycled or reused as such in developing new infrastructure.

14.3.2 Industrial Waste

Waste that is generated from industries includes both hazardous and nonhazardous wastes. These include chemicals, pesticides, fluids used in cleaning, medical wastes, etc.

Hazardous waste can reflect the following characteristics:

Toxic Chemicals that reveal the toxicity at a stage. The chemicals have a pathway to imbibe into blood by the pulmonary pathways and circulate in the whole body.

Corrosive Corrosion due to strong alkali and acids can be dangerous. They can cause harm to skin or eyes. It can lead to permanent damage including poisonous emission.

Explosive Materials which release compressed gases if ignited and can explode with a touch of heat.

Flammable Materials or Compounds who can be ignited easily and have a tendency to burn out with great speed and liberates heat up to great extent.

Chemically reactive Materials so reactive that it can burn with the exposure of atmosphere hence stored accordingly with care and precaution.

Hazardous waste can be divided into the following types (UNEP 2010):

- *Listed wastes*
  Environmental Protection Agency (EPA), USA, has prepared a list of waste, and those that come under this category are called listed wastes.
- *Characteristic wastes*
  Waste that has ignitability, corrosivity, reactivity, and toxicity.
- *Universal wastes*
  This comprises of poisonous metal-containing equipment, e.g., mercury, pesticides, lamps, and batteries.
- *Mixed wastes*
  It contains both radioactive and hazardous waste.
- *Health-care wastes*
  The hazardous nature of health-care waste falls under the following properties:
  - Infectious agents
  - Genotoxic or cytotoxic properties
  - Toxic or hazardous chemical
  - presence of radioactivity
  - Presence of used sharps

14.3.2.1 Mercury

In normal condition, mercury metal remains in liquid form with shining silver color. Mercury can be transported with air currents and accumulates at the bottom of water bodies, which is ultimately converted by bacteria in methylmercury which subsequently enters in food chain.

Hg is useful but can be very toxic or can be fatal in some forms and can be imbibed through dermal pathway. The adverse effect can harm central nervous system, digestive system, and pulmonary system along with failure of renal and immune system. The adverse effect of mercury also includes several types of neurological deformity and developmental deficits during pregnancy (WHO 2005a).

14.3.2.2 Effect of Mercury on Human Health Through Environmental Exposure

Mercury is useful for manufacturing of medical devices especially for diagnosis, but it is a challenge for long-term safe disposal. Batteries used in medical devices for the power are generally using mercury which is again an additional challenge in terms of disposal. The awareness of harmful effects has stopped the use of mercury in batteries in the USA and EU, but still third world countries are using it up to some extent. Health-care facilities have started gradually replacing mercury with other alternatives.

Released mercury in water bodies from untreated wastewater/sewage adds approximately 5% of total mercury pollution to the environment effecting aquatic ecosystem. Once pushed in the aquatic ecosystem, it quickly enters the food chain.

The dental procedures contribute half of the mercurial contamination along with medical incinerators in the environment as per US Environmental Protection Agency in the EU and USA (Sources: Risher (2003) and WHO (2005a)).

14.3.2.3 Silver

Silver is another metal which is being used with more applications in the arena of disinfectants as a bactericide and in advance field of nanotechnology research due to its properties. Silver can demonstrate variety of potential effects on bacterial resistance which will be an additional problem to health-care research and treatment (Chopra 2007; Senjen and Illuminato 2009).

14.3.2.4 Disinfectants

Chlorine and ammonium compounds are used in large quantities in hospitals, pathology, PHC, etc. as antimicrobial agents. It is not advisable to use large quantities in the closed environment because of toxic fumes.

14.3.2.5 Pesticides

The improper storage of pesticides generally creates leakage that trickles down to the groundwater during the rainy season leading to contamination of groundwater and subsequently enters the food chain causing hazardous mutations in the DNA giving long-term effect of genetic defects in human race.

14.3.2.6 Hazards from Genotoxic Waste

The chances of toxicity of genotoxic waste depend on the extent and duration of contact for health-care professional. The exposure may occur during treatment by particular drugs. The main route of exposure is pulmonary or dermal or through food, and bad laboratory practice such as mouth pipetting is also responsible. Infection may occur due to contact with body fluids and secretions of patients of oncology. The cytotoxicity of many drugs affects the processes such as DNA synthesis and cell division. Alkylating agents are cytotoxic at any point in the cell cycle.

Many cytotoxic drugs are potent irritants when come in direct contact with the dermal area and eyes. Side effects of cytotoxic drugs can be dizziness, nausea, headache, or dermatitis.

14.3.2.7 Hazards from Radioactive Waste

Radioactive waste can cause various problems associated with nervous system. It can cause a temporary or permanent sift in the nucleotides of DNA causing either nonfunction of gene or defective expression of genes. The contamination of even low radioactivity substances can happen due to improper storage condition and containers. People in the vicinity are at greater risk.

14.3.2.8 Health-Care Waste Hazard

Specific hazards are posed by different types of health-care waste. There are occupational hazards associated with treatment processes. If poorly operated, it may cause health concerns, associated with increased cardio and pulmonary failure (Fritsky et al. 2001; Matsui et al. 2003; Brent and Rogers 2002; Lee et al. 2002; Segura-Muñoz et al. 2004).

- Physical injury can happen by ash from the incineration and burnt-out needles and glass. Further, ash containing high level of heavy metals supports the synthesis of dioxins and furans at 200 °C–450 °C.
- Autoclave and steam disinfection treatment may cause serious burns due to steam and high temperature if not maintained properly and poorly operated. The elevated concentrations of organic and inorganic compound discharges to sewerage systems should be in regulated limits.
- The equipment used in health-care industry as shredding and compactors can cause physical injury.
- Burial sites situated at wrong place as in densely populated area of the city are threat to the people living in the vicinity. The estimation to measure the potential and amount of risk is difficult to calculate and estimate. The chemical contaminants or pathogens in landfill may infect the groundwater which can affect the aquatic ecosystem which will ultimately affect the food chain. Sites at densely populated areas can pose a threat to the population of smoke and dangerous gases including workers.

14.3.2.9 Nonhazardous Waste

This includes wastes generated by industries and is recyclable. Mostly the large portion of total waste generated by health-care industry is nonhazardous waste. They also can be considered as solid municipal waste, e.g., paper, cardboard and plastics, discarded food, metal, glass, textiles, plastics and wood, etc. The wastes composition is a characteristic of health-care industry. In the past, the waste was buried at the dumping sites or burnt in the open air. But nowadays major awareness regarding proper disposal has compelled for the safe disposal. Most of the nonhazardous waste is recyclable such as paper, plastic, cardboard, wood, and metal articles, hence managing the general waste.

There are no clear guidelines for the disposal of the general waste and its classification. The understanding of the transmission of disease is important to prevent the spread of disease. The infection requires sufficient potential to cause disease also called as virulence including mode of transmission. Some countries have a proper SOP for collection, transportation, and disposal, whereas some countries are not even having the proper container and proper protection for the persons handling.

14.3.3 Plastic Waste

The term plastic is used for polymers of high molecular weight substances, which can be synthetic or semisynthetic, mostly derived from petrochemicals. They may be partially natural also. Plastic products have become a basic need in our day-to-day life. Approximately more than 10 million tons of plastic products are being processed and consumed every year. The plastic industry has seen phenomenal growth since the beginning of polystyrene production in 1957. Because of being lightweight and durable, plastic has most versatile uses, thus becoming ubiquitous in its presence. Plastic has entered in every spectrum of daily use, such as grocery, shopping and garbage bags, packaging and wrapping material, storage containers, household products, toys, and even clothing. Also it is frequently utilized as protective packaging for mobiles, appliances, furniture, medical devices, etc. Around 1 trillion plastic bags are used worldwide each year, and maximum of these items end up in landfills, dumpsites, and water bodies. Domestic plastic consists of majorly polythene bags, bottles (soft drink, water, or shampoo), and lids. In agriculture and horticulture, plastic is employed for food grains' storage and transportation, irrigation pipes, etc. and has replaced jute bags and glass in storage and packaging. The use of plastic in roads, railways, and shipping infrastructure has been in pipes, wires, cables, waterproofing membranes, wood PVC composites, etc. The increase in domestic consumption of plastic has increased its potential for plastic industry worldwide. At industrial level, plastics have made significant contribution in automobile, electronics, health care and pharmaceuticals, construction, textiles, and FMCG sectors. Many newer applications of plastic have also emerged like reinforced thermoplastic with corrosion and chemical resistance, vacuum packaging, textile fibers which can regulate body temperature and are resistant against bacteria, tough plastic bags with enhanced storage life, and so on. The plastic industry is growing at a rate of 10% and has reached 100,000 crores business by 2015.

Plastic constitutes almost 10% of household waste, which was more than 250 million in 2007 (Verma et al. 2016). This consumption and production of waste are increasing also with each year (UNEP 2009). Plastic is a crude polymer of carbon and thus takes years to decompose completely. Therefore they are said to be non-biodegradable, and the time for their complete removal is estimated to be hundreds to thousands of years (Kershaw et al. 2011). According to UN map of ten rivers worldwide to carry plastic waste into oceans, the Ganga-Brahmaputra-Meghna river system is among them, with the threatening effects on marine life and even microplastics in drinking water. With the increase in plastic use in every minor or major field in emerging and developing economies, this problem of plastic waste generation, its management, or recycling would require additional focus (Table 14.2). According to the overview of plastic waste management report (2013) by Central Pollution Control Board, India, there are a number of environmental concerns due to indiscriminate littering and recycling of these non-biodegradable wastes. Such improper disposal leads to contamination of groundwater, changes in microbial flora of soil, and increase in poisonous compounds in the atmosphere, posing grave multidimensional problems, like serious health issues in human beings as well as animals, when these stray cattle feed on throwaway plastics (Fig. 14.2).

Table 14.2 Some of the most plastic-polluted rivers of the world (Schmidt et al. 2017)

River	Location	Reason
Yangtze River	The longest river of Asia, going into East China Sea near Shanghai	Highest in flowing the most plastic waste into oceans
Indus River	One of most important rivers of Indian subcontinent, reaching the Arabian Sea	Carrying highest amount of mismanaged plastic debris
Yellow River	Also known as "China's sorrow," it is the second longest river	With more than 25% fish species extinct, river is almost non-potable now
Hai River	Connects Tianjin and Beijing and runs into the Bohai Sea	High population density without proper disposal system
Nile River	This longest river flows through 11 countries before reaching Mediterranean Sea	Though it dries up during summers, it still carries enough plastic into the sea
The Ganges	Most important river of North India, it reaches Bay of Bengal	Unmanaged and unchecked domestic as well as industrial waste disposal has made it one of India's most polluted rivers
Niger River	This is Western Africa's major river. Reaches into the Atlantic Ocean.	Construction and oil spills along with plastic pollution causing major water contamination
Mekong River	The river covers a distance of more than 2500 miles and flows through Southeast Asia, including Vietnam and Laos	Responsible for dumping most of 8 million tons of plastic reaching seas

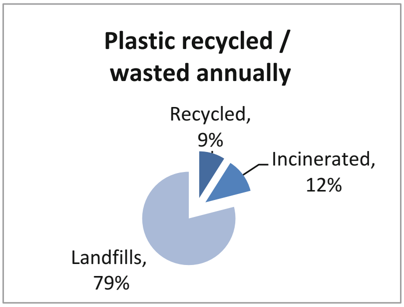


Fig. 14.2 Waste generated by plastic bottles and percentage of recyclable plastic waste

14.3.3.1 Environmental Contaminants of Plastics: Phthalates, BPA, etc.

BPA or bisphenol-A and phthalates are commonly called everywhere chemicals due to their frequent and common use in making everyday plastic products, viz., bottles, disposable utensils, personal and baby care products, and toys. BPA is used in hard, clear plastic, whereas phthalates make plastic flexible. Both these substances are known to percolate or leak from plastic into food and liquid and finally into our system. Much scientific evidence suggests BPA and phthalates are associated with many hormonal and developmental problems. Infants and young children, who are vulnerable during early developmental years, are likely to be at potentially most risk from exposure to "everywhere chemicals" such as BPA and phthalates.

BPA, a neurotoxin and endocrine disruptor, has been found to be harmful in many experimental studies. Also a comprehensive study on BPA and its related harmful effects on human beings has reviewed more than 90 similar studies showing correlation of BPA with health. This published work by Rochester (2013) had outlined the association of BPA exposure with many health issues, like reproductive and developmental effects, metabolic diseases, and even behavioral effects in children. A number of works have now demonstrated correlation between phthalate and BPA exposure with altered levels of steroid hormone in adults (Ehrlich et al. 2012; Sathyanarayana et al. 2017) and also in infants (Araki et al. 2014; Lin et al. 2011). BPA and phthalate exposure in utero may also alter female reproductive development (Watkins et al. 2017). Therefore it becomes pertinent that phthalates and bisphenols are regularly monitored in various environmental and biological samples. The conventional methods include separation and spectrometric techniques; however modern electroanalytical methods and other analytical methods with high sensitivity, selectivity, easy automation, low investment, and running costs for large-scale monitoring are the need of the hour.

14.3.3.2 Plastic Waste Management

The excess use of plastic materials nowadays is serious worldwide environmental and health concern. Disposal of plastics waste has drawn attention of environmentalist due to their non-biodegradability and unscientific disposal with possible leaching to contaminate soil, subsoil, and water. Also, the unchecked littering and nonscientific processing of plastic waste is becoming a major problem. Such waste eventually reaches water bodies through drains and rivers. The waste plastic is either recycled or dumped in landfills or dumpsites. However, the high cost and decreased space for dumping are major deterrent factors forcing government agencies and environmentalists to find out alternative options for plastic waste disposal (Zia et al. 2007).

Plastic recycling, despite being effective alternative, is more difficult than glass, paper, or metals. Because different varieties of plastic would contain different polymers which may have different properties or melting temperature, one uniform recycling process cannot be employed. This also makes proper separation of plastics necessary. According to physical properties, plastics are broadly categorized as (i) thermoplastics, which are of hard or tough elasticity and can be melted, (ii) elastomers are soft and elastic but cannot be melted, and (iii) thermosets, which are of hard elasticity range and can't be melted. But the recycling of plastics also has several limitations and is found to be more harmful to the environment than its virgin counterpart because different colors, additives, stabilizers, and flame retardants are mixed during recycling process and it can be repeated for two to three times only. After every recycling, the strength of plastic material is also reduced due to thermal degradation. The Central Pollution Control Board of India in its 2013 report states that indiscriminate and unskilled recycling or reprocessing is also causing a number of environmental issues, with many fugitive emissions released during polymerization process. The toxic gases, like CO, Cl (chlorine), HCl, dioxin, furans, amines, nitrides, styrene, benzene, 1, 3-butadiene, carbon tetrachloride, acetaldehyde, etc., are released during burning of plastics, causing many environmental and health issues. Also unchecked dumping of plastic waste on land is rendering the soil infertile and poses serious aesthetic issues in the surroundings. Therefore, it is better to reuse the plastic products rather than recycling them. This will save much energy and resources.

14.3.3.3 Recycling of Plastic

The recycling of plastic is being done in effective manner now, and the plastic industry has developed many technologies which can effectively treat and recycle waste from discarded products. More than hundred thousand tons of polyethylene from discarded plastic is being converted into various parts of textiles (Gobi 2002). According to European Union's report of 2007, UK alone has recycled ≈250,000 tons (almost 95%) of plastic waste (EA 2008). There are four major classes in plastic waste treatment and recycling process: re-extrusion (primary), mechanical (secondary), chemical (tertiary), and energy recovery (quaternary; Mastellone 1999).

In re-extrusion, which is the primary recycling, the plastic scrap and industrial or single polymer plastic are reintroduced to produce products of the similar material. This process utilizes scrap plastics that have similar features to the original products (Al-Salem et al. 2009a). However, this process is not very favorable with recyclers as it can make use of only semi-clean scrap.

The secondary recycling, which is the most preferred and widely used mechanical recycling method, involves reusing the plastic to manufacture plastic goods through mechanical means (Mastellone 1999). In mechanical recycling, first the plastic is reduced or resized to a more suitable form like pellets, powder, or flakes. It can be achieved by milling, grinding, or shredding (Zia et al. 2007); however it can recycle only particular type of polymers, e.g., polyethylene terephthalate (PET) and high-density polyethylene (HDPE) bottles have high recyclability, whereas polyvinyl chloride (PVC) and other materials have limited recyclability due to very high chlorine content in PVC and other harmful additives. Since mechanical recycling requires particular type of plastic, segregation and cleaning such plastic waste increase the operational cost. Mechanical recycling process has been employed to produce many recycled products, like grocery bags, pipes, shutters, etc. The only limitation with this process is its old design components and thus release of harmful gases. Also the laminated plastics and carry bags still remain the challenge for the process and thus have become an important issue in R&D.

The most advanced technology in plastic waste recycling is chemical or tertiary recycling which employs conversion of plastic materials into smaller molecules, usually liquids or gases, suitable as a feedstock for the production of new petrochemicals and plastics (Mastellone 1999). The chemical recycling process includes pyrolysis, gasification, liquid-gas hydrogenation, viscosity breaking, steam or catalytic cracking, and the use of plastic waste as a reducing agent in blast furnaces. PET and nylon, the condensation polymers, undergo degradation to produce monomer units, i.e., feedstock (Yoshioka et al. 2004), while vinyl polymers such as polyolefins produce a mixture containing numerous different components to be used as a fuel.

If plastic waste cannot be recycled due to economic or any other constraints, it can be utilized for energy recovery. Energy recovery is the process where waste is burnt to produce energy in the form of heat, steam, and electricity. This process can be very useful in plastic waste treatment as plastics possess a very high calorific value when burned and produce water and CO_2 like any other petroleum-based fuels (Dirks 1996). If incineration of nonrecyclable plastics is performed with high-efficiency energy recovery, less CO_2 is released than by disposing plastic waste in landfills. However, in developing countries, cost-effectiveness of investing in incineration infrastructure must be assessed to ensure financial sustainability in the long term. Also the environmental concerns are associated with burning plastic waste, because of emission of many air pollutants such as CO_2, NO_x, and SO_x as well as volatile organic compounds (VOCs), smoke (particulate matter), and heavy metals. Carcinogenic substances (polycyclic aromatic hydrocarbons (PAHs), nitro-PAHs, polychlorinated dibenzofurans, dioxins, etc.) have been identified in particles from combustion of synthetic polymers such as polyvinylchloride (PVC), polyethylene terephthalate (PET), polystyrene (PS), and polyethylene (PE; Al-Salem et al. 2009b).

To date about 75 countries in the world have taken actions to reduce the consumption of plastic bags, either by total ban on use and sell of plastic bags or by levying fee on retailers and consumers (UNEP 2017). However, mixed policy of total ban on thin plastic bags and levy on thicker ones has been quite effective in reducing plastic use in many countries, including India. However, plastic waste is derived from oil and has a recoverable energy; thus it is important to consider recycling and energy recovery methods in plastic manufacturing and converting facilities. Many technologies have shown promising results and need further research and development in this area.

14.3.4 Electronic Waste

Electronic waste also called as e-waste is basically the bulk of unwanted electronic items that have exceeded their shelf time. Some examples of the items that contain harmful toxic components that need to be recycled are cell phones, batteries, monitors, TV scenes, stereos, etc. Electronic waste may account for a lesser percentage of trash in landfills but constitutes for a higher percentage of toxic garbage. Products that contain maximum electronic items are the main source of generation of e-waste (computers). E-waste has both the components – hazardous and nonhazardous substances. The hazardous components include plastics, mercury, lead, arsenic, and cadmium which pose high amount of risks to human health. Often the people who are mainly involved in the recycling and recuperation of the e-waste are more prone toward the chronic diseases like cancer.

Technology is changing every day, and as a result electronic equipments are discarded in abundance both in rising countries and also in the developed countries. The decreased self-time of electronic items and the affordable price of new

Table 14.3 Various categories of e-wastes

S. No	Categories of e-waste	Percentage contribution of total e-waste
1.	Consumer electronic televisions, VCR/DVD/CD players, radios, CCTV cameras, etc.	21
2.	Large household appliances like refrigerators, air conditioners, dryers, washing machine, etc.	49
3.	Lightening equipments like fluorescent bulbs, tube lights, halogens, sodium lights, etc.	3
4.	Other equipments like sewing machines, electric saw, treadmills, medical devices, etc.	4
5.	Small household appliances like coffee machines, irons, toasters, vacuum cleaners, electric kettles, geezer, toys, automatic dispensers, etc.	7
6.	Telecom equipments and computer-related equipments like fax machine, PCs, laptops, mobiles, earphones, mouse, printers, scanners, etc.	16

Table 14.4 Hazardous compounds present in e-waste

S. No.	Components	Hazardous compounds in them
1.	Polymers and plastics	Teflon and PVC as polymers, Cd, Pb, phthalates as additives
2.	PC boards (printed circuit as boards) and toner cartridge, batteries	Sn in solder, Pb, Be, and Hg in switches and contacts, As in LEDs, Ni and Cd in batteries, tonner carbon black ink
3.	Capacitors containing PCBs and refrigerating circuits	PCB and Feron
4.	LCDs (liquid-crystal displays)	Liquid crystals in the screen
5.	CRTs (cathode-ray tubes)	Sb and Pb in CRTs, Ba in electron gun

technologies with advanced features have led to the enormous creation of e-waste. This e-waste generated offers a good opportunity to the secondhand sale of electronic item industries. These e-wastes are categorized according to their properties (Table 14.3).

The imminent presence of various heavy metals in the e-waste makes it very difficult to degrade and possess high risk to the surroundings as well as human well-being. Adding on, the people occupied in the management, shipping, and clearance of these wastes are directly exposed to these hazardous elements. The manufacture of majority of equipment is PCB based which in turn contains high number of dangerous compounds like stibium, lead, arsenic, gallium, mercury, and cadmium. The list of hazardous compounds found in various wastes is listed in Table 14.4.

There is a compatible e-waste management system that encompasses compilation, storage, recycling, reclaim, incineration, and reuse of the waste generated. The following is the schematic diagram for the first step in a typical e-waste recycling process (Fig. 14.3).

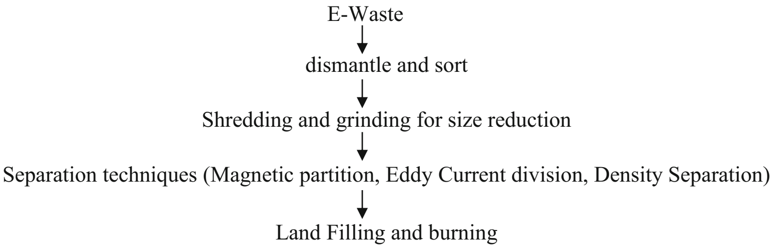


Fig. 14.3 Schematic representation of e-waste recycling process

14.3.5 Biomedical Wastes

Knowledge and awareness about health-care wastes have now become more prevalent among the government, medical practitioners (private), and civilians. Medical staff and administration have to be more attentive and responsible in the collection and disposal of waste. Improper handling practices should be discouraged, and the concerned person should ensure the proper parking of waste at proper place in a proper manner. The responsibility of each and every person related to health-care industry should follow the SOP of disposal till end.

The characteristic feature of each health-care industry produces waste pose to patients, staff, and the environment, guiding regulatory principles for developing local or national threat approaches for health-care waste management and converting into action plan for regions and individual health-care facilities. Specific technologies are described for waste minimization, segregation, and treatment. The advantage and disadvantage of each technology including environmental characteristics need to be acquired.

The wastewater treatment must be connected to difficulties of handling health-care wastewaters and generation of new guidelines on the various wastewater treatment options to central sewage systems. The awareness and training regarding occupational safety, hygiene, and infection control should be made for general population.

14.3.5.1 Generation of Health-Care Waste

Knowledge of quantity and types along with the storage conditions and disposal techniques are must to understand before safe disposal. Generation of waste and the quantity estimation will allow to predict the capacity, type, storage, and transportation of containers as well as the storage area of these containers (Fig. 14.4). It will further increase revenues from recycling, controlling the waste quantity, and improving the environmental conditions.

The assessment of waste will provide an opportunity to increase efficiency of current practices, which will give a more efficient option of saving the cost involved. Cost-effective recycling will be beneficial in two ways: one by cutting cost of recycled goods and another by saving cost of manufacturing new goods which

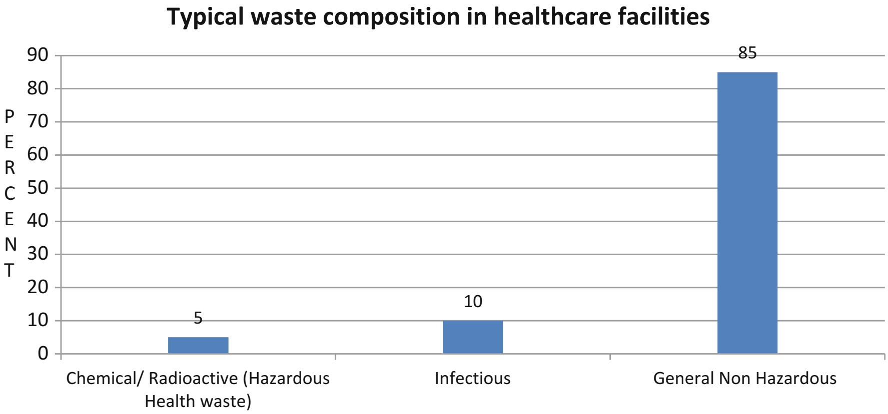


Fig. 14.4 Categorization of biomedical wastes

will again pose a threat to the environment by increasing quantity on the globe and cause environment degradation.

The waste-assessment program can be of different approaches as estimation of waste generation per bed is done by collection of waste segregated in separate containers and weighed from different areas divided by number of beds in the area regularly. Calculation and data collection for a longer period are essential to accurately estimate considering seasonal variation and prevalence of an epidemic with respect to normal days. This also reveals the generation of waste capacity facility wise and individual parts of a facility.

Survey of the staff is the other way for the assessment of quantification of waste. The questionnaire asking staff reveals the information regarding the measurements of facilities to estimate waste quantities. When extrapolating the data, the sample size is always taken into account and facility size.

14.3.5.2 Factors Affecting the Waste Generation

Generation of waste is measured in terms of occupied beds, patients per day, department, location, regulations on waste classification, segregation practices, temporal variations, and infrastructure development of the country.

In rural and urban areas, the health-care facilities may be different in services, size, complexity, and resources including number of medical and staff. Regulations on types of waste and segregation practices affect waste generation rates.

Comparison of waste data from other countries may be used with care because the variation within the country may be tracked and monitored for various conditions also. The different types of establishments should also be taken into account.

14.3.5.3 Physicochemical Characteristics

Development of waste minimization plan is essential and associated with physicochemical composition of health-care waste. Composition of waste is the deciding

Table 14.5 Types of infections causative organisms and transmission vehicles found in waste

Type of infection	Examples of causative organisms	Transmission vehicles
Gastroenteric	*Salmonella*, *Shigella* spp., *Vibrio cholerae*, *Clostridium difficile*	Feces and/or vomit
Respiratory	*Mycobacterium tuberculosis*, measles virus, *Streptococcus pneumonia*	Inhaled secretions, saliva
Ocular	Herpesvirus	Eye secretions
Genital	*Neisseria gonorrhoeae*, herpesvirus	Genital secretions
Skin	*Streptococcus* spp.	Pus
Anthrax	*Bacillus anthracis*	Skin secretions
Meningitis	*Neisseria meningitidis*	Cerebrospinal fluid
AIDS	Human immunodeficiency virus (HIV)	Blood, sexual secretions, body fluids
Hemorrhagic fevers	Junin, Lassa, Ebola, and Marburg viruses	All bloody products and secretions
Septicemia	*Staphylococcus* spp.	Blood
Bacteremia	Coagulase-negative *Staphylococcus* spp. (including methicillin-resistant *S. aureus*), *Enterobacter*, *Enterococcus*, *Klebsiella*, and *Streptococcus* spp.	Nasal secretion, skin contact
Candidaemia	*Candida albicans*	Blood
Viral hepatitis A	Hepatitis A virus	Feces
Viral hepatitis B and C	Hepatitis B and C viruses	Blood and body fluids
Avian influenza	H5N1 virus	Blood, feces

factor for efficient waste disposal. Physicochemical parameters in low moisture content in waste advocate the use of microwave in treatment technology.

Estimate of storage capacity, transport mode and condition, treatment chamber capacities, as well as output of the compactors, shredders, and other size reduction equipment is required.

14.3.5.4 Overall Management of Health-Care Waste

Personnel dealing with waste should be trained and be made aware of the main categories of health-care waste specified in national or local regulations. The officers should conduct regular inspection of the facility to identify the medical areas that produce waste. Assessment and observation with the support of survey and questionnaires will help in providing data to identify problems and rectification (Table 14.5).

The poor management of waste can sometimes lead to human immunodeficiency virus and hepatitis viruses B and C. These infections are further transmitted to the mass population unknowingly. For example, if a patient admitted in hospital comes in contact with the HIV-infected needle due to carelessness and poor waste disposal practice which can infect the population in the family by the contact of body fluid, the family members then further start chain reaction in the society (Source- Puro et al. 1995; Trim and Elliott 2003; Ganczak et al. 2006).

Cuts from sharps can infect these wounds if they are contaminated with pathogens. Poor management of waste handling is the main cause of microbial resistance to the drugs and disinfectants (Source-Novais et al. 2005).

Hazards from Chemical and Pharmaceutical Waste

The expired drugs or outdated chemicals and pharmaceuticals are disposed off as waste. Their toxicity can be manifested in the skin and mucous membranes through inhalation or ingestion by contact with flammable, corrosive, or reactive chemicals.

Occupational exposures of some workers had been reported as infection to the CDC from blood, body fluids, and laboratory specimens containing HIV and are considered as occupational threat. Spread of hepatitis B in Gujarat in 2009 is the case of the reuse of injection equipment (Harhay et al. 2009).

Impacts of Genotoxic Waste

Data on long-term health impacts of genotoxic health-care waste are scanty due to non-certainty of type of compound to which human are exposed.

Handling of antineoplastic drugs, manifested by increased urinary levels of mutagenic compounds in exposed workers and an increased risk of abortion. Exposure of staff while cleaning of urinals poses potential danger.

Impacts of Radioactive Waste

Many incidents resulting from improper disposal of radioactive waste have been regularly reported. In Brazil the shifting of health-care facility dealing with radioactive waste was ignored the old premises leading to leakage of radioactivity causing carcinogenic impact on the general population. Some people got access to the old facility was exposed the radioactive waste in revealing it due to curiosity.

Survival of Pathogenic Microorganisms

Pathogenic microorganisms can survive up to a certain extent. Ability of specific microbes and their resistance to environmental conditions, such as temperature, humidity, ultraviolet irradiation, availability of organic substrate material are the key variables.

Hepatitis B virus can survive in discarded needles for up to 7 days resistant to slight exposure to boiling water and will be viable for up to 10 h at a temperature of 60 °C and also can survive exposure to 70% ethanol.

HIV can survive for 15 min with 70% ethanol and only 3–7 days at normal condition but became nonfunctional at 56 °C. Prions are the agents of degenerative neurological diseases that are very resistant like viruses (Johnson et al. 2006 and Saunders et al. 2008).

Due to antiseptics in the health-care waste, they are not good media for the survival of pathogens in the health-care industry; ironically it sounds unusual as the microbial load is very low. The survival and spread of pathogenic microorganisms by rodents, insect, flies, and cockroaches, generally feed or breed on organic waste.

Need for Further Research and Epidemiological Surveys
At national and international level, an organization dealing with health-care waste should devise a universal SOP and guidelines for the collection of data starting from village to international scale. This uniform data collection technique will give a broader picture of the waste management status at national and global level at the same time. This will help in predicting of spread of epidemic or pandemic in the country or globally.

The monitoring and collection of information and creation of a database would lead to control outbreak recognized and investigated. It also provides a basis for introducing control measures, assessing their efficacy, reinforcing routine preventive measures, and determining avoidable infection.

14.4 Waste Policy

14.4.1 National Policy

Policy should be able to support demands and rectify the problems in the country, considering the international agreements and conventions adopted to govern public health and sustainable development.

National policy legislation for health-care waste governance is essential. Effective regulations should be capable of fulfilling the expectation and need of health-care staff and reinforce for their implementation. Professional organizations must provide official regulations with practical guidelines, codes of best practice. A national policy must be capable to handle regional differences in community pertaining to socioeconomic conditions (WHO 2005b).

14.4.1.1 Guiding Principles

Five principles are used for the effective and controlled management of wastes as mentioned below.

The principle called as "polluter pays" states that all producers of waste are legally responsible for the safe and environmentally sound disposal failing to which liability can be fixed to the party that causes damage.

The principle called as "precautionary" is defined under the Rio Declaration on Environment and Development (UNEP 1972) named as Principle 15. "Where there are threats of serious or irreversible damage to the environment, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental depletion."

The principle called as "duty of care" translates that the responsibility of the person handling and managing hazardous wastes and related equipment is to ensure use utmost care. It can be achieve with the cooperation of all the parties involved.

The principle called as "proximity" suggests that treatment and disposal of hazardous waste take place at the closest possible location to its source to minimize the risks involved in transport. Every community should be aware, encouraged, and equipped with the facility to recycle the waste it produces, inside its own territories.

The consent principle called as "prior informed" embodied that the information regarding the risk involved should be circulated in the community well in advance with permission of the stakeholders. It can be applied to the transport of waste and the setting up of waste treatment and disposal facilities.

14.4.2 International Policy

14.4.2.1 International Agreements and Conventions

The below-mentioned international agreements and conventions are particularly related to the waste management, environment protection, and sustainable development,

14.4.2.2 The Basel Convention

The Basel Convention means the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and is the most comprehensive global environmental treaty on hazardous wastes. It has 170 member countries globally and aims to protect human and environment against the adverse effect of generation, management, transboundary movement, and disposal of hazardous and other wastes.

The Basel Convention basically is about the transport cross boundary after prior information and consent. Each party is required to follow national or domestic legislation to prevent punishment and legal action. In addition, the convention obliges its parties to ensure that hazardous and other wastes are managed and disposed of in an environmentally sound manner. It also ensures the minimum waste generation and transport in the benefit of the environment. Strong controls are used from movement to storage, transport, treatment, reuse, recycling, recovery, and final disposal.

The Basel Convention consists of:

Y1 – Clinical wastes from hospitals, medical centers, and clinics
Y3 – Waste drugs and medicines

In convention, hazardous characteristics are defined as "H"– infectious substances which contain viable microorganisms, toxins. The convention has *Technical Guidelines on the Environmentally Sound Management of Biomedical and Healthcare Wastes (Y1; Y3)* (UNEP 2003).

The Basel Convention is modified by regular Conference of the Parties, e.g., to prohibit hazardous waste shipments from industrialized to developing countries.

14.4.2.3 The Bamako Convention

The Bamako Convention is based on the import into Africa and the control of transboundary movement and management of hazardous wastes within Africa.

Organization of African Unity at Bamako, Mali, in January 1991 is a consortium of 12 countries and came into force in 1998. Bamako Convention arose from criticism of the failure of the Basel Convention to prohibit trade of hazardous waste to less developed countries and from the realization that many developed nations were exporting toxic wastes to Africa. The Bamako Convention is much stronger in prohibiting all imports of hazardous waste. In nutshell it is a form of Basel Convention to save the interest of African countries and their environment.

14.4.2.4 The Stockholm Convention

Stockholm Convention is global treaty to protect human health and environment against persistent organic pollutants (POPs). These are the chemicals that stay in the environment for long periods, are widely distributed, generally accumulate in the fatty tissue of living organisms, and are toxic to living beings.

Especially polychlorinated dibenzo-p-dioxins and dibenzofurans released to the environment by medical waste and other combustion processes. Governments must ensure best available techniques and promote best environmental practices (UNEP 2006) released in 2006 to prevent the emission of POPs to the environment.

14.4.2.5 Conferences

Various conferences, viz., United Nations Stockholm Conference 1972 followed by World Commission on Environment and Development 1980, World Summit on Sustainable Development in Johannesburg in 2002, and Earth Summit (2012), were held where various plans have been drawn to safeguard the environment.

14.4.2.6 Transport of Dangerous Goods

According to the United Nations Economic and Social Council's Committee transport dangerous goods from developed to transports through developing countries. Not applicable to the bulk transport through sea route of dangerous goods through very large carriers.

It is expected that governments, intergovernmental organizations, and other international organizations are responsible and will conform to the principles of these model regulations, thus contributing to global equality. The model regulations which are mandatory do not apply to the bulk transport of dangerous goods in seagoing or inland navigation bulk tank vessels.

14.4.2.7 Economic Commission for Europe

The international carriage of dangerous goods by road was framed in Geneva on 1957 under the auspices of the United Nations Economic Commission for Europe (UNECE 2010). It came into force in 1968. There were 43 signatories, covering countries in the European Union and beyond.

The ADR's structure is consistent with that of the UN recommendations on the transport of dangerous goods; model regulations; the international maritime dangerous goods code; and the technical instructions for the safe transport of dangerous goods.

14.4.2.8 Aarhus Convention

The Convention is on information accessibility, public participation in decision-making, and justice in environmental matters that came in the existence in 1998 at Fourth Ministerial Conference in the "Environment for Europe" process. It is not only an environmental agreement; it is also a convention about government accountability, transparency, and responsiveness. The Aarhus Convention grants the public rights and imposes on parties and public authorities' obligations regarding access to information and public participation with access to justice (UNECE 2000).

14.4.2.9 World Health Organization

The WHO policy 2004, safe health-care waste management, recommends that countries should adopt the strategies outlined below.

14.4.2.10 Short-Term Strategies

Syringe components using the same plastic to facilitate recycling

Selection of PVC-free medical devices

Identification and development of recycling options wherever possible (e.g., for plastic, glass)

Research into, and promotion of, new technology or alternative to small-scale incineration

Developing countries are safer for the environment and health require operation of incinerators including waste reduction, waste segregation, relocating incinerators away from populated areas, satisfactory engineered design, construction, periodic maintenance, staff training, and management.

14.4.2.11 Medium-Term Strategies

Further, efforts should be made to reduce the amount of hazardous health-care waste that needs to be treated and the research to reveal the health effects of chronic exposure to low levels of dioxin and furan and effective levels in the environment. Risk associated with incineration and exposure to health-care waste should be assessed properly and with utmost care.

14.4.2.12 Long-Term Strategies

Scaled-up and promotion of non-incineration technologies for disposal prevent the disease burden from:

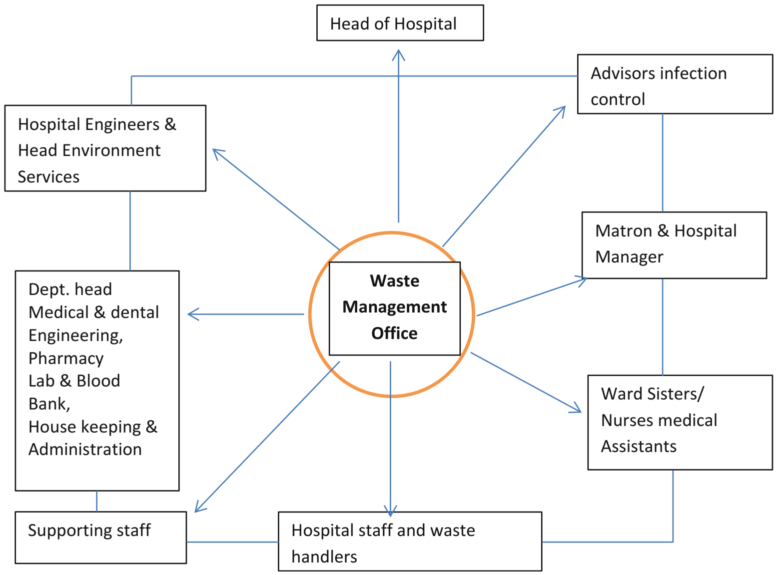
(a) Unsafe health-care waste
(b) Dioxins and furans challenges

Government should develop and implement a national plan, policies, and legislation on health-care waste.

The organizations should promote sound health-care waste management, develop innovative solutions to reduce the volume and toxicity of the waste, and help by investment in the sector for development and growth.

14.4.2.13 International Solid Waste Association

The International Solid Waste Association is recognized as an international, independent, and nonprofit-making association, working in the public interest to promote and develop sustainable waste management globally.



14.5 Recommendations and Future Waste Management

Charging from customers for the food they throw to the conversion of waste into energy resulted in change of attitude toward waste disposal. The model of make, use, and dispose has to be circularized to make, use, degrade, and reuse. This circular thinking and implementation can help to solve the problem of the hour – waste handling.

Converting waste into energy like biogases, biofuels, and novozymes (an enzyme-based solution that converts low-grade oils and cooking oils into biodiesel) is an attractive initiative. Another important aspect is the recyclability of certain products like plastics. Identification of one plastic polymer from another is very challenging and hence their recyclability. All the developing countries need to ratchet up the recyclability procedures. Further, the attitude of people needs to

Table 14.6 Various bioinformatics concepts applied in bioremediation processes

S. No	Area of study	Examples
1.	Proteomics	Detection of key proteins involved in the response of microorganisms in a particular physiological status Identification of up- and downregulated proteins in reaction to the occurrence of specific pollutants
2.	Genomics	Identification of genes involved in biodegradation process and their amplification
3.	Systems biology	Studying the interactions of different genes and proteins inside a system (organism) for their correlation in degradation process
4.	Computational biology	Gene identification, mutational studies, gene mapping, structural modeling for genes identified for biodegrading process
5.	Phylogenetic analysis	Evolutionary relationship analysis of 16s rRNA sequences of dye degrading strains
6.	Molecular docking	Docking studies of dyes with their inhibitor enzymes, enzyme dye-binding profile study

change drastically for waste generation. Convincing consumers for not ending up their food in bins can bring a great change in the waste generation.

Bioremediation is the emerging green technology of environment conservation by eradicating, transforming, and infringing of various contaminants, particularly by harnessing the potential of microbes for degradation of xenobiotic compounds. Bioinformatics, which is an amalgamation of biology and information science and centrally deals with the computer-based examination of large data sets, has taken a new dimension with the introduction of field of bioremediation. There are many significant concepts of bioinformatics which could be applied in the field of bioremediation, namely, the study of microbial proteomics, systems biology, genomics, and computational biology. The highlights of impact of bioinformatics in waste treatment by means of bioremediation are summarized in Table 14.6

There is a strong need to shake up the waste industry, for recycling process, and to counsel the consumers hand in hand for proper future waste management process to observe the sustainable development.

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Recycling of Agriculture Waste into Efficient Adsorbent

15

Sucharita Tandon and Nandini Sai

Abstract

This chapter addresses the possibility of application of agricultural waste material in wastewater purification and summarizes the process of recycling the agricultural waste into an efficient and a multi-pollutant-adsorbing material. There are many novel adsorbents being studied in the adsorption field, but it is the affordability, abundance, and chemical characteristics of the agricultural wastes which make them eligible precursors for adsorbents, for example, activated carbon used for wastewater purification. This chapter focuses on adsorption efficiency for heavy metals of different adsorbents prepared from two different raw materials applying different activation techniques. The application of adsorbents made from agricultural waste supports the "3R," reduce, reuse, and recycle, rule of waste management strategy and can prove to be an efficient and revenue-generating management practice for agricultural sector.

Keywords

Agriculture waste · Waste recycling · Adsorption · Adsorbent

15.1 Introduction

Agricultural waste results from various farming activities and is rich in organic and inorganic content. To be specific, all steps involved in crop production starting from land preparation, sowing of seeds, irrigation, fertilizing, crop harvesting, and packaging generate wastes and runoff that enter into water, air, or soil and lead to

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_15

environmental pollution. In addition modern farming techniques like the use of machineries, slaughterhouses, and animal rearing amplify the risk as they release infectious chemicals and pathogens, thereby increasing the risk of waterborne diseases. Even though the waste generated is not as significant when compared to other types of waste poisoning the planet, but still it is a potential pollutant due to its production and improper handling (Poonam et al. 2018; Poonam and Kumar 2018). Its organic and inorganic content make it both biodegradable and non-biodegradable (Ahalya and Ramachandra 2002). The need of the hour is to avoid or minimize its generation through improved farming practices or recycling the waste and upgrading it into a valuable resource. One such application is converting this organic waste into an efficient adsorbent for wastewater treatment. Till now activated carbon has been the most widely available and used adsorbent which removes a wide range of pollutants from the wastewater, but there are many other materials like agricultural wastes which can be explored for their adsorption efficiency (Khadija et al. 2003; Selomulya et al. 1999).

On the basis of compressibility, agricultural wastes which are being used to produce carbon are majorly classified into the following two major groups:

Group 1: Soft compressible waste products including materials like sugarcane bagasse, rice straw, soybean hulls, peanut shells, and rice hulls

Group 2: Hard, dense, and incompressible materials, such as nutshells from pecan and walnut

Intensive research has been carried out on the application of lignocellulosic materials as adsorbents, and studies suggest that lignin is the major component, controlling the adsorption efficiency of adsorbents prepared by such lignin and cellulose-rich raw material (Suhas et al. 2007). Gergova et al. (1994) in their study suggested that adsorbent microstructure depends on the original plant texture of the corresponding raw material.

Agricultural material is rich in polysaccharides and lignin and fulfills the criteria of high carbon content for adsorbent production. These polysaccharides and lignin are associated with functional groups which are majorly responsible for metal ion adsorption (Aloko and Adebayo 2007). The raw material used in this study can be an optimal adsorbent option because of 4Es beneficial nature:

- Economical
- Environmentally neutral
- Easy to handle
- Efficient because of its high surface area, affinity, and capacity

The chapter discusses the efficiency of plant-based biomass wastes as adsorbents for heavy metals on the basis of detailed laboratory studies. The chapter also gives an insight into preparation, characterization, and application of adsorbent prepared from agricultural waste material. All types of adsorbent prepared from sugarcane bagasse and rice straw were applied for adsorption of the selected metal ions from their laboratory stimulated solutions (Alluri et al. 2007).

15.2 Adsorption

Adsorption is the process in which large molecules from a solvent accumulate on the surface of a solid phase. The solid phase is termed as adsorbent and acts like a sponge adsorbing dissolved species like dyes and metal ions from the liquid phase (solvent, normally water). Due to the higher "affinity" of the adsorbate for the adsorbent, the latter is attracted to the solid and is bound due to different mechanisms. The adsorption process continues till an equilibrium is attained (Afshin et al. 2011).

15.2.1 Factors Affecting Adsorption

The process of adsorption is affected by the following factors.

15.2.1.1 Agitation

The rate of adsorption is controlled by either film or pore diffusion – depending on the amount of agitation. Film diffusion is dominant since surface film around the adsorbent is thicker because of lower agitation rate (continuous system). Higher agitation rate will lead to pore diffusion (batch type contacting system).

15.2.1.2 Adsorbent Characters and Nature

The amount of adsorption is proportional to specific surface area. Specific surface area can be defined as that portion of the total surface area that is available for adsorption. Thus the amount of adsorption accomplished per unit weight of a solid adsorbent is better if the solid is more finely divided and highly porous (Ioannidou and Zabanitou 2007).

15.2.1.3 Adsorbate Solubility

The solubility of the solute is one of the main controlling factors for adsorption equilibria. In general, an inverse relationship can be expected between the amount of adsorption of a solute and its solubility in the solvent from which adsorption occurs. The greater the solubility, the stronger the solute-solvent bond and the smaller the amount of adsorption.

15.2.1.4 Adsorbate Molecule Size

Molecular size of an adsorbate is very important because they have to enter into the micropores. Adsorption is strongest when the pores are just large enough to permit the molecules to enter. Most wastewater contains mixture of compounds of many different molecules. However, the irregular shape of molecules and pores and constant motion of the molecules prevent such blockage from occurring. In addition, smaller molecules allow a greater mobility and diffuse much faster into the pores than the large molecules (Gareth and Judith 2003).

15.2.1.5 pH

Adsorption of adsorbate from the solution varies with the pH of solution. The adsorption sites get saturated by H^+ at acidic pH, and thus the metal adsorption is low which increases with the increase in pH as the adsorption sites become available (Gergova et al. 1994).

15.2.1.6 Temperature

Adsorption reactions are normally exothermic; thus the amount of adsorption generally increases with decreasing temperature. The changes in enthalpy for adsorption are usually of the order of those for condensation or crystallization reactions.

15.3 Adsorbent Preparation

The search for a suitable adsorbent is generally the first step in the development of an adsorption process. A practical adsorbent should meet four primary requirements: selectivity, capacity, mass transfer rate, and long-term stability. A number of other factors can affect adsorption such as pore size distribution, molecular size of the impurity, particle size of the carbon, temperature of the carbon treatment, and the pH of the solution (Mattson and Mark 1971).

The following relationships, however, generally apply when other variables are held constant:

- Adsorption efficiency α 1/particle size of the impurity
- Adsorption efficiency α 1/temperature
- Adsorption efficiency α 1/contaminant solubility
- Adsorption efficiency $\alpha =$ contact time

15.3.1 Pretreatment of Raw Material

The preparation and functionalization of these novel sorbents involves pretreatment of the biomass or the raw material followed by its pyrolysis at a high temperature. Each of the different available pretreatment processes affects the adsorption properties of adsorbent such as:

- the number of sites in the biosorbent material,
- the accessibility of the sites,
- the chemical state of the site (i.e., availability) and
- Affinity between site and metal (i.e., binding strength)

Biomass can be pretreated directly; however, if it is larger in size, they are sized into fine particles or granules, and they are further treated in several ways. Methods involved in pretreatment include heat treatment, washing, employing acids, alkalies, enzymes, etc. Heat treatment, acids, and washing expose additional metal-binding groups; enzymes destroy unwanted components and increase sorption efficiency (Alluri et al. 2007). There are a few methods in preparation of adsorbent from biomass, mainly being chemical activation techniques and physical activation.

The chemical activation of both sugarcane bagasse and paddy straw can be done using orthophosphoric acid and nitric acid for pretreatment of the raw materials and later pyrolysis at 300 °C. Physical activation method comprised of mere pyrolysis at 300 °C. For the purpose of this study, the prepared adsorbents were named with the following abbreviations:

CSBB, carbonized sugarcane bagasse sorbent; PSBB, phosphoric acid-treated sugarcane bagasse sorbent; NSBB, nitric acid-treated sugarcane bagasse sorbent; PPSB, phosphoric acid-treated paddy straw sorbent; NPSB, nitric acid-treated paddy straw sorbent; and CAC, commercially activated carbon.

15.3.1.1 Effect of Physical Activation/Pyrolysis

When any organic substance or lignocellulosic material is pretreated with high temperature, the process is termed as pyrolysis. It is a thermochemical method that yields a product with superior and different characters than mother material and thus changes waste materials into valuable adsorbents (Sen and Dastidar 2010).

When the raw material is pyrolyzed at a temperature of 300 °C and above, the cellulose part of biomass has been found to rapidly decompose to gaseous products and residual char, while in contrast at lower temperatures, the cellulose decomposition is time-consuming (Fierro et al. 2005)

15.3.1.2 Effect of Chemical Activation/Pretreatment: Chemical Activation Can Be Better Understood as Functionalizing the Surface of Raw Sorbent with Some Chemical Prior to Its Pyrolysis

This modification of the raw material increases its sorption capacity. Studies in the past have also reported that chemical treatment functionalized the adsorbent surface with functional groups which play a major role in the adsorption of contaminants like metals from wastewater. The adsorption capacity of orthophosphoric acid modified sugarcane bagasse and paddy straw was much greater than sorption capacity of untreated ones which could be attributed to the formation of new surface functional groups, leading to addition of metal-binding sites on the material surface. Fierro et al. (2005) studied the pyrolysis of kraft lignin impregnated with orthophosphoric acid up to a temperature of 650 °C and found that mixed lignin and H_3PO_4 react completely in less than 1 h and longer contact time did not affect the char content of the end product (Fiore and Babineau 1977).

15.3.1.3 Advantages of Chemical Activation Over Physical Activation

Being a one-step process, chemical activation saves time over physical activation as both carbonization and activation are being carried out together. Because the material is acid pretreated, it is pyrolyzed at lower temperature, thereby producing an adsorbent with much better porosity.

Results of the present study show that both phosphoric acid and nitric acid proved to be an effective activating agent. But adsorbent produced by phosphoric acid activation had higher Brunauer-Emmett-Teller (BET) surface area, iodine adsorption efficiency, and methylene blue adsorption efficiency, thus producing a better adsorbent with much better porous structure.

Thus application of combination of chemical and physical activation methods for producing such novel adsorbents can be a sustainable method for production of economical yet efficient adsorbents (Senthil and Kirthika 2009).

15.4 Adsorbent Properties

All the prepared adsorbents need to be evaluated for their standard adsorption properties including surface area, ash content, moisture content, bulk density, and carbon content which in turn affect their adsorption efficiency. Surface area of the prepared adsorbents may be studied by BET isotherm method where the samples are made to adsorb liquid nitrogen under high pressure. Other important characters like the ash content (%), moisture content (%), pH, bulk density, and carbon content may also be studied and calculated. Carbon content of the adsorbents can be evaluated by EDX analysis along with SEM (Santhy and Selvapathy 2004).

15.4.1 Surface Area and Morphology

Adsorption capacity of any adsorbent is directly proportional to its surface area as more adsorptive sites would be available with greater surface area. Pretreatment of adsorbents with orthophosphoric acid produces material with higher surface area. Large surface area is generally a requirement for good adsorbent. Literature study reveals that presence of greater lignin content in the raw material results in more macroporous adsorbents, while the ones with a higher cellulose content produce microporous material (Ioannidou and Zabanitou 2007).

Surface morphology of the adsorbents studied from their scanning electron micrographs reveals a more porous surface in the chemically activated samples (Fig. 15.1). This could be possible due to the chemical interaction between acids used and the surface of the precursor. SEM micrographs show the presence of wide variety of pores in the prepared adsorbents along with fibrous structure. When compared to untreated one, both acid-impregnated adsorbents (PSSB, PPSB, NPSB, NSSB) were observed to have a more canal-like structure (Fig. 15.2).

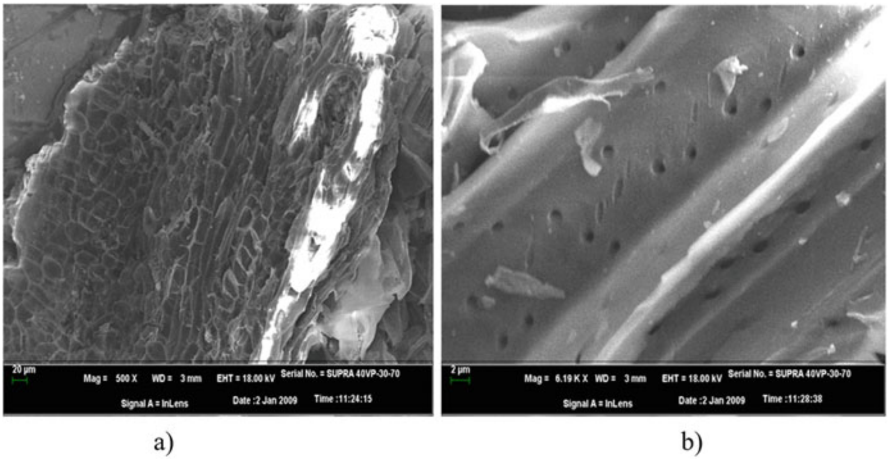

Fig. 15.1 Scanning electron micrograph of (**a**) physically and (**b**) chemically treated sugarcane bagasse sorbent

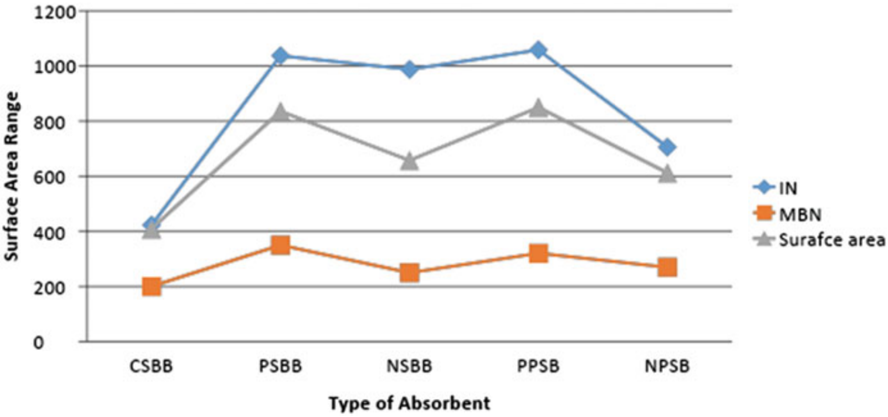

Fig. 15.2 Relation between surface area, methylene blue number (MBN), and iodine number (IN) range of various adsorbents. *CSBB* carbonized sugarcane bagasse sorbent, *PSBB* phosphoric acid-treated sugarcane bagasse sorbent, *NSBB* nitric acid-treated sugarcane bagasse sorbent, *PPSB* phosphoric acid-treated paddy straw sorbent, *NPSB* nitric acid-treated paddy straw sorbent

Orthophosphoric acid used as activating agent for lignin from kraft black liquor leads to higher surface area and well-developed porosity in lignin (Gonzalez–Serrano et al. 2004).

15.4.2 Pore Size Distribution

Determination of the pore size distribution of an activated carbon is an extremely useful way to understand the performance characteristics of the material. IUPAC defines the pore size distribution as micropore ($d < 2$ nm), mesopore (2 nm < d < 50 nm), and macropore ($d > 50$ nm). The macropores are used as the entrance to the activated carbon, the mesopores for transportation, and the micropores for adsorption (Kannan and Thambidurai 2008).

15.4.3 Bulk Density

Bulk density is an important characteristic for any adsorbent and majorly depends on the quality of the raw material used for adsorbent production. Studies showed that all chemically treated adsorbents had higher bulk density. Also among the chemically treated adsorbents, phosphoric acid-treated adsorbents had higher bulk density than nitric acid-treated adsorbents which could be due to the sticking of phosphoric acid sticks to the surface of the raw material, thus making the end product denser (Shuddhodan 2007).

15.4.4 Ash Content and Carbon Content

Ash content is the indicator of the quality of an adsorbent. It is the residue that remains when carbonaceous portion is burned off. The ash consists mainly of minerals such as silica, aluminum, iron, magnesium, and calcium (Freese et al. 2000). Ash in an adsorbent is not desirable and is considered an impurity. Ash may also interfere with carbon adsorption through competitive adsorption and catalysis of adverse reactions. Usually materials with the lowest ash content produce the most active products. A good adsorbent must have low ash and carbon content. The higher the carbon content of adsorbent, the better would be its adsorption efficiency (Fongsatitkul et al. 2009).

15.5 Adsorption Capacity

The effectiveness of any adsorbent in removing a particular contaminant from the target water sample can be termed as its adsorption capacity. For comparison, several standard compounds are used for these measurements; like the iodine number, being the most fundamental parameter, it is used to evaluate the adsorption efficiency of adsorbents and describe capacity of adsorbent to adsorb substances with low molecular weight. It also informs about micropore content of activated carbon.

Another qualitative test applied is estimation of methylene blue number (MBN) which speaks about the mesopore structure of the prepared adsorbent. It has been observed that iodine number and methylene blue number both reveal the porous structure of the adsorbent. The higher the iodine number, the more is the methylene blue adsorption capacity (Garacia et al. 2003).

15.6 Analysis of Efficiency of Prepared Adsorbent in Adsorption of Metals from Their Aqueous Solutions

The prepared adsorbent efficiency in removing target heavy metals from their lab solutions needs to be evaluated. Heavy metals are introduced into the aquatic system significantly as a result of various industrial operations (Ahalya et.al. 2003). The following factors have been identified to affect the adsorption of any solute from its solution:

- Chemical and physical nature of the adsorbent which includes its porosity
- Chemical and physical nature of the solution which includes its concentration, pH, and solute solubility (Senthil and Kirthika 2009)

The adsorption efficiency of the adsorbent and the amount of metal adsorbed can be calculated using the following formulas:

$$\text{Adsorption} = \frac{\left(C_i - C_f\right) \times 100}{C_f}$$

And amount of metal adsorbed can be calculated using

$$q\ [\text{mg/g}] = V\ [\text{L}]\ \left(C_i - C_f\right)\ [\text{mg/L}]/S\ [\text{g}]$$

where:

V is the volume of the metal-bearing solution contacted (batch) with the sorbent [L].
C_i and C_f are the initial and equilibrium (residual) concentrations of the metal in the solution, respectively. They are expressed as mg/L.
S is the amount of the added (bio)sorbent on the dry basis [g].

15.6.1 Effect of Initial Concentration on Heavy Metal Adsorption

The rate of sorption is a function of initial concentration of metal ions, which makes it an important factor to be considered for effective adsorption. The initial concentration provides an important driving force to overcome mass transfer resistances of metal ions between aqueous and solid phase. At low concentrations, adsorption sites took up the available metal more quickly (Fig. 15.3) (Ahalya et al. 2005).

Adsorption capacity is directly proportional to initial metal concentration; the higher the concentration, the higher would be the adsorption capacity as there would be more number of sorbate particles to bind to the adsorbent. Phosphoric acid-treated

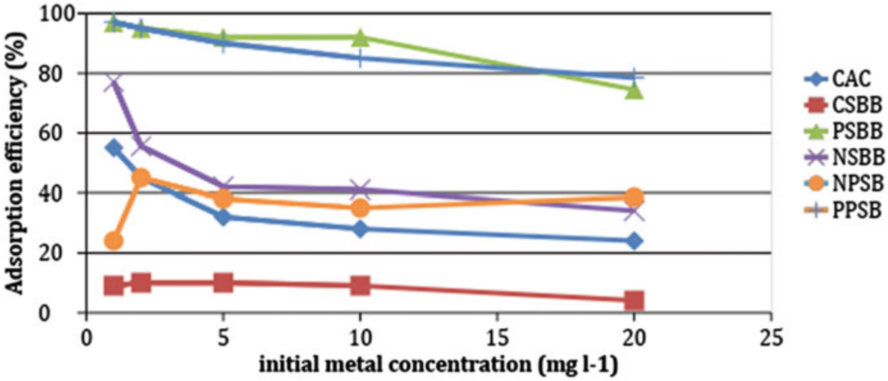

Fig. 15.3 Effect of initial metal concentration on % adsorption of copper from single-component solution (*CSBB* carbonized sugarcane bagasse sorbent, *PSBB* phosphoric acid-treated sugarcane bagasse sorbent, *NSBB* nitric acid-treated sugarcane bagasse sorbent, *PPSB* phosphoric acid-treated paddy straw sorbent, *NPSB* nitric acid-treated paddy straw sorbent, *CAC* commercially activated carbon)

sugarcane bagasse adsorbent (PSBB) showed best adsorption results for various metal ions from their single metal. Though the fall in adsorption efficiency was observed to decrease with increase in metal concentration, overall efficiency was still better as compared to others (Ahalya et al. 2006).

15.6.2 Effect of Adsorbent Dosage on Heavy Metal Removal

Generally adsorption increases with increase in adsorbent dose. This is expected due to the fact that the higher the dose of adsorbents in the solution, the greater the availability of exchangeable sites for the ions (Fig. 15.4). After a certain amount of adsorbents, there was no further increase in adsorption. This suggests that after a certain dose of adsorbent, the maximum adsorption sets in, and hence the amount of ions bound to adsorbent and the amount of free ions remain constant even with further addition of adsorbent (Orhan and Buyukgngor 1993; Akporhonor and Egwaikhide 2001).

15.6.3 Effect of Contact Time

Rate of adsorption is higher during initial phase and slows down with increase in time period. The rate of adsorption is higher in the beginning due to large available surface area of the adsorbent. After the capacity of the adsorbent gets exhausted, i.e., at equilibrium, the rate of uptake is controlled by the rate at which the adsorbate is transported from the exterior to the interior sites of the adsorbent particles (Fig. 15.5).

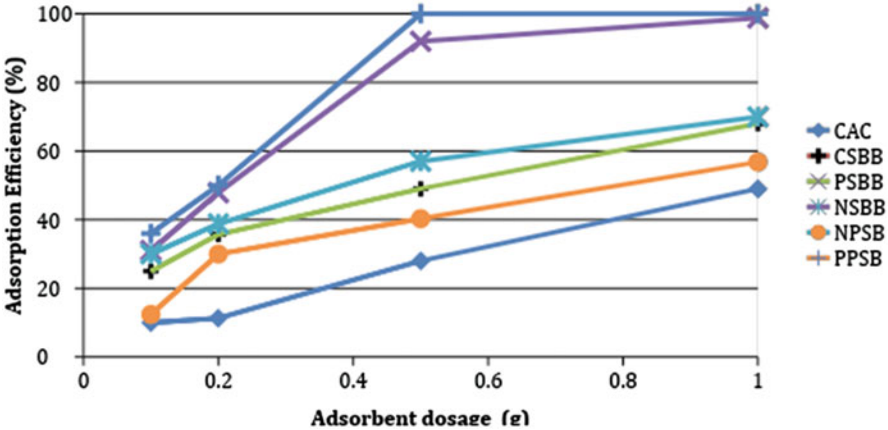

Fig. 15.4 Effect of adsorbent dosage on % adsorption of copper from single-component solution (*CSBB* carbonized sugarcane bagasse sorbent, *PSBB* phosphoric acid-treated sugarcane bagasse sorbent, *NSBB* nitric acid-treated sugarcane bagasse sorbent, *PPSB* phosphoric acid-treated paddy straw sorbent, *NPSB* nitric acid-treated paddy straw sorbent, *CAC* commercially activated carbon)

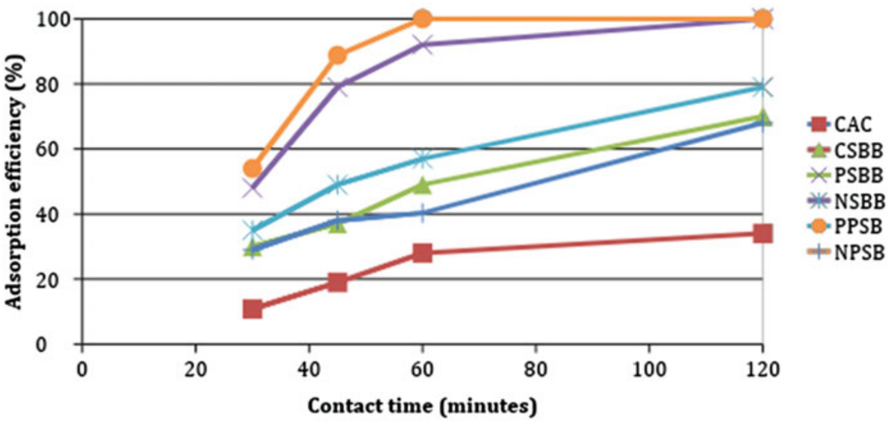

Fig. 15.5 Effect of contact time on % adsorption of copper from single-component solution (*CSBB* carbonized sugarcane bagasse sorbent, *PSBB* phosphoric acid treated sugarcane bagasse sorbent, *NSBB* nitric acid treated sugarcane bagasse sorbent, *PPSB* phosphoric acid treated paddy straw sorbent, *NPSB* nitric acid treated paddy straw sorbent)

The uptake of heavy metal ions by adsorbent has often been observed to occur in two stages: (i) rapid and quantitatively predominant and (ii) slower and quantitatively insignificant. The rapid stage is probably due to abundant availability of active sites on the biomass. With gradual occupancy of these sites, the sorption becomes less efficient in slower stages (Siddiqi and Paroor 2004).

The biosorption capacity, *q*, of various adsorbents increased with an increase in concentration for metals. Adsorption efficiency and biosorption capacity of various adsorbents were in the following order:

$$\text{PSSB} > \text{PPSB} > \text{NSSB} > \text{NPSB} > \text{CAC} > \text{CSBB}$$

where

CSBB is carbonized sugarcane bagasse sorbent, PSBB is phosphoric acid-treated sugarcane bagasse sorbent, NSBB is nitric acid-treated sugarcane bagasse sorbent, PPSB is phosphoric acid-treated paddy straw sorbent, NPSB is nitric acid treated paddy straw sorbent, and CAC is commercially activated carbon.

Thus it was realized that sorption is a surface reaction and is majorly affected by surface properties such as surface area and polarity of the adsorbent. Most of the available biosorbents are microporous in nature with large specific surface area. The micropore size controls the accessibility of adsorption surface to the adsorbate molecules. In addition to this, presence of macropores also plays an important role, as they serve as diffusion paths of adsorbate molecules from outside environment to the interior micropores of the adsorbent being used (Shunnian and Paul 2008).

15.7 Isotherm Studies

The two important aspects for the evaluation of adsorption process are its kinetics and equilibrium for which the adsorption isotherm is the most extensively employed method. The adsorption isotherm speaks about the adsorbate, the adsorbent, and the adsorption process, giving information about the surface area of the adsorbent, the volume of the pores, and their size distribution. In short the isotherms describe the interaction of adsorbate and adsorbents. Adsorption efficiency is usually analyzed by the extent to which the solute is adsorbed from the solution. Both Langmuir and Freundlich adsorption model may be applied to all adsorption experiments. The values for Langmuir constants Q_o, b, and R_L and Freundlich's constants K and n can be analyzed. With the increase in the initial metal concentration, adsorption increases while the binding sites are not saturated. The values of Q_o, b, and R_L show that adsorption follows the Langmuir adsorption model. The essential characteristics of the Langmuir isotherms can be expressed in terms of a dimensionless constant separation factor or equilibrium parameter, RL. The R_L value indicates the shape of isotherm. R_L values between 0 and 1 indicate favorable adsorption conditions (Shuddhodan 2007; Ahalya et al. 2006).

The Freundlich's constants K and n which are constants that incorporate all parameters affecting the adsorption process, such as adsorption capacity and intensity, respectively, can be calculated from the slopes of the Freundlich plots (Ahmedna et al. 1997; Sabrina and Hasmah 2008).

15.8 Conclusion

Production of waste materials is an undeniable part of human society, and efficient waste management looks like a hard to achieve goal. The "3R" practices of reduce, reuse, and recycle need to be implemented strongly in order to change any type of waste to wealth. The production of adsorbents similar to activated carbons from agricultural by-products serves a dual purpose of changing unwanted, surplus agricultural waste to useful, value-added adsorbents, and secondly it serves as an economical and efficient tool for wastewater purification. Thus upcycling organic waste for water purification can prove to be a sustainable solution for an ever rising problem of waste management and water pollution.

Paddy straw and sugarcane bagasse can serve as a better alternative for sorption process as both are cheap and possess good sorption capacities when functionalized properly. Functionalization of the raw material surface included heat treatment following activation with phosphoric acid (H_3PO_4) and nitric acid (HNO_3) which improved the micropore structure of the mother materials. Chemically treated adsorbents with H_3PO_4 were observed to have a low ash content due to removal of both organic and inorganic sulfur from its structure which leads to its ring opening. Sulfur is a major constituent of ash in the adsorbents, so low ash content is favorable for adsorption process as high ash content reduces the mechanical strength of adsorbent and affects its adsorptive properties.

Both the Freundlich and Langmuir models could be used to fit the data and estimate model parameters for the evaluation of adsorbent efficiency. The results have shown that the adsorbents derived from bagasse and paddy straw can be successfully employed for the removal of Cu(II), Cr(VI), and Ni(II) from wastewater though copper was the most efficiently adsorbed metal from single metal solution as compared to nickel and chromium.

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Environmental Hazards and Management of E-waste 16

Shalu Rawat, Lata Verma, and Jiwan Singh

Abstract

E-waste is among the fastest growing solid waste classes and represents a serious hazard for the environment. It consists of a mixture of hazardous inorganic and organic materials, for example, heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and brominated flame retardants, along with valuable metals, such as Au, Ag, and Pd. Direct e-waste disposal to landfills without any prior treatment creates threats to the environment due to leaching of metals in water and soil. Improper e-waste recycling, such as by open burning and acid baths, creates hazardous and toxic compounds, like dioxins, furans, and acids. Management of e-waste is different from the other solid wastes. The management of e-waste need advance as well as environmental friendly technologies with respect to its recycling and recovery of precious and valuable materials. Because e-waste contains a number of precious and base metals in large quantities, it can be utilized as an alternative or secondary source of such metals (Tanskanen 2013). Utilization of this secondary source instead of primary resources for metal extraction can reduce stress on primary metal sources for sustainable use, which will result in lowering the market value of those metals. Currently metals are extracted from e-waste by three main processes: pyrometallurgy, hydrometallurgy, and biometallurgy through the use of high temperature, chemical leaching, and microorganisms, respectively. Biometallurgy is a recent, environmentally friendly, and promising technique and that is currently used in the efficient extraction of metals from low-grade ore.

Keywords

E-waste · Recycling · Recovery · Hazards

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_16

16.1 Introduction

The term electronic waste or e-waste applies to all electronic materials that are unwanted, no longer work, are outdated, or damaged. Because equipment and capabilities are improving on a daily basis, the usable life of an electronic product is quite short (Nnoroma and Osibanjo 2008). Modern and developing society requires the latest technologies, enhancing the utilization rate of electronic products and creating a vast amount of e-waste as those products' usable life ends (Özkır et al. 2015). All categories of outdated electronic products make up e-waste, for instance, videocassette recorders (VCRs) were replaced by digital video discs or digital versatile discs (DVD) players, which in turn were replaced by blu ray players. All unusable and outdated electronic products, for example, televisions (TVs), computers, mobile phones, compact discs (CDs), and electronic chips, contribute to e-waste. Based on daily usage of electric and electronic equipment (EEE), the amount of daily e-waste being generated is rising all over the world (Bhat and Patil 2014).

The manufacture and use of electric and electronic products have increased rapidly along with the increase in the global human population, which has resulted in the growth of e-waste generation at the end of the products' life (Pérez-Belis et al. 2015). The global population has doubled, with a stable trend toward urbanization in the last 50 years. About 50% population of the world now live in urbanized zones. Along with population, the quantity of waste generated is also increasing, with different generation rates in different countries. E-waste generation is increasing more in countries that are developed in comparison with developing countries (Tansel 2016).

The category of solid waste is growing fastest across the globe. On the basis of a European Union study, the rate of e-waste growth is 3% to 5% annually, and it is growing about three times faster than any other single category of solid waste (Herat and Agamuthu 2012). According to a report by the United Nations (UN) (UNEP and UNU 2009), computers will increase by up to 500% in India and about 200% to 400% in South Africa and China by the year 2020 in comparison with the year 2007. This report also stated that e-waste generation by discarded mobile phones will be 18 times more in India and approximately 7 times more in China by the year 2020 (Herat and Agamuthu 2012).

Due to growth in the electronics industry, the environment has been affected in two ways: the disposal of e-waste in landfills in large volume and a rising demand for precious metals from primary resources. The disposal of e-waste creates lots of health issues in the environment, as the released toxic and hazardous compounds contaminate the air, water, and soil and damages the aesthetic importance of the affected location (Cayumil et al. 2016). The health hazards connected to e-waste can occur due to contact with hazardous materials like heavy metals (e.g., chromium, lead, cadmium), polychlorinated biphenyls (PCBs)/brominated flame retardants (BFRs), directly by toxic fumes, and due to contamination in air, water, soil, and food. In addition, e-waste can also generate toxic byproducts that could affect human health. In a decade-long study in the period 2004–2014, several investigations have regularly provided evidence of pollution by trace metals and organic compounds in the environment in areas like Guiyu (Guagdong Province) and Wenling (Zhejiang Province), where e-waste is recycled (Duan et al. 2016).

There is a critical need to establish an environmentally friendly method of e-waste recycling and reducing the amount of solid waste in the environment to address these problems (Cayumil et al. 2016). Elemental recycling methods of valuable materials from e-waste, like dismantling, burning, and acid washing, have created an environmental issue by contaminating soil around the world. Several trace metals, like Zn, Cd, Cu, and Pb, have been found in the upper layer of soils. This soil contamination also pollutes surface and ground water by run-off and through the percolation of water and causes heavy metal accumulation in plants. The soil of Guangdong and Zhejiang provinces in China is heavily polluted due to the electronic dismantling of e-waste (Cui et al. 2017).

E-waste contains precious metals and trace metals in a large amounts, so the recycling of e-waste and the recovery of precious metals from it make it a good alternative resource for precious metals (Kaya 2016). Reuse, remanufacture, and recycling are the main routes to handling e-waste today, and nonrecyclable waste is incinerated or landfilled. Sometimes partially useful electronic products are discarded by users, but they are still valuable for others who can resell or donate the products. Reuse of electronic waste includes the extension of useful life in the secondary market and it is given first priority in e-waste management. Reuse of electronic equipment reduces the amount of waste to be treated. Remanufacturing includes production of new or like-new products from discarded electronic equipment by disassembling, cleaning, repairing, reassembling, and testing. Recycling involves the destruction of useless equipment, recovery of valuable elements, and discard of nonrecyclable materials for incineration or landfilling (Cui and Zhang 2008).

Electronic waste consists of both hazardous elements, for example, PBR, mercury, lead, cadmium, and chromium, and precious materials like gold, silver, and copper (Wath et al. 2010). These hazardous substances make soil, sediments, surface water, and ground water extremely polluted, and they become toxic for biological as well as ecological systems (Chauhan and Upadhyay 2016). Precious metals are extensively used in other industries, so demand for them is ever increasing, but due to their insufficient supply, their price is increasing immensely. This has resulted in an urgent need to recover valuable materials from secondary sources. E-waste is an efficient alternative/secondary source of precious metals because the amount of precious metals it contains exceeds levels found in natural ores (Won et al. 2014). Reuse of recovered metals reduces pressure on primary ores, increasing their lifetime, which also reduces carbon and ecological footprints. In comparison with the extraction of aluminum and copper from primary ores, recycling saves about 95% and 85% on energy use, respectively (Işıldar et al. 2018).

Conventional methods and tools for recycling of waste electric and electronic equipments (WEEE) includes mainly plastic burning, toxic soldering, and acid baths with few or without any protection for human health and the environment, that causes air, water, and soil pollution. Open burning of printed wiring boards (PWBs) and polyvinyl chloride (PVC)-coated wires in controlled experiments emits dioxins, furans (chlorinated and brominated), and heavy metals in high amounts in remaining fly ash and bottom ash.

It is a very complex task to manage huge amounts of e-waste in an effective and efficient manner. A few countries have well-developed systems for the collection, segregation, recycling, disposal, and monitoring of e-waste, while the remaining countries need to develop a proper management system for e-waste to minimize its hazardous impacts on humans and the environment (Wath et al. 2010).

There are some major requirements and considerations to develop an organized system of e-waste management:

- Distinct and reasonable demands for collection of waste electric and electronic products from origin and transportation to treatment, recycling, recovery, reuse, or disposal.
- E-waste requires special treatment before the disposal of products to lessen the negative impacts on the environment, as it contains various hazardous materials that are very toxic to both humans and the environment.
- However, electronic waste is also among the best sources of precious metals that can be recycled and reused again in production after recovery.

16.2 E-waste Generation Globally

About 44.7 million metric tonnes (Mt) of e-waste waste were generated in 2016 worldwide, and per capita generation of e-waste was approximately 6 kg. E-waste generation is expected to increase in coming years. Approximately 18.2 Mt. e-waste was generated Asia in the year 2016 and the rate of generation of e-waste was occurred 4.2 kg/capita. The maximum e-waste generation rate was reported in Oceania that was 17.3 kg /capita; however, the total e-waste generation was reported approximately 0.7 Mt, which is lowest quantity of e-waste generated in the world.

Europe and Russia together generated 12.3 Mt of e-waste, about 16.6 kg/capita. Africa, with 1.9 kg/capita, was the lowest generator of e-waste per capita, and 2.2 Mt of e-waste was generated at the continental level. In 2016, 11.3 Mt was generated in the Americas (7 Mt in North America, 3 Mt in South America, and 1.2 Mt in Central America). There was a remarkable difference among developing countries and developed countries in the generation of e-waste: developed, rich countries generated 19.6 kg/capita, while the poor developing countries generated only 0.6 kg/capita (Baldé et al. 2017).

16.3 Composition of E-waste

Electronic waste is composed of a diverse and complex mix of substances. It includes thousands of hazardous and nonhazardous substances, and, due to the rapid evolution of technology and its upgrades, the composition of e-waste is

Table 16.1 Classes of e-waste

Sl. no.	Class	Equipment
1.	Major domestic appliances	Television, washing machines, refrigerators, cooking appliances etc.
2.	Small domestic appliances and machines	Vacuum cleaners, driers, lawn mowers, fans, and others.
3.	IT and telecommunication equipment	Personal computers, photocopying machines, printers, telephones, mobiles, fax machines, and so forth.
4.	User products	Televisions, radios, cameras, entertainment systems, and so forth.
5.	Lighting products	Compact fluorescent lamps, electronic bulbs, and so forth.
6.	Tools	Electric drills, saw, sewing machines, and so forth.
7.	Toys, leisure, and sports products	Personal computers, electronic toys, robots, video games, and so forth.
8.	Hospital appliances	X-ray machines, magnetic resonance imaging machines, and so forth.
9.	Monitoring and regulating instruments	Smoke detectors, heating regulators, thermostats, and so forth.
10.	Subparts of electronic equipment	Electronic chips, compact disks, DVDs, Printed circuit boards, wires, cables, and so forth.

continuously growing. According to the "EU" 2002 e-waste can be roughly classified as given in Table 16.1 (Wath et al. 2011; Cayumil et al. 2016).

E-waste consists of various toxic and nontoxic elements that include plastic, glass, ceramics, steel, silicon, lead, mercury, copper, gold, cadmium, aluminum, BFRs, PVCs, and other organic compounds. The presence of all these elements in e-waste makes it hazardous for humans and the environment. A single waste electronic product contains high levels of hazardous materials in recoverable amounts, for example a single average computer consists of 7.24 kg plastic, 1.98 kg lead, 0.693 g Hg, 0.4095 g As, 2.96 g Cd, and 1.98 g, 9.92 g, and 4.94 g of Cr, Ba, and Be respectively (Akcil et al. 2015; Ari 2016).

16.4 Hazardous Effects of E-waste

It was estimated by the United Nations Environment Programme that global production of e-waste is 20 to 50 million tonnes per year (Robinson 2009). Due to the unmanaged handling/disposal of e-waste, the world encounters many environmental challenges. E-waste contains many hazardous materials that are very harmful for humans and the environment. Health and safety worries accompanying e-waste generation stem from various harmful effects, like surface and ground water contamination, toxic fume inhalation, and exposure to radiation from ashes, dust, and smoke from dump sites (Jibiri et al. 2014). In recent years, due to the excessive use of electrical appliances, large amounts of e-waste have been generated that causes many health-related problems for humans and the environment. E-waste contains highly toxic materials that can result in external or internal exposure. The external exposure to radiation is due to the increased concentration of 40 K, 226Ra, and 232Th in the soil, but exposure could be internal as a result of inhaling prosterity of radon (chemically inert gaseous element that is formed by deccaying of radon) in fumes and dust from e-waste disposal sites (UNSCEAR 2008).

E-waste is very hazardous; for example, personal computers contain many toxic components like brominated and chlorinated substances, toxic metals, harmful acids, plastic, plastic additives, and toxic gases (Wei and Liu 2012). Inappropriate management of this waste causes many threats to living environments by the release of inorganic (heavy metals) and organic pollutants in huge amounts in the workplace and its surrounding environment. Many studies have demonstrated the presence of lead, mercury, cadmium, copper, and other heavy metals, many more organic contaminants like polycyclic aromatic hydrocarbons (PAHs), dibenzofurans, and polychlorinated biphenyls that are highly toxic in dumping and disposal sites that pollute the air, soil, and water (Tang et al. 2010). Direct inhalation, ingestion of food and water contaminated with pollutants, and dermal exposure to these toxic compounds can affect local residents and workers. These compounds are persistent in nature and stored in certain tissues through bioaccumulation and biomagnification, which results in creating a burden on the human body.

Human exposure to these toxicants is much higher than is recommended by the World Health Organisation (WHO). People engaged in the recycling of e-waste have very high amounts of lead and cadmium in their blood (Chatterjee 2007). To minimize the risk of exposure to hazardous contaminants, appropriate disposal of e-waste is necessary. Computer circuit boards contain various heavy metals such as cadmium, and lead batteries contain cadmium, tube lights contain lead oxide and barium, cables, and plastic casing, copper coated with PVC, and plastic hardware, which produces large amounts of dioxins and furans. These are also substances of concern. Several govermental and nongovermental organizations, such as Green Peace and Toxics Link are working on collection of data related to these activities that may prove to be effective for controlling this hazardous trade (Mary and Meenambal 2016).

E-waste contains many toxic materials, some of which are discussed in what follows.

Lead Lead is mainly found in solders of PCBs, glass, panels, and gaskets in computer monitors. Lead is a neurotoxin that causes neurological disorders in living beings and is one of the most harmful toxicants and has many other detrimental health impacts resulting from high levels of exposure to it. Due to the inappropriate recycling process of lead, huge amounts of fumes, dust, and hazardous waste are discharged into the environment that pose a serious public health risk (Tian et al. 2017). Lead enters the human body through ingestion and inhalation. Sources of lead in the human body are mainly leaded paint, soil, dust, and water contaminated by lead (Jarvis et al. 2018).

Cadmium Cadmium can be naturally found in the environment but its concentration in the environment is increasing at a fast rate due to anthropogenic activities. In e-waste it is found, for example, in semiconductors and cadmium batteries. Cadmium is highly toxic when discharged into aquatic systems, resulting in bioaccumulation in aquatic organisms. The half-life of cadmium is very long, up to 10–30 years in the human body (Mu et al. 2018). It is an abundant metal and causes renal and bone diseases, cancer, dysfunction of the cardiometabolic system, and death even at lower exposure levels (Moynihan et al. 2017).

Copper Copper is a very important trace metal and very useful in smaller amounts, but high concentrations of Cu are very harmful. Copper is mainly used in wiring, chips, PCBs, semiconductors, and so forth. Chronic toxicity of copper predominantly affects the liver and enters the blood (Gaetke and Chow 2003). It results in liver cirrhosis and destroys the brain, renal tubules, and other body organs. Cu poisoning also results in weakness, anorexia, and lethargy and also causes necrosis in hepatic cells and acute necrosis in kidney (Barceloux 1999).

Mercury Mercury is used in relays, switches, and PCBs. It damages the brain and respiratory system and also affects the skin.

Beryllium Beryllium is used in motherboards and is known to cause cancer.

Chromium Chromium is used in the protection of galvanized steel from corrosion and in decorations or as a steel hardener. Hexavalent Cr damages DNA.

Plastic and Brominated Flame Retardants These are used in cables, computer housing, and circuit boards. They can interrupt the functioning of the reproductive and immune systems and also cause hormonal disorders.

An improper way of e-waste disposal leads to many environmental problems and to a steady loss of secondary materials, so appropriate e-waste handling and management reduces the risk of serious environmental damage, and valuable material recycling and recovery from waste creates profitable business opportunities (Chibunna et al. 2012). Some developed nations have found an easy way to get rid of this hazardous waste by sending it to developing nations for processing; this is very profitable but also very harmful to living beings. The toxicity of the components present in e-waste when burned in an unmanaged way leads to many environmental or socioeconomic problems and deteriorates environmental systems (Grant et al. 2013).

16.5 Management of E-waste

Extensive studies have been done to manage e-waste for the mitigation of this global problem at the national and international level. Currently most countries have no proper management system for e-waste; only European countries manage electronic waste in a proper way. E-waste management includes the following methods.

16.5.1 Incineration

Incineration is a commonly used method for e-waste management in some African countries, as well as in China and India. Incineration of e-waste generates toxic elements and includes pyrolysis, which is the treatment of e-waste at high temperatures in the absence of air and conversion into fumes, oil, and char, whereas in gasification, conversion of e-waste to fumes, ash, and tar is done by supplying a sufficient amount of air. The treatment of plastic at high temperatures releases toxic fumes that include carcinogenic substances like polycyclic aromatics (PCA), polychlorinated dibenzo-para-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs). Incineration also releases carbon monoxide, sulfur dioxide, and nitrogen oxide, along with trace amounts of some metal oxides like the metals antimony, lead, nickel, mercury, manganese, thallium, arsenic, and copper (Sivaramanan 2013).

16.5.2 Recycling of E-waste

Recycling is an essential process for the management of e-waste, not just from the viewpoint of its management but also it leads to the recovery of valuable materials. According to the U.S. Environmental Protection Agency (EPA), recycling has seven major advantages, like energy savings and pollution reduction. Today e-waste recycling can be classified into three main phases:

Disassembly This process include disassembling of waste electronic equipment into its components and seperation of valuable materials for further processing. It is an essential step of e-waste recycling.

Upgrading Upgrading includes processing by mechanical or metallurgical means to upgrade a particular appropriate matter, preparing the material for refining.

Refining Refining is the last step and includes retreatment or purification of the recovered material by chemical metallurgical processes for their reuse.

Recycling and metal recovery from e-waste has many advantages (Ari 2016):

- Helps in the management of primary sources of metal by their conservation,
- Decreases the amount of solid waste,
- Saves energy,
- Reduces environmental pollution due to e-waste.

An overall recycling process is given in Fig. 16.1. E-waste recycling comprises a series of steps, describe in what follows.

Sorting The first step of e-waste recycling includes sorting of the different elements involved.

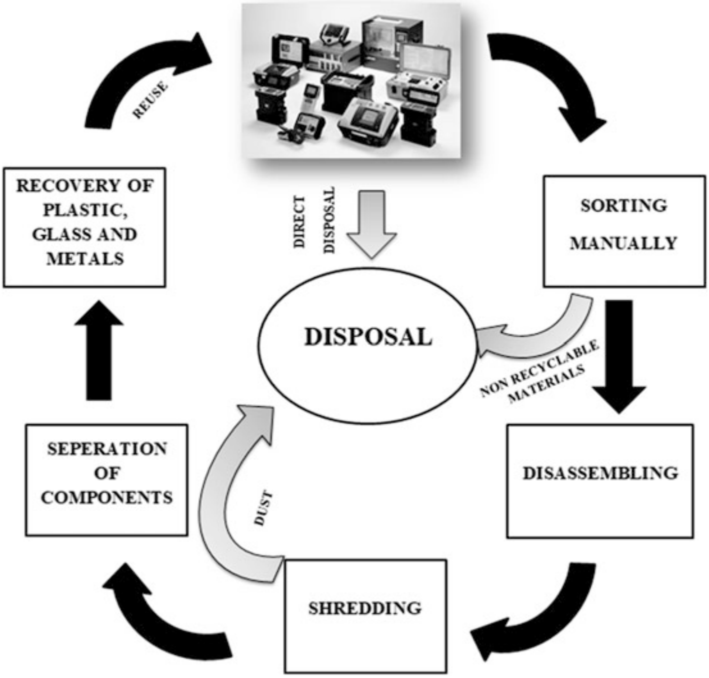

Fig. 16.1 Recycling of e-waste

Disassembly After the e-waste is sorted, it is manually disassembled. In this step the e-waste is separated into its different components, which are categorized into material that can be reused, recycled, or discarded.

Size Reduction Equipment that cannot be disassembled properly is decomposed into small pieces, having size less than 5 cm along with other dismantled parts. Then the shredded pieces of e-waste are transferred to a conveyer belt, where the pieces are further broken into smaller sizes. The remaining dust is removed in this process and discarded at a disposal site.

Separation of Ferrous Material In this step all the ferrous material present in the shredded e-waste is separated with the help of magnets.

Separation of Other Metallic and Nonmetallic Materials After isolation of ferrous components from the waste, other metals like copper, aluminum, and brass are separated by application of an eddy current separator.

Water Separation In this step, plastic is separated from glass in a water medium because plastics float and become separated from surface and glass that settle at the bottom.

The separated material can be resold as raw material or recovered to make fresh material.

16.5.3 Recovery of Valuable Material from E-waste

Once all the different components of the e-waste are isolated, they are then processed for conversion into new products. Recoverable materials from the e-waste are given in what follows.

Plastic The separated plastic is transferred to recycling units, where they are used for the manufacture of plastic sleepers, trays, vineyard stakes, and other plastic items.

Glass Glass is mostly present in cathode ray tubes (CRTs) that are used in monitors and TVs. Recovering glass from CRTs is a very complex task because CRTs are made up of various hazardous materials including lead, a dangerous component that can adversely affect humans and the environment. CRTs contain a high amount of lead, along with other toxic materials like barium and phosphor. The following steps are considered for environmentally benign recycling of CRTs for the extraction of glass:

- Manual separation of CRTs from monitors and TVs;
- Elimination and disposal of dust generated in process of shredding CRTs in environmentally friendly way;
- Removal of metals and nometals from glass materials using magnetic separators;
- Use of a washing line (It is a particular area where glass is washed for removal of unwanted elements or washable elements in the process of recycling) for the removal of oxides and phosphor from glass;
- Sorting of glass into leaded glass and nonleaded glass; the extracted glass can be used for the preparation of new screens.

Mercury Devices containing mercury are sent to facilities to recycle the mercury. These facilities have special equipment for the extraction of mercury for reuse in dental amalgams, measuring instruments, and fluorescent lighting.

Batteries Batteries are sent to specialized recycling units where their plastic body is removed. The recovery of metals, nickel, steel, cadmium, and cobalt is accomplished by smelting in special conditions, then they are used for the production of new batteries and the fabrication of stainless steel.

Metals Metal recovery from e-waste is done through three main processes, as shown in Fig. 16.2. Pyrometallurgy includes the treatment of metals at very high temperature. It is the most polluting method of metal recovery. Hydrometallurgy

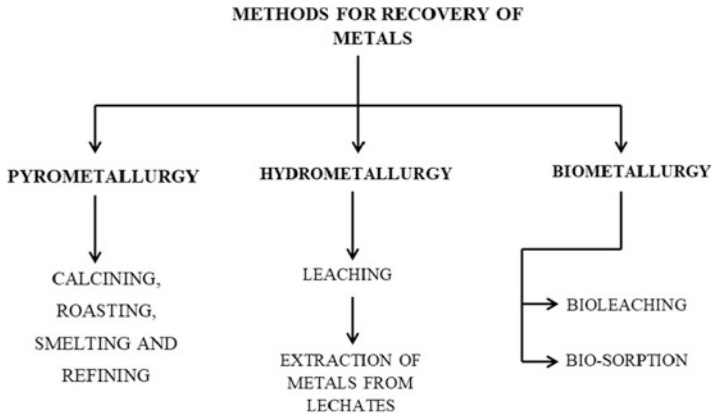

Fig. 16.2 Methods for the recovery of metals

includes the leaching of metals from the solid phase to the liquid phase by means of chemicals (e.g., acids, bases). Finally, biometallurgy entails the leaching of metals with the help of microorganisms.

Pyrometallurgy

The pyrometallurgical process of recovery consists of incineration, smelting, sintering, melting, drossing, and gas phase reaction at elevated temperature (Lee et al. 2007). It is a conventional method for the recovery of precious metals and nonferrous metals from electronic waste that has been widely used in the past 20 years.

In Quebec, Canada, about 100,000 tons of e-waste is recycled annually using the Noranda process in smelters. This is approximately 14% of the total e-waste generated. In this process, the material being recycled is first immersed in a molten bath at (1250 °C) after entering a reactor. Then it is churned using a supercharged mixture of air having about 39% oxygen. The cost of energy is reduced from the use of plastic and other combustible material as feed matter. Oxidation transforms scum along with metals fixed in the slag of silica. The slag is crushed after cooling to recover more metals before their final disposal. Precious metals containing copper is removed and conveyed to the converter. Then the blistered liquid copper is purified in an anode furnace, and then 99.1% pure copper is cast on an anode after progression in converter. The remaining 0.9% is accounted for by valuable metals like silver, gold, palladium, and platinum, with some metals like nickel, selenium, and tellurium that are recoverable. Subsequent electrorefining of the anode helps in the recovery of these metals (Veldbuizen and Sippel 1994).

Hydrometallurgy Smelting and blast furnaces in addition to secondary lead or copper smelters were the conventional and prominently applied methods for metal recovery from waste electronic scraps from the 1970s up to the mid-1980s. After that, hydrometallurgical processes changed the trend of metal recovery. In comparison with pyrometallurgy, hydrometallurgical processes are more precise, predictable, and easy to control. Hydrometallurgy includes leaching of solid waste by an acid or base. And then the leachate is subjected to the purification of desired metals from leachates by various procedures like precipitation, adsorption, and solvent extraction, for example (Cui and Zhang 2008).

Leaching

Leaching is the process of metal solubilization in liquid phase from solid phase with the help of a solution. It is the foremost step in hydrometallurgy. The most commonly used leaching agents are cyanide, halide, thiourea, and thiosulfates.

Cyanide Leaching

Cyanide has been used in gold mining as a lixiviant for more than a century in mining industries. The dissolution of gold using a solution of cyanide is basically an electrochemically based process; the reaction of gold with cyanide is given below (Dorin and Woods 1991):

$$4Au + 8CN^- \rightarrow 4Au(CN)^{2-} + 4e. \tag{16.1}$$

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \tag{16.2}$$

Halide leaching

Prior to use of cynides for dissolution of gold, halides (fluorine, chlorine, bromine, iodine and astatine) were used. All halogens are used for the extraction of gold, except fluorine and astatine (Cui and Zhang 2008).

To dissolve gold (and other metals of the platinum group) aqua regia has been used conventionally; it consists of a mixture of three parts concentrated HCl and one part concentrated HNO_3. The reaction for the extraction of metals by aqua regia is given in Eqs. 16.3 and 16.4 (Sheng and Etsell 2007):

$$2HNO_3 + 6HCl \rightarrow 2NO + 4H_2O + 3Cl_2 \tag{16.3}$$

$$2Au + 11HCl + 3HNO_3 \rightarrow 2HAuCl_4 + 3NOCl + 6H_2O \tag{16.4}$$

Many studies have been done to find a more effective leaching agent between cyanide and acid. The application of acids is difficult in comparison with cyanide, for two reasons:

- Acids are highly corrosive and oxidative, so the use of special stainless steel and lining of rubber must be used.
- Control of chlorine gas is required to prevent any health issue caused by the highly poisonous nature of chlorine.

Thiourea Leaching

Thiourea ($(NH_2)_2CS$) is a promising agent for the extraction of gold from ores in recovery methods. Thiourea solubilizes gold by forming a cationic complex in acidic medium; the thiourea reaction is fast and results in 99% extraction of gold (Hilson and Monhemius 2006). The reaction on an anode is as follows:

$$Au + 2CS(NH_2)_2 \rightarrow Au\big(CS(NH_2)_2\big)_2 \tag{16.5}$$

Thiosulfate Leaching

In many studies, thiosulfate ($S_2O_3{}^{2-}$) is proposed as a substitute for cyanide for metal extraction; thiosulfate is a chemical that is mainly used in photography and pharmaceutical industries. Solubilization of gold in ammoniacal thiosulfate solution is supposed to be a cupric ion catalyzed electrochemical reaction (Cui and Zhang 2008).

Extraction of Metals from Leachate

After leaching, the leachate-containing metal is subjected to the extraction and purification of metals. Several methods have been studied and applied for metal extraction or recovery from leachate that include solvent extraction, adsorption, ion exchange, and cementation methods majorly.

Cementation To recover gold from cyanide leachate zinc cementation has been used for about 20 years on the commercial level. The actual process that is employed and globally used is called the Merrill–Crowe process. Zinc cementation involves the introduction of gold-loaded cyanide solution upon zinc chips. It is based on the fact that Ag and Au are more noble metals in comparison with zinc, so the introduction of gold-loaded cyanide in the zinc results in the reduction of gold to its native state (Au^0 or Ag^0) and zinc combines with cyanide to form zinc-cyanide complex.

Solvent Extraction Solvent extraction is a liquid-to-liquid separation technique in which the desired element is extracted from a solution on the basis of its solubility in two different solvents that are completely immiscible. For extraction of metals from leachates various solvents are used on the basis of the solubility of metals.

Ion Exchange The ion-exchange reaction occurs between a solution and its insoluble solute. It involves the exchange of ions of solute in electrolytic solution.

Carbon in Pulp (CIP) In this method activated carbon is used to recover metal from leachate solution. Mainly it is used for gold extraction from cyanide solution. In 1946 this technique was used and patented by McQuiston and Chapman for the first time for silver and gold recovery. This method uses adsorption of metal chelates or complexes from the leachate and then extraction of metals by desorption.

The recovery of gold from e-waste is mainly done by the application of aqua regia as it is flexible and easy to use and carries low capital costs. Leaching of gold from e-waste involves few steps, initially the separation of electronic chips from printed circuits through leaching by nitric acid. After leaching the mechanical crushing of electronic chips and coagulated epoxy resins is carried out. The final leaching involves leaching of gold from crushed chips with aqua regia. Then the pure gold is recovered from the leachates.

Biometallurgy

Biotechnology has been shown to be a promising technology in metal recovery in the last 10 years. Several studies have been done to understand the biochemical processes involved in biometallurgy in the past 20 years. Today many studies are being performed for the recovery of various metals like, copper, zinc, cobalt, nickel, silver, and gold. Bacterial leaching is performed only for the removal of interfering sulfides of metals from precious metal bearing ores before cyanide leaching in the extraction of silver and gold. Microorganisms use metals for structural or catalytic functioning. Eukaryotic and prokaryotic microorganisms bind metal ions that is present outside the cell, or transport them intracellularly. The interaction between microorganisms and metal is responsible for the recovery of metals selectively or nonselectively. Some microbes used for bioleaching are *Leptospirillum ferroxidans, Thiobacillus ferrooxidans, Acidothiobacillus thiooxidans, Sulfobacillus* (bacteria), and *Fusarium sp*., (fungus) (Hoque and Philip, 2011). The two main streams of biometallurgy are bioleaching and biosorption (Morin et al. 2006).

Bioleaching has been applied to metal sulfides, the main bearer of bases and precious metals for metal recovery, by their reaction with bacteria. Currently copper and gold are recovered by bioleaching at the industrial level.

Mechanism of Bioleaching

In general there are two mechanisms by which microorganisms can enhance leaching of metals from ores. In direct reaction with metals, microorganisms directly solubilize metals from ores by oxidation (Suzuki 2001):

$$MS + H_2SO_4 + 0.5O_2 \rightarrow MSO_4 + S^0 + H_2O \tag{16.6}$$

$$S^0 + 1.5O_2 + H_2O \rightarrow H_2SO_4 \tag{16.7}$$

In indirect reaction the leaching oxidation of minerals is done by involvement of ferric ions (Fe^{3+}), and microorganisms are involved for regeneration.

Both of the mechanisms, direct and indirect, can take part in bioleaching in natural conditions.

Biosorption involves an inactive physicochemical attraction between oppositely charged metal ions and the surface of microorganisms. Biosorption can involve both living and nonliving organisms. Various microbes are recognized for actively gathering precious metals and heavy metals inside their cells, like bacteria, yeast, algae, and fungi. In comparison with conventional recovery methods, biosorption requires low operating costs and smaller release of chemicals or biological sludge, and it is highly efficient in the detoxification of effluents.

For the application of biohydrometallurgy for metal recovery heap/dump leaching and stirred tank leaching are used. For about the last 40 years the extraction of copper from low-grade ore that contains secondary minerals like covellite and chalcocite where heap leaching is applied.

16.6 Disposal

Disposal of e-waste in landfills before treatment is hazardous to the environment. Such waste persists and produces harmful effects on the environment for many years. E-waste may leach toxic elements into the soil and water like acids and heavy metals from batteries and circuit boards. Consequently, these metals are mixed in surface water and groundwater, causing harmful effects on humans and animals. The United States and Australia dump about 50% of their e-waste in landfills and the remaining 50% is transported to Asia and Africa.

16.7 Legislation

TEe-waste management is quite problematic because of two main reasons. First, the amount of e-waste generated annually is ever increasing. The second problem is its disposal in an environmentally safe way (Wath et al. 2010). Along with technologies, legal frameworks are also needed for the proper management of e-waste. Several legal structures are enacted and imposed for the regulation of e-waste on an international level. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal has a very important role in restricting the trade of e-waste from Organisation for Economic Co-operation and Development (OECD) countries to countries that are not members of OECD (Wath et al. 2011). Even after the enforcement of the Basel Convention on the Control of Transboundary Movement of Hazardous Waste and their Disposal (1989), that controls the movement of hazardous waste across nations, there is still absence of strict rules in several nations for the e-waste management. European countries lead globally in terms of implementation of policies for the management of e-waste (Kiddee et al. 2013).

Legal Scenario in India

The national authority of India, Ministry of Environment and Forest (MoEF) is authoritative for the enforcement of legislation covering the management of waste and environmental protection. MoEF (2008) has approved guidelines for e-waste management in an environmentally sound way in its approved vide letter no. 23-23/2007-HSDM dated March 12, 2008, for guidance to identify different sources of waste electrical and electronic equipment and recommend e-waste handling methods in an eco-friendly way. Nevertheless, there is no law or regulation that specifically addresses the problem of e-waste. Almost all hazardous elements present in electronic waste are considered to be hazardous and nonhazardous waste within the purview of “The Hazardous and Waste Management Rules, 2008” (Wath et al. 2011).

16.8 Conclusion

The amount of e-waste generated on a daily basis is increasing across the globe due to the demand for electronic equipment by the rapidly growing digital population**.** This creates many environmental issues because of the composition of e-waste, which includes various types of organic and inorganic compounds. In addition, electronic waste also contains a huge number of precious and rare metals that can be recovered efficiently. Therefore, e-waste may represent a secondary source of valuable metals. This feature of e-waste makes its management different and critical in comparison with other solid wastes. Recovery of precious metals from e-waste may help to conserve primary/essential metal sources for the future. There is a need to develop an efficient, economical, and environmentally sound technology to recover metals from e-waste. A proper management system for e-waste must be developed along with a strict legal framework for industries and consumers to establish proper management practices.

Acknowledgements The authors gratefully acknowledge the University Grant Commission (UGC), Government of India (UGC-BSR Research Startup Grant Project F. 30-382/2017, BSR) and the Science and Engineering Research Board (SERB), Department of Science and Technology (DST), India (Reference ECR/2016/001924) for their financial support in the form of a research grant.

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Greenhouse Gas Emissions from Municipal Solid Waste Management Practice

17

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Abstract

Municipal solid waste management sector is significantly contributing towards global greenhouse gas emissions. Population explosion has worsened the condition by generating huge amount of waste. Irregularities in management practices and lack of improved waste management practices at local level are the considerable factors while inspecting the greenhouse gas emissions from waste sector. Landfilling is the most prevalent method for waste management in developing countries which is one of the significant sources of methane and carbon dioxide emission. This chapter represents the classification of waste generated as well as its management practices in India and highlighted the problem of contribution of municipal solid waste in global greenhouse gas accounts from the municipal waste management scenarios in India also.

Keywords

Municipal solid waste · Waste management · Greenhouse gas emissions

17.1 Introduction

Solid waste generation has become a major problem at global level because of modern lifestyle and consumer-based society. Earlier solid waste management was not the problem as people used to live in harmony with nature and lead a simple life.

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_17

The population explosion and rapid industrialisation has made a significant impact on human environment and biodiversity. The problem of waste disposal due to unmonitored and unrestricted urbanisation has been increased severalfold in developing countries in the recent past. Government at national and state level is putting their best efforts to provide the basic facilities to the people residing in their territories, but the elevated standard of living of the urban dwellers has changed the pattern of consumption of goods, and this consumption of goods is directly proportional to the generation of the solid waste (SW). Waste generation is a ceaselessly growing problem at the local as well as global scale and has become a challenging task for many municipalities.

Solid waste (SW) is defined as a mixed discarded material (organic/inorganic) produced by varied anthropogenic activities like household, agricultural commercial or industrial activities. Based on the composition and source, solid waste is categorised into municipal solid waste (MSW), biomedical waste (BMW), hazardous waste (HW), industrial waste (IW) and electronic waste (E-waste). Illegitimate disposal of solid wastes is a significant source of air, land and water pollution. According to 'European Council's' directives, 'Waste is any substance or object which the holder discards or intends or is required to discard'. The hazardous or toxic waste can be a storehouse of many diseases and can even be harmful to the environment. Developing countries are more prone towards the solid waste problem due to their rapid economic growth and urbanisation.

17.2 Municipal Solid Waste

Municipal solid waste (MSW) is also known as 'trash' or 'garbage'. It includes various kinds of material wastes such as durable and nondurable goods, packaging boxes and other garden and food wastes. MSW generally refers to household waste, office and retail wastes, but excludes construction waste, industrial and hazardous wastes (Municipal Solid Waste Factsheet 2013). The definition of MSW is non-identical for different countries around the world. MSW contains domestic, commercial and industrial waste generated in a municipality. In India, MSW comprises solid or semi-solid residential and commercial wastes generated in municipal areas, excluding the industrial hazardous wastes (Ministry of Environment and Forests 2000). Table 17.1 shows the various categories of MSW along with its description and source of generation.

17.3 Quantification, Composition and Characterisation of Municipal Solid Waste

MSW is heterogeneous in nature, and its generation, quantity and composition vary throughout the world. At a global level, composition and quantity of MSW depend upon the demography, geographic zones and seasons; however, at a community

Table 17.1 Classification of municipal solid waste (MSW) constituents

MSW waste categories	Description of waste	Source
Food waste (garbage)	Waste generated during the preparation and cooking of food and leftover food	Households, hotels, restaurants, vegetable markets, stores, etc.
	Waste generated from storage, handling and sale of vegetable and food products, crop residues	
Rubbish	Newspaper, cardboards, leather and rubber waste, plastic material, wooden cartons, plant waste (grass, leaves and yard trimmings), cloth waste	Households, packaging industry, plantation
	Home construction material like stones, bricks, glass/glass bottles, tin cans, metals waste, ceramics and crockery waste	
Bulky waste	Waste from home appliances such as refrigerators, stoves, furniture, large automobile parts, tyres, large wooden waste including crates, tree stump, branches, etc.	Households, parks, automobile industry, wood industry
Street waste	Dirt and dust from street sweepings, animal droppings, plantation waste (leaves, etc.),	Streets and roads
Dead animals	Pets including cats, dogs and horses, poultry animal (hens and chickens), buffalos, cows, calf, etc.	Household, poultry, cowshed
Construction and demolition waste	Cement and concrete waste, plaster waste, roofing and sheathing scraps, wires, pipes, insulation waste, etc.	Home and building construction sites and building demolition, repairing and remodelling sites
Industrial waste and sludge	Waste generated from industrial activities (manufacturing process, processing, etc.), scraps from metal, wood and plastic industries, waste from sewage treatment plant	Manufacturing industries, processing units of factories, sewage treatment plants, etc.
Hazardous wastes	Toxic and hazardous wastes: waste from pathological assays, radioactive material waste, etc.	Medical institutions, industries, etc.

Source: Solid Waste Management in Developing Countries by Bhide and Sunderasan, INSDOC April, 1983

level, it is affected by cultural habits, socio-economic status of the community, commercial activities, etc. (Selvi and Amarnath 2011).

In India, a huge population is migrating from villages to cities due to rapid industrialisation and population explosion. An increase in MSW quantity from 6 million tons in 1947 to 48 million tons in 1997 with an annual growth rate of 4.25% has been recorded in India which is expected to rise up to 300 MT by 2047

(Central Pollution Control Board 2004). It is mandatory to have adequate knowledge of composition and quantity of MSW for proper planning and management of urban solid waste (McDougall et al. 2001; Zeng et al. 2005). The quantity of the waste plays an important role in waste management practice as it directs the quantity and size of functional units and equipments required for management. The quantity of waste is calculated in weight and volume, where the weight is quite constant whereas the volume is extremely fluctuating (Gawarikar and Deshpande 2006). The characterisation of waste is also an important segment of waste management practice to determine its potential environmental impacts (Alamgir and Ahsan 2007). The information regarding the waste characteristics, including both the physical and chemical compositions, is an essential element in order to have efficient solid waste management system.

17.4 Municipal Solid Waste Management (MSWM)

MSW management starts from collection, transportation, disposal to the landfills and recycling of MSW generated in a locality. Population explosion and swift economic growth with escalating living standards of communities has accelerated the MSW generation rate, which is ultimately creating problems for its management throughout the world (Seo et al. 2004). In developing countries, the insufficient and inefficient MSW management system is of major concern as the large amount of produced waste is dumped in to the open dumping sites. The complete information on the quantities and composition of MSW collected, recycled and dumped to MSW disposal sites is not available at national and sub national level (Box 17.1).

Box 17.1: Steps Involved in the Municipal Solid Waste Practices

- *Collection*: The collection of MSW is the first step of waste management. MSW is collected from different points of the city. Source-specific separation is not available in India, so the waste collected from different pickup points is mixed waste.
- *Transportation*: The waste collected is transported to the managed or unmanaged landfills, waste disposal site or material processing unit for further processing.
- *Waste handling and separation*: The waste is separated into different categories like food waste, plastic waste, metal waste, wood and street waste, inert waste, etc.
- *Processing of solid waste*: The processing and management of waste are done as per their characteristics such as the management of food waste by composting process and management of plastic and metal waste by recycling and reuse. The other management practices include materials recovery facilities (MRFs), incineration and energy recovery system that are not common in India.

(continued)

Box 17.1 (continued)

- *Disposal*: Finally, the leftover waste that is inert waste is disposed to the open landfills. In India the problem of open dumping (unmanaged dumping) prevails in the majority of the places. Managed landfills are not so usual in India.
- *Energy generation from MSW*: Energy generation from MSW can be done by various technologies such as combustion, landfill gas capture, gasification, pyrolysis and plasma arc gasification; however, it is not a usual practice in India.

The management of MSW is an indispensible segment of environmental planning to ensure a secure and healthy environment for humans (Vishwanathan and Trakler 2003). Integrated municipal solid waste management (ISWM) is a laborious venture which requires the synchronous fulfilment of all the technical, economic and social constraints. ISWM is an intermix approach of waste collection and treatment methods in an eco-friendly, effective, inexpensive and socially acceptable way (McDougall et al. 2001). The beneficial aspect of waste includes the use of recyclable components as secondary resource for production processes, whereas the negative aspect includes the danger posed by some of its toxic and harmful constituents due to improper handling. The fundamental approaches of waste management are source reduction, composting of organic waste, waste-to-energy conversion facilities, recycling of plastic and metal waste and finally the land filling.

The crucial steps involved in waste management are quantification and characterisation of waste to be managed. It is necessary to quantify and characterise the waste at source for proper management. At present, the quantification of waste is done on the basis of total waste generation in the city, not on the basis of quantity of different categories of the waste (Bhoyar et al. 1996).

It is necessary to establish proper legislation, regulations and managerial practices for the development of an effective solid waste management system. These rules and regulation should not only be wide enough so that it could be applied on a national level but also specific to address the MSW management issues on the local level. The establishment of suitable procedure and its implementation demands some crucial information that can be acquired by analysing the existing MSW management system (Hristovski et al. 2007).

17.5 Solid Waste Management in India

With the continuous increase in urban population of the developing countries, there is a discontinuity in the waste management due to the prevailing insufficient and inefficient waste management practices (Daskalopoulos et al. 1998; Ehrlich and Ehrlich 1996). The problem of disposing the huge quantity of generated solid waste is of major concern at national as well as subnational level. Especially, India contributes about 18% in total world human population with an increasing rate of 31.8% in one decade and has become the third largest country in the world in terms of its population (Census of India 2011). The country has huge population pressure, and as per the availability of resources at local as well as country level, several major issues are prevailing around the country. The change in economy, lifestyle, demographic status, land use change patterns as well as technological advancements has led to increase in amount of municipal solid waste generated at the community level (Jha et al. 2007).

The waste management system in India consists of collection and disposal of generated solid waste from the streets or from the community bins to the landfill site. Every city and town is facing the problem of annual increment in waste quantities and failure of municipal authorities in having improved facilities required for proper management of generated MSW. In many places, citizens are also not accustomed to use the available storage facilities (dustbins) set up by the local waste management agencies and litter the garbage on roads and footpaths. Majority of places in the country do not have organised house-to-house collection of waste and have developed the littering habits among its inhabitants. As per the Central Pollution Control Board assessment, there isn't any town/city in the country which is completely using and maintaining its proximity in accordance with the Municipal Solid Wastes (Management and Handling) Rules, 2000 (CPCB 2012). Hence, we can say that solid waste management has become the major challenge in front of the present authorities at local level, local government or urban development authorities or environmental protection agencies involved in this business. India being a developing country, the majority of waste quantities consist of organic content (40–60%) in its overall MSW generated at national level. Inability in MSW management has raised the various environmental issues and natural resources degradation and ultimately has become the major sector contributing towards climate change. It has also disturbed the public health and has affected the quality of life of all the individuals (Annepu 2012). Hence, we can say that the increasing rate of MSW generation has led to environmental, biological as well as economic losses. The high rate of degradation is caused by higher atmospheric temperature because of which the organic and moisture content of the MSW in India is higher in comparison to the waste generated from developed countries (Rawat et al. 2008).

17.6 Municipal Solid Waste Management (MSWM) Rules in India

In 2002, the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, has introduced the MSW (Management and Handling) Rules to ensure the improved collection, segregation, transportation, processing and disposal of MSW for better municipal solid waste management (MSWM) system. It further includes the guidelines for upgrading the prevailing facilities to abate the soil and groundwater pollution and is applicable to every existing municipal authority throughout the country. The municipalities are directed to submit the annual status reports to their respective pollution control boards in order to monitor the implementation of those rules. In addition, some states has their municipal corporation acts such as the Delhi Municipal Corporation Act, 1959; Himachal Pradesh Corporation Act, 1994; Uttar Pradesh Municipal Corporation Act, 1959; and Karnataka Municipal Corporation Act, 1976. The respective state government at local level with ultimate objective to overcome the environmental loss introduced those acts. For example, the Delhi Plastic Bag (Manufacture, Sales and Usage) and Non-Biodegradable Garbage (Control) Act, 2000, was introduced to reduce the usage of plastic bags for packing the foodstuff and decreasing the problems caused by throwing or disposing non-biodegradable waste in public place. As compared to other basic services, in terms of economic benefit, MSWM is not a favourable approach, as it requires huge amount for its operation and sometimes it acts like a burden for the municipal authorities to maintain management practices from its routine budget. As a result, a number of negative concerns are related to the management of MSW; the solid waste management services are still under developing phase at national as well as subnational level (MOEF 2000; Siddiqui et al. 2006; Kansal 2002; Gupta et al. 1998).

17.7 Greenhouse Gas Emission from Municipal Solid Waste Dumping Sites

During the disposal and treatment of MSW, it produces significant amount of harmful greenhouse gas (GHG) emission and ultimately contributing towards climate change (Fig. 17.1). After the generation of solid waste by individual level, it

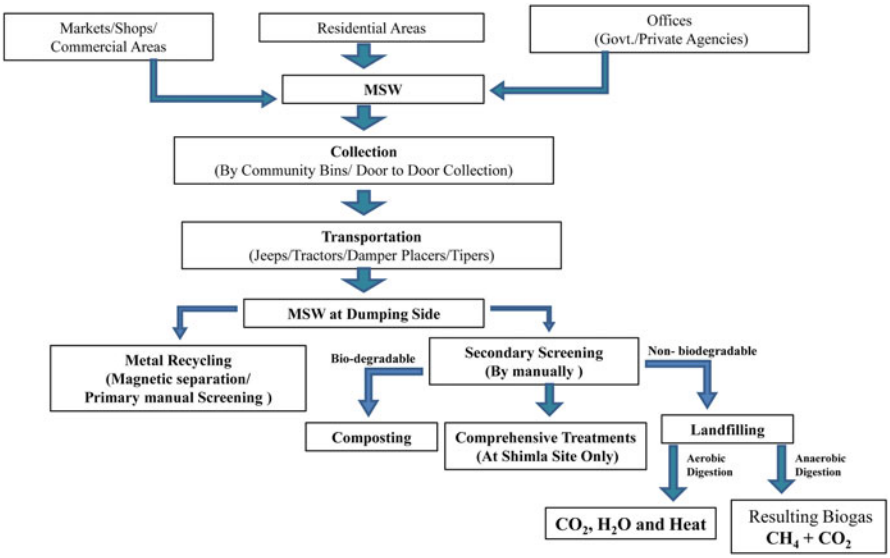

Fig. 17.1 Greenhouse gas emissions from municipal solid waste management practices

Box 17.2: Greenhouse Gas Emissions and Climate Change

The greenhouse effect is the process in which the long-wave terrestrial radiation in the atmosphere produced by observing the shortwave solar radiations warms the earth's surface. Generally, the greenhouse gases act like a thermal blanket around the globe and protect the earth's surface from harmful effect of ultraviolet radiations. If the concentration of those gases in the atmosphere increases, then the trapping of long-wave terrestrial radiations will increase, and ultimately it will lead to increase the temperature of earth's atmosphere and results in global warming.

Planet Earth consists of layer of different gases surrounding its surface commonly known as atmosphere. The main gases are nitrogen (78.09%), oxygen (20.95%) and argon (0.93%) along with some trace gases such as carbon dioxide (CO_2), methane (CH_4),carbon monoxide (CO), nitrous oxide (NO_2), nitric oxide (NO), chlorofluorocarbons (CFCs), water vapour (H_2O) and ozone (O_3). The agriculture, industry, deforestation, waste disposal and transportation especially burning of fossil fuel have increased the concentration and composition of these gases in the atmosphere from last 200 years resulting in the change of atmospheric composition and ultimately leading to climate change due to global warming.

The increase in sea levels, floods in coastal areas, increase in mean precipitation mainly in the tropical areas and decrease in precipitation in sub-tropical areas are the common effect of global climate change which has negatively affected the biodiversity and human wellbeing.

goes through a series of continuous stage, i.e. collection, transportation, segregation, etc., before its disposal by landfilling, recycling, incineration or waste-to-energy. The contained organic waste in overall generated MSW is broken down by aerobic and anaerobic digestion process and finally result in the formation of methane (CH_4) and carbon dioxide (CO_2) by means of bacterial actions at the landfill site (termed biogas or landfill gas) and further bacterial biomass. Other local physical factors like moisture, pH, temperature conditions, etc. play an important role in the series of bacterial action towards organic waste. Generally, the landfill gas produced by dumping solid waste at the landfill site consists of approximately 50% CO_2 and 50% CH_4 by volume (IPCC 1992) (Box 17.2).

The landfill sites are of two types managed 'landfill' and 'open dump' sites. Both types of landfill sites contribute towards significant amount of harmful gas emissions. The uncontrolled CH4 produced at the landfill site can cause a serious threat to local environment and surrounding areas and will affect the local biodiversity of the particular region and cause unpleasant odours. It may cause fire incidence/ hazard at the landfill site if the concentration of generated CH_4 will increase from 5% to 15% in the air. Methane is one of the harmful greenhouse gases generated by anthropogenic activity and solid waste landfill sites which contributes a significant proportion of annual global CH_4 emissions and ultimately contributing towards climate change. Reducing global greenhouse gas emission from all the anthropogenic factors has become a challenging task in front of every nation (Gomez et al. 2009). Specifically, the global warming potential of methane gas emissions from landfills is very high, and there is the requirement of immediate mitigation of such harmful greenhouse gas emissions to provide the environmental and social benefits by reducing the adverse health impact for the local communities and ultimately leads to sustainable development (Papageorgiou et al. 2009).

17.7.1 Factors Affecting the Greenhouse Gas Emission from Solid Waste Dumping Sites

- *Waste disposal practices*: Waste disposal practices of concern for CH_4 emissions vary in the degree of control of the placement of waste and management of the site. In general, waste disposal on land will result in CH_4 production if the waste contains organic matter. Managed disposal (controlled placement of waste), in particular, tends to encourage development and maintenance of anaerobic activity.
- *Waste composition*: The composition of waste is one of the main factors influencing both the amount and the extent of CH_4 production within SWDSs. Municipal solid waste (MSW) typically contains significant quantities of degradable organic matter. Different countries and regions are known to have MSW with widely differing compositions.
- *Physical factors*: Moisture content is an important physical factor influencing landfill gas production. Moisture is essential for bacterial growth and metabolism, as well as for transport of nutrients and bacteria within the SWDS. The moisture content of a SWDS depends on the initial moisture content of the waste, the extent of infiltration from surface and groundwater sources and the amount of water produced during the decomposition processes. Temperature, pH and nutrient availability will affect the growth rate of the bacteria. Under anaerobic conditions, landfill temperatures are generally between 25 °C and 40 °C. These temperatures can be maintained within the SWDS regardless of the ambient surface temperatures. Outside of these temperatures, CH_4 production is reduced. Optimal pH for CH_4 production is around neutral (pH 7.0). Important nutrients for efficient bacterial growth include sulphur, phosphorus, sodium and calcium.

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Introduction to Fast Fashion: Environmental Concerns and Sustainability Measurements

18

Pooja Garg

Abstract

Human requires the basic necessity of food, clothing, and shelter for survival, which primarily remains true throughout our lives. Needless to say, it is of immense importance. So the question arises how to procure the food, clothes, and shelter throughout life and also make sure the supply remains intact to us and our future generations to come without any hindrances or quality down gradation. With the increasing popularity of Dime Box, fashion shows, Miss and Misses India's, Miss and Mr. Worlds, and likewise those of universe, every teenager dreams of either participating or at least imitating the glamour world, clothing, and its lifecycle phases have impact on our surroundings and ecosystems. As all fashion brands wish to showcase the latest collections in order to increase profit margins, their brand reputation, and buzz, fast fashion has become a major contributor to the world's clothing waste problem. It is a quite recent phenomenon which has completely changed the fashion industry. Fashion industry linked to textile industry has a deep connection with our environment. In this chapter, we have discussed on what fast fashion is, what the business model behind it is, and what as individual consumers should be done to resist its negative effects and achieve sustainable fashion.

Keywords

Fast fashion · Business model · Sustainable fashion · Clothing · Waste management

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V. Shukla, N. Kumar (eds.), *Environmental Concerns and Sustainable Development*,
https://doi.org/10.1007/978-981-13-6358-0_18

18.1 Introduction

Top fashion brands have one thing in common that they are all manufacturers and at the same time retailers also. They control the complete process right from the designing of the garments to finally reaching the end consumer. This strategy allows them extremely short-rotation cycles from the start of the process which is the design idea of the garment until clothes are on the racks in the stores ready to buy (Domina and Koch 2001). The complete cycle is only 2–4 weeks' duration. To reach such a speed, companies drastically optimize all the steps involved in the life cycle of a garment. Right from the inception of design to the sewing, to the quality, the fabric is done at minimum cost humanly possible. Fast fashion retailers are always looking out to make trendy clothes which means they make clothes every 2 weeks that are meant to come out of fashion within 2 weeks! This phenomenon has hugely increased the production and consumption of clothing worldwide (Fletcher 2008). This also means for a consumer, rather a fashion-conscious consumer, a new style of clothing has entered the markets alluring them to desperately want to own it. Another tempting reason to buy these new styles of clothing when you enter the stores is that they are very cheap and also they will no longer be there on the new arrival shelves in about after 2 weeks. So either you buy them now or you miss out on the chance. This vicious cycle continues continuously. It will not be an exaggeration to say that fast fashion is like fast food basically unhealthy because the quality is very poor and "addictive" because the prices are so appealing, similar to fast food, where it is unhealthy for the body to consume but so cheap that mindless buying happens all the time (Cachon and Swinney 2011; Butler and Francis 1997). Also when you look around and see that everyone is buying and consuming them guilt-free, you don't think twice about its negative effect on the body or on the environment (Birtwistle and Moore 2007).

18.1.1 Business Model

Firstly fast fashion retailers copy the designs which are already there in the market, and then they produce huge quantities of clothes to cut down the unit cost per piece of clothing and reproduce everything because of extremely short cycles of only 2–4 weeks which means if they do not sell everything, it basically goes "waste" and reaches the landfills, a major contributor to environmental pollution (Brandenburger and Nalebuff 1996; Mitchell and Coles 2003).

Retailers make sure that they produce their clothing in countries where human labor is extremely cheap. They choose, on purpose, such countries where ethical human rights and safety laws are not so strictly enforced. When as a consumer buys a garment and sees the label attached to the garment as "made in X country," it actually just indicates that this garment was manipulated last in that X country. Everything that happened before that X country does not have to be labeled! For example, if you buy the fabric in one country, get threading done in second country, and then buy human labor somewhere in the third country, the garment gets put together in the fourth country, and the packaging is done in the fifth country. The made in label on the garment does not need to show the names of the first, second, third, or the fourth country. Therefore at all these steps involved right from number 1 to 5, solid cost-cutting happens without thinking of the hazards the garment manufacturers are making to the environment as well as to the mankind (Bhaduri and Ha-Brookshire 2011; Schaltegger et al. 2011).

18.1.2 Fast Fashion Has a Pollution Footprint

As we know, the very first ingredient in making of any garment is *FIBRE*. Sixty percent of all the clothing made in the world is made from petroleum, and the other 30% is made from cotton (Baffes 2004). Both fiber and petroleum require tremendous amounts of natural resources.

There are many environmental impacts in the textile production process. Let us take a look at how polluting and harmful these textile industries can be to the environment. Keeping textile factories running requires huge amounts of energy and resources. In many countries the textile industry is dominated by cotton. Turning each ton of cotton into finished fabric uses about 65,000 kilowatt hours of electricity + 250,000 liters of water (Nigam et al. 2016). Out of which almost three-quarters of the water is used for what is called as wet processes. Activities like washing, bleaching, and dying take up huge amounts of water. With limited funds available to the government, meeting the water and power needs of this rapidly growing textile industry is posing a major challenge. All the electricity produced in factories adds to the pollution. When it comes to water, factories often get priority over people. As textile industry seems to grow due to increased consumption of clothing by the masses, the situation will continue to get even worse. To sum up, huge water and energy uses are main reasons textile industries worldwide are impacting our environment (Kemp 2008).

18.2 Pollution at Multiple Levels Caused by the Manufacturing of Garments

The steps involved in the cotton production process to start with cotton seeds are sown and irrigated to produce the fluffy balls of cotton. Self-driving machines then harvest these parts, and industrial machines then separate the cotton balls from the seeds, and cotton lint is pressed into bales. As nature would have it, the cotton plant requires huge quantities of water as well as pesticides. Cotton in fact uses more insecticides and pesticides more than any other crop grown in the world (Nigam et al. 2016). And these pollutants can be carcinogenic causing a lot of harm to the health of the field workers and damage to the surrounding ecosystems (Chen and Burns 2006; Ellis et al. 2012). When the cotton bales leave the farm, they are shipped to the spinning facilities across various countries like India, China, and Bangladesh where high-tech machines then blend, card, comb, pull, stretch, and then finally twist the cotton into snowy ropes of yarn.

These yarns are then sent to the mills where they are weaved into sheets of grayish fabric. Then it is treated with heat and chemicals until they turn soft and white, and the fabric is dipped into commercial bleaches and acid dyes that are responsible for the vivid coloring of about 70% of the textiles.

18.2.1 Chemical Pollution Caused During the Garment Production Processes

During the manufacturing processes, there are a number of chemicals used while dying, printing, bleaching, and washing due to which the rivers of these manufacturing countries get blackened and covered in foam (Toprak and Anis 2017). Heavy metals are now found in these water bodies which used to be once filled with clean healthy water. People cannot even dare to use these rivers for swimming or fishing. Cadmium levels, for example, in the rivers of China are 128 times the national standard and strongly alkaline water reached pH values of almost 12 (Zhao et al. 2018). This is just an example of the data that indicates that many countries involved in the garment or textile production like China, India, Bangladesh, and Cambodia, to name a few, have a global effect on climate change.

Secondly from inks to dyes to caustic soda and all sorts of alkalis and bleaches, most of the wet processes in the manufacturing process of textiles involve usage of many harmful chemicals. The result is that the water gets hugely contaminated and, when this contaminated water leaves the factories untreated, it can have a massive effect on the environment.

All of these chemicals used can cause cancer as they contain lead, chromium, and mercury; also, the untreated waste from the dying and washing processes which flows freely from the factories into the main water bodies like seas and rivers makes immense adverse impact on biodiversity and alters the ecosystem balance.

18.2.2 Other Harmful Impacts

In many advanced countries, the whole process of producing fiber to build clothing has been fully automated without the involvement of human hands, but, once it gets shipped to places like Bangladesh, China, and India, human labor is required to stitch the clothes into garments. This intricate process has its own share of problems. The people employed by these countries for the stitching job face poor living and working conditions due to very low wages. Once these garments are made, their shipment procedure to high-income countries by rail, ship, etc. is responsible for giving cotton an enormous carbon footprint (Nigam et al. 2016).

Some countries which produce their own cotton for usage cut out this polluting stage, but generally clothing production accounts for 10% of the global carbon emissions, and this number keeps going up. Availability of cheaper garments in the market and willingness of public to buy new clothes more often boosted the global production from 1994 to 2014 by 400% to around 80 billion garments per year. Finally to reach a consumer's home, an outfit goes through one of the most intensive resource phases of its lifetime (Nigam et al. 2016).

The pollution problem doesn't end here. In an average household, in high-income countries, people wash almost 400 loads in their washing machines in 1 year each load using about 40 gallons of water. Both washing machines and dryers use large amounts of water and energy (National Mayor's Challenge for Water Conservation 2015). In fact to run the dryer, you require five to six times more energy than a washing machine. This dramatic shift of consuming clothes over the last 20 years driven by large corporations and the fast fashion has caused the environments the health of farmers and driven questionable human labor practices (Christmann and Taylor 2001). Thereby turning fashion industry as one of the second largest polluter in the world after oil and is responsible massively for both negative environmental and social impacts to the society such as long hours, poor wages, child labor, working conditions, health and safety issues of the workers involved in this huge garment industry. The awareness of these negative environmental and social issues has led to the increased requirement of sustainability in the fashion industry (Dickson et al. 2009; Nidumolu et al. 2009).

18.2.3 Heavy Usage of Pesticides

Today 84 million pounds of pesticides and 4 billion pounds of fertilizers are sprayed on cotton fields each year (Cubie 2006). These toxins have been linked to autism, cancer, and hormone disruption. The pesticides, dyes, and other chemicals used in the textile industries have their sources in petroleum. So it will not be wrong to hold guilty "the big oil" for its devastating ecosystem disasters.

The dyes and other agents used in textiles are rooftopping in polluting the environment that are currently around. About 10,000 chemicals are roughly used in the USA alone on textiles. These chemicals are transported long distances causing *carbon pollution*. Even chances of accidents of spillage happen all the time. In fact 20% of the chemicals polluting the environment are there because of the textile industry. When the fabric is treated, dyed, and printed known as "wet processing," 200 tons of freshwater is used and polluted for every 1 ton of textile produced (Schoeberl et al. 2004; Ozturk et al. 2009). Our polluted rivers never get rid of these toxic chemicals, even the plants and animals inside these water bodies get infected by the hazardous chemical piling which keeps sitting at the bottom of these water bodies attached near the garment factories.

Once these toxic clothes reach factories to be sewn by people, these workers also get exposed and affected by these pesticides. Even the most expensive clothes have highly poisonous residues stuck to them. The same holds true for kid's clothing too. We all know that the immunity system of kids is not as high as that of an adult and the power to fight these germs is a lot less in children. Basically exposing our little ones to these pesticides and germ-producing residues via brand-new clothing can prove as self-bought destruction. These toxins can get into our homes via clothing and enter our bodies through dermal contact.

When we wash our clothes, the poison gets down in our drains and ends up in our streams and oceans that's destroying our ecosystems. Water is life and fast fashion is killing it. In **China**, the largest supplier of apparel to the USA, 70% of the waterways are contaminated by wastewater from the textile and dye industry (Zhao et al. 2018). Meanwhile tanneries in **Kanpur**, the leather capital of India, 400 tanneries dump toxic chromium into the water supply, and it's ending up in food. Even microparticles from our nylon, acrylic, and polyester clothing subsequently end up in the oceans and 83% of our drinking water after each wash cycle (Webber 2017).

Eighty percent of **marine pollution** starts on land. Scientists have found that fibers like those used in synthetic clothing are contaminating the quality of aquatic life. Substantial numbers of commercially important fish and shellfish are contaminated with small pieces of plastic including fibers. Higher risks are imposed from fibers called microfibers which can also be easily ingested by a fish, and then it stays there in its intestine. A major source of plastic comes from our clothes about 190,000 tons, and it makes its way in our oceans, whereas significantly less 35,000 tons of plastic also comes from our cosmetics (Webber 2017).

18.2.4 Leather Apparels and Accessories

The manufacturing of leather shoes and clothes creates pollution abundance. The impact of chemicals used in tanning greatly affects the workers and the environment. The negative relationship between chemical exposure of tanning to the environment and the harmful chemicals affecting them is humongous. When the leather is tanned, it has enormous negative impact on the environment and the workers involved in the tanning processes. More than 20 dangerous chemicals are involved in the treatment process of leather apparels to get that smooth desired finished look of the garment. Chromium is one of the cheapest chemical used to tan leather and the workers exposed to this dangerous chemical suffer from several and severe skin diseases. Leather industry is known to be a labor-intensive craft; chromium when mixed into water bodies via wastewater disposal of the leather is disastrous to the environment. Smoke emitted from tanneries is a major cause of air pollution the air ending into various bronchitis and respiratory infections and also a variety of cancers.

18.2.5 Synthetic Fibers (Nylon, Polyester) Causing Pollution

These are fibers made from a complex process of polymer synthesis and are therefore plastics. It requires small molecules that can bind chemically to other molecules to form a polymer chain. The compounds used to make synthetic fibers come from petrochemicals. So synthetic fibers are not grown in the soil but are actually made by the lab technician using chemicals. These are toxic man-made fibers. Examples of such fibers are rayon, nylon, polyester, spandex, Lycra, acrylic, etc. We use a lot of clothing made out of these synthetic fibers. They are made entirely from carcinogenic petrochemicals that contribute to numerous health and environmental problems (Kim and Damhorst 1998; Kozlowski et al. 2012). These toxic fibers unfortunately make up to 70% of the world's entire fiber production which is no doubt a lot. Thousands of carcinogenic chemicals are used to make these fabrics. Another major impact of these synthetic fibers is that they are not biodegradable. Manufacturing them pollutes our air, water, soil, and also wildlife. Toxic air pollution is caused by the manufacturer of these synthetic fibers. Recycling of synthetic clothes is another issue since we throw away the ones that cannot be recycled. So they are not biodegradable. They are energy-intensive, polluting fibers; rayon is even held responsible for causing deforestation as it comes from wood pulp.

18.2.6 Bamboo (Viscose/Rayon)

Bamboo is a strong plant that can grow up to a meter in a day. It needs little water and only very few pesticides. It is technically a grass. So when you try to convert hard strong plants like bamboo into a soft blouse, you basically break down its fibers. So humans use chemicals like carbon disulfide and sodium hydroxide to spin bamboo into cloth, and by now we know that the usage of chemicals has many negative effects on us and because these chemicals get dumped or evaporate into the environment, they are held responsible for further environmental chaos. Viscose is basically prepared in a non-eco-friendly manner too.

To summarize the pollution caused at various levels due to textile industry, we could say that textile industry has polluted our air. The carbon dioxide levels have increased amazingly. The water has been contaminated drastically, and tons and tons of fuel that is consumed in the manufacturing of garments and the carbon dioxide emissions that happen polluting the greenhouse gases are thereby responsible for global warming.

Hence, the urgent need of the hour is to make a shift to a more sustainable and sociable environment and to ask questions on the integrity of the garment we buy and wear, that is, is it environmentally and socially ethical?

As responsible humans, the mind-set should be A) to use organically and herbally produced clothing as far as possible even if they cost a bit more than their nonorganic counterparts and most importantly B) to support recycling as a lifestyle choice. If we are able to develop a green culture and most importantly to educate the masses and bring awareness on the Sustainability Perspective of Fashion Industry only then the shift will become possible.

18.3 Sustainable Fashion

This term simply means producing fashion by ethical means! meaning adopting an approach in the designing, sourcing, manufacturing, and selling of clothing in a way that can maximize the benefits to the people and communities worldwide and at the same time which aims at minimizing the negative impacts on the environment (Jones 2006). On the contrary, being beneficial to the environment (Armstrong and LeHew 2011; Carter and Rogers 2008).

Following this approach we can also say that clothing made when No humans were tortured with poor working conditions or wages, clothing made by not killing animals are all such examples of ethical clothes. We as consumers should be discarding wearing jackets, belts, shoes, bags made of leather procured from slaughtering and killing animals and removing their skin (Walker 2006; Welters 2008).

Especially when we have availability of and access to so many non-animal-derived materials in the market like cork, pineapple leather, mushroom leather which are all great materials sustaining our look and fashion Consciousness without costing us the blame of killing our animals is totally worth the shift (Sheth et al. 2011).

These relatively newer products are full of pros, for example, *pineapple leather* is made out of pineapple leaves. So it is a smart way of choosing sustainable fashion, and it is definitely a by-product of the pineapple production. If these leaves were not used, they would anyways go as waste, but today they are being used to make a number of shoes.

Even *cork* is a very water-resistant material which we harvest from a tree; it can be harvested every 9 years without damaging the tree or our environment. So it is an eco-friendly and ethical option compared to the animal skin. Many designers are using *mushroom leather* too, which even looks very much like real leather. It is also salt on our skin depending on the softness or stiffness of the mushroom leather used in making that particular piece of garment. The drawback is that it cannot be produced in huge quantities at a time. But being such a hypoallergenic material, we sure can consider it as a good alternative to animal leather.

After leather let's not forget to talk about the *wool*. Many manufacturers unethically procure it from animals which have been modified genetically to get more hairs out of them in the greed of making more clothing, thanks to fast fashion. But there are alternatives present in the market so we do have eco-friendly, sustainably produced wool too. It is on us to make conscious choices before buying our clothes.

Animal by-product used heavily for fashionable clothing is *feathers* especially the winter wear or outer wear like jackets and coats in which we use a lot of goose feathers to make these products. We have eco-friendly alternatives to this which is called as *down* jackets; this is a by-product of the food industry. In most of the Western countries, down jackets and coats serve as a symbolism of fashion icon on one hand and print elati toward animals on the other hand; it is for sure a topic of debate.

Let's not forget about the *fur* being used in the making of a lot of clothes as part of the garment industry. If not the full quarter dress but usually many coats and jackets have a dream of fur on their hoodies. We can't even imagine how much animal fur is used in the fashion industry. A good alternative to this is *faux fur*. It cannot be called as a very environment-friendly material, but it is cent percent vegan (without using animals).

All of this indicates that there are for sure, vegan alternatives present in the market in place of all the animal source materials, which may not always be very sustainable though.

Another method that can be adopted by us is to use only sustainably grown bamboo, hemp, cotton, or/and linen clothing because we know that these fibers were grown by using lesser pesticide and lesser water resources.

There are however few other factors invoving finer details that need to be considered to stamp a garment or footwear as 100 percent ethical. An example of finer detail could be to check the source of the glue used in the making of our leather shoes. Was that glue that was used also animal-free? We have a lot of food for thoughts just by buying a fox fur jacket instead of an animal fur jacket; we can never be hundred percent sure of ethical fashion because there is a big chance that it was made by a child who was paid extremely low wages or he was subjected to a lot of air and water pollution during the manufacturing of that faux fur jacket (Fletcher and Grose 2012).

18.4 More Solutions Iterated Pointwise

As image consultants and fashion designers, there are a few things that even we can do for environmental sustainability.

18.4.1 Build Sustainable Supply Chains

As we all know, that's the biggest environmental impact that comes from growing and producing cotton, viscose, wool, and cashmere at the farm level (Wong and Taylor 2000).

1. We should build supply chains that use sustainable raw materials, such as sustainable pull from the Patagonian grasslands.
2. Ensure that all cellulose fabrics are sourced from *sustainably managed forests* and that we are not contributing further to the destruction of ancient and endangered forests.
3. Preserve and protect water: As designers we need to start working with fabric producers who act responsibly and are governed by strict rules on water management and pollution. We can start using waterless dying technologies such as **dry dye**, using pressurized carbon dioxide in place of traditional water.

4. Minimize greenhouse gas emissions: The fact is that the making of textiles, fibers, and apparel products consumes significant quantities of fossil fuel, accounting for approximately **10% of the global total carbon impact**. We need to start using renewable energy whenever possible, for example, taking the help of wind energy.
5. We also need to work with suppliers to reduce energy used and wasted in textile manufacturing.
6. We can surely reduce energy and carbon impact during raw material production, for example, by using recycled cashmere and sustainable wool for our designs.
7. Each one of us should do our bit to reduce toxic chemicals usage: As mentioned earlier, large quantities of chemicals are used in the production of fibers like cotton, and wastewater discharges containing toxic chemicals can then enter public waterways polluting our rivers and also enter our bodies and the bodies of animals that stay in the water. To avoid this many designers are adhering to Kering groups' restricted substance list to help our fabric mills improve.
8. Our aim should be to source certified organic cotton and other organic fibers which are definitely less toxic at all stages along the supply chain whenever possible.
9. Use recycled and innovative materials lining: For all of our handbags with recycled polyester from waste plastic water bottles and recycled cashmere made from free consumer manufacturing waste. We should avoid using any animal products no leather, no fur, no skins, and no feathers in any of our clothing designs for mankind.
10. We need to strongly eliminate animal products in all of our designs.
11. Humanity says that we should use only cruelty-free wool and that every wool supplier provides certified and signed documentation stating that they practice animal-friendly farming practices. Last but not least, never test any products or fragrances on animals.
12. Educate consumers about garment care: This is a very important step as far as the future of the fashion industry is concerned. The way that consumers clean and care for garments can have a large impact in water and energy use.
13. As designers we should try making products that last for long time. People should be able to use them for a lifetime. We can use Clevercare labels which inform the customers on ways that can reduce the impact from washing and drying their garments.

Therefore, by shifting our minds and hearts toward greater care, compassion, and respect for other living entities (including humans, animals, plants and ecosystems) can we begin to create truly sustainable, harmonious, and flourishing societies. As responsible human beings, our vision should be to fully decarbonize the global economic system and lock away carbon from the atmosphere by decarbonizing our depleted soils and ecosystems, so that the fossil fuel-dependent communities are benefited and we can transit to a "carbon positive" economy that limits global warming substantially and provides us with clean energy, mobility, and meaningful livelihoods (Granzin and Olsen 1991).

18.5 How Can We Achieve Environmental Sustainability?

Even before getting into the ways or measures we need to take for environmental sustainability, it is important for the companies related to the garment industry to know about all the environmental, social, as well as human labor impacts they're making to the society and the ecosystems (Antil 1984; Blake 2001). Once the measurement of these impacts is established and then they mindfully acknowledge it, then they need to brainstorm the methods they can adopt to achieve improvement during the production and packaging processes through correct methods, thereby stepping closer to environmental sustainability (Hoffmann 2012).

Some of the ways could be to recycle the used clothing bought from their own stores, also pledging to produce high-quality clothes made from organic materials only, which have less carbon footprint, even though a little more costly. Another method is to check the "quantity" by producing less number of clothes in each fashion cycle. They can also start services for fixing or mending the used clothes bought from their own stores instead of just selling only brand new clothes, in order to bring down the huge filing of clothing words by it sitting in the landfills and becoming a major source of pollution (Hines and Swinker 1996).

Research team should focus on the production of their clothing line using fewer resources meaning less energy, less water. There should be a cooperative effort from their ends to turn the *fast fashion* business models into a *slow fashion* one (Fletcher 2010). They need to take another important measure to convert the waste generated as a result of this huge Apple industry production into NEW FIBER which can be the linchpin of this entire system. All this can successfully lead to environmental sustainability in the coming times which is a must for the masses and a big step in checking/stopping further destruction to our environment (Fletcher and Grose 2012; Hustvedt and Bernard 2008).

18.5.1 Ways to Produce Sustainable Fashion

18.5.1.1 Recycling Cotton and Turning It into New Clothes

A proven fact since ages is that the fabric cotton is hard to recycle. At the max, if you gave away your old cotton jeans away for recycling, it might most probably be in shredded up. There is a new process now where an environment-friendly solvent is being used to dissolve old cotton clothing into cotton-like natural material that can then respond into new fibers, in which way one can eliminate both waste and the problems that come with growing new cotton (Gwilt and Rissanen 2011).

18.5.1.2 Recycling Through Polyester Eating Microbes

Polyester as you know is not an easy fabric to recycle without losing quality and is also now the most common material used to make clothes. But luckily now we have a new type of microbe that can eat an old shirt and break the polyester polymer down into a basic raw material that can be sold back to polyester manufacturers. This process has also found success on fabrics that are a mix of materials like cotton mixed with polyester; this method is also surely hundred percent cheaper than making brand-new fabric from petroleum and increasing environmental pollution levels.

18.5.1.3 Recycling Food Waste into Yarns

How many of us drink orange juice and eat oranges as part of a daily breakfast meal? Many of us right! Have we thought how much wasted peels and seeds go as a waste each year? It is around 25 million tons of waste a year. One startup came up with a brilliant process of turning these citrus by-products into raw material that in the finally spun into yarn. Isn't this a fantastic savior of our environment?

18.5.1.4 Switching to Algae-Based Fabric

Producing the traditional fabric like cotton has an enormous footprints which is 20,000 liter of water to grow enough cotton for a single pair of jeans plus cotton crop also uses more insecticides than any other crops in the world, thereby also damaging our environment in turn (Nigam et al. 2016). Quick-growing algae on the other hand do not require extra water besides the oceans and lakes in which it grows in naturally, thereby leaving the land free for growing food instead. There is a brilliant startup working as an open-source process to turn algae into fabric. It is surely an answer to conserve huge tons of water.

18.5.1.5 Developing a Database to Track Wasted Fabric on Factory Floors

While manufacturing clothes, almost 15% of the fabric ends up as trash or waste. There is a startup that is designing a database that tracks the leftover material so that the designers can make use of it. Let us hope that all such fantastic ideas save our planet and our fashion industry from polluting and wasting the resources provided by Mother Nature.

18.5.1.6 Avoid Fabrics Using Petroleum and Chemicals

We need to think how our each piece of clothing that we are buying is being manufactured in the first place. If possible we can stop buying petroleum-based synthetic materials such as polyester or nylon, which are actually plastics that take forever to break down once thrown away, and each time when such clothes are washed in the washing machines or by hand, they shed thousands of microbes that end up polluting our rivers and oceans (National Mayor's Challenge for Water Conservation 2015). Advanced technology is making an effort to produce special filter bags that can drop such microbes in laundries, but unfortunately not many of us know about these, and they are not easily accessible in many countries worldwide. For that matter, even the natural fabrics like cotton should be selected with a lot of care, as cotton growth requires pesticides; bamboo has been voted as a more ethical option, but, while the plant is framed sustainably, toxic chemicals are used to turn bamboo into fabric. That is the reason why organic cotton and organic bamboo are better, as is hemp, linen, silk, and wool as these are grown without the use of any pesticides, thereby not polluting our environment (Joergens 2006).

18.5.1.7 Buy Ethical Labels

Other than these abovementioned ways, *alternative solutions* also do exist.

We, humans, can surely buy less and choose better quality items that are manufactured as ethically as possible, and how can we do this? Let's take a look at few steps or measures that we can take.

18.5.1.8 Buy Clothes Made Locally by Ethical Labels

By doing so we will also help our economy and give value and revival to the forgotten handmaid's beautiful pieces that are a royal heritage of our past. This will give our villagers a chance to sell their clothes and on a decent livelihood for their families.

18.5.1.9 Choose Ethical Labels Through Online Marketplaces

We can also stay abreast of emerging ethical labels via our online marketplaces, where you can get handmade clothes. This is an excellent way that empowers local residents to break the cycle of poverty, also helping them improve their and their families' lifestyle and education needs, making better future for themselves. Such fabrics produced by these incredible persons are all beautiful hand-dyed and hand-embroidered fabrics. It is our responsibility to save our planet, our tradition, and our values and make smarter choices. There are many apps available for free on Internet that rate mainstream fashion brands based on publicly available info. There are reports that great companies on labor rights and the possibility of exploitation in their supply chain. We can surely choose the ones that are with A+ ratings as far as ethical fashion is concerned (Joy et al. 2012).

18.6 Different Ways to Make Sustainable Fashion Choices

Listed below are eight different things we can do to exit the destructive, toxic, and poverty- and illness-inducing industry without resigning ourselves to just one or two outfits a year.

18.6.1 Wear Your Clothes for Longer Duration

What is the best way to curb our urge to buy new clothes, thereby helping the environment become more sustainable? I guess the answer lies in wearing them to their bitter end. Two ways to achieve this is to fix them when they need it by either sewing/mending them ourselves or by another person who loves to sew, instead of simply throwing them in the waste bin. Second tip is to find ways to keep them interesting, so that we want to continue wearing them as our "favorite pieces of garment" that we happily own. Just if a shirt/blouse/trouser has missing buttons or broken zippers, rips, and stains, mend them. When you genuinely get bored of some outfit, you can either pass it on to someone else or think of restyling it into something interesting that can then be used passionately by you for times to come. For example, if you are tired of wearing a heavy beautiful dupatta, you can think of turning it into a long kurta with adding design elements like buttons, rhinestones, studs, lace, pins, and colors and make it into something completely new and brilliant.

Sewing, the forgotten art in today's times is infact very relaxing and rewarding because the end result is so satisfying you will feel proud of your own creation especially when you get compliments for it from your family and friends, each time you flaunt that special piece of clothing. There is no bigger sense of accomplishment than wearing a self-made garment, and your heart and mind also feel the pleasure of giving back to the environment by not buying a fast fashion garment instead. If you are scared of trying your hands on ceiling, you can even invite some like-minded friends over and try together to create some awesome pieces which are priceless.

Once your favorite jeans have become shapeless, torn, and stained and you can't, in good faith, pass them on or wear them out anymore, take what you can use, and turn that into something else. You can make patches for other clothes or cut them into shorts. You can turn shirts worn past their use as shirts into dust cloths and old towels into wash cloths. You can take parts of old clothes and make additions to the clothes you currently have: flower pins or epaulettes, patches, bows, cuffs, collars, belts, clutches, reusable lunch bags, art, quilts, or anything you can imagine.

18.6.2 Restyle Your Clothes So That They Fit You Correctly

You need to love your clothes so that you keep wearing them for long. The key to this is that they should keep fitting you well. Sometimes, even when you buy ready-made clothes, they may not fit your body perfectly. They might be too long or too snug in one area or to lose in another. So firstly identify the clothes that you don't usually want to wear and which keep hanging in your wardrobe for no reason. If you figure out that the reason is that they don't fit your current body shape perfectly, then consider getting them fitted to your perfect size, thereby ensuring that you start wearing or using them.

At times it's also possible that they fit correctly but you feel that something is missing in them. Take one aspect of the design. Change it. Take off decorations you don't like, and add on ones that you do. Don't be afraid to cut, paint, and sew – even if sewing means nothing more to you than slicing into a T-shirt and weaving ribbons up it. So do not let go your chance of flaunting your shooting skills just by attaching that beautiful lace patch or pockets, or consider getting it done from a boutique. It surely is worth it. Make your clothes yours, and you'll love, and wear them so much more – rather than feeling a need to purchase new ones.

18.6.3 Consider Shopping Clothes from Companies Concerned About the Environment

More and more, design companies are popping up that are as concerned with the Earth as with the styles they produce.

18.6.4 Choose Most Environment-Friendly Clothes and Turn to Local and Environment-Friendly Designers

Being a little conscious about our buying habits can go a long way. Once we know that fabrics like organic cotton, organic bamboo, hemp, and telcel are environment-friendly clothes, let's try and make an effort to choose such clothes for buying and wearing. More and more, local designers are the people to turn to when you want brand new clothes that are environment-friendly – especially if you seek out the designers who are committed to making clothes that are gentle on the environment (Brosdahl and Carpenter 2010).

There are several ways that designers can commit to sustainable fashion, but the more ways they commit, the better. Look to see if all clothing assembly happens in their studio or in the same city. Check out what type of fabric they use – organic or upcycled? Do they have a zero-waste design (zero-waste means they don't throw away a single piece of fabric from the large swaths of fabric they use to cut their patterns out)? Local designers will also sometimes make items specifically to you, upcycle clothes, run sewing classes, or be willing to make your clothes fit you.

18.6.5 Buy Long-Lasting Clothes

Try and buy Valmet clothes that bring out your personality rather than buying cheap fast fashion clothing. At the end of the day, well-made clothes will make you feel and look happy, more powerful, artistic, capable, and a nature lover, environment-friendly human being, which sure serves a huge purpose and a giant step toward environmental sustainability.

Think buying clothes as an art form! Make your wardrobe collection like an artist's prized possessions which are appreciated by one and all. Only buy such clothes that you intend to keep for a long time as your precious piece of wardrobe rather than buying some garments that go in the dustbin after a few days due to maybe poor quality of fabric or manufacturing defect or poor design and last but not the least poor fit.

There's no need to buy clothes from fast fashion houses whose business plans are based on the idea that their clothes won't last or from brands that dump pollutants into the environment and put its workers at risk. Explore all the ways you can have the wardrobe you want without contributing to the toxicity of the fashion industry. Notice how you change as you check out of buying from the mainstream fashion industry. You'll probably find that you're doing yourself a favor too: you'll spend less money on clothes, you'll become more creative, and your wardrobe will become so much more interesting.

18.6.6 Organize Clothing Swap Parties Periodically

Make it a point to organize clothing swap parties seasonally. You can invite your friends,who can bring along their friends too who are interested in clothing swaps.

They can all bring their clean gently used clothes that they no longer use. Whatever gets gathered, have it sorted in different sections like bottoms and tops and then into subsections, for example, skirts, trousers, tops, shirts and another section for shoes and sandals and place them in separate locations. Then let people dive in and try on other people's clothes that they might like. Once people take them back home and you might still be left with a few unwanted pieces, you can have some friend take them to a donation center.

When you are organizing the clothing swap, you can reach out to people who are just acquaintances but maybe might be interested, and the best way to do so is by posting the event on social sites like meet up in order to increase the diversity of clothing sizes. Most likely, you'll leave with some new treasures that you'll actually be wearing, rather than those items that have just sat in closet, waiting to be loved. This way you can get some new clothes that you like, and you also declutter your wardrobe and also contribute to a donation.

18.6.7 Buy Used Clothing

Used clothing stores are great places to find all sorts of treasures from so many different eras that you'll never find at corporate clothing stores who all sell the same thing. They're also excellent places to buy basic items to make into something far more interesting. And you'll spend less money on used clothes than new, win-win situation. There are a few different types of stores that sell used clothing. Used clothing shops buy directly from anyone who walks in with clothes to sell. They generally sort through the clothes; accept only those without stains, tears, and other signs of wear; and sell everything from shoes to jeans to dresses. Consignment shops tend to have higher end selection of clothing. Instead of buying the clothes right away from the seller, the store accepts the clothes, hangs them up, and when they sell, pays the seller for them. If they don't sell within a certain amount of time, the would-be seller takes them back. Vintage stores are excellent options to try when you have a fancy event coming up. These stores tend to sell a combination of clothes from decades ago and more recent designer duds. Though they're usually more expensive, the clothes they sell are also well-made and will last. Not all cities have such a variety of used clothing.

You can also try online used clothing stores. ThredUp, for example, hosts an incredible sale. If they don't sell within a certain amount of time, the would-be seller takes them back.

18.6.8 Pass on Clothes That You Don't Love or Need

Many of us have clothes that sit unworn in the back of our closets. We know that they're there, but we still don't wear them – or get rid of them.

Those clothes that you bought 2 years ago and still have the tags on them, that outfit that you bought for an event but ended up wearing something else, and the barely worn clothes that you never consider putting on anymore, these are the items to send out into the world. If you're struggling for cash but dying for something new in your closet, oftentimes you can trade a few of your items for new-to-you pieces that you'll love and wear. If you just aren't wearing them, pass them on. Make a few different piles of clothes you want to try to sell, clothes to donate or to give away, but make sure that they'll go to someone who will use them. Cleaning out space in your home of things you don't use or wear also has a positive impact on your mental health.

If you have extra clothing that you're not using, but is in good condition, pass it on. Cleaning out closets takes a dedicated few hours, but it feels so good to let go of things that you don't use like me. I'm sure that so many choices already go into how you dress and what you choose to put on every day. You dress to please your aesthetics and your needs, you voice, and you do it while navigating the politics of clothes – how society polices women's fashion, for example, or the whiteness of the beauty industry – but the biggest way clothes impact others is when the materials are being processed, the cloth made, and the clothes constructed. Getting rid of things you don't use helps you to maintain organization because you have less things to take care of.

18.7 Hindrances to Turn to Sustainable Fashion

Let us think for a minute as what is stopping us from wearing sustainable fashion. The problem can be identified at four levels. First set of people who say they have no idea what is actually going on in the garment factories, so they're ignorant to the business models or the pollution caused during the production of the fast fashion jeans they're wearing right now.

Second set of people are those who know the truth behind closed doors of these textile factories but are not sure of the difference between fast fashion and ethical or sustainable fashion, so most of the times, they're making mindless purchases even though they could afford that organic cotton T-shirt versus a T-shirt made out of fast fashion one that they're wearing right now.

Third set of people are people who say that I am just a single person on this huge planet and even if I start to buy clothes manufactured out of fast fashion Cycles how will it be a big difference at the end of the day.

And the last set of people are those who may say that I don't want to or I cannot afford to spend more on ethical eco-friendly or organic compounds when the stores are already flooded with cheap fast fashion garments.

So only if we could change the mindsets of at least the first three sets of people, it can bring about such a vast gap for the sales of fast fashion brands that they will be forced to change their supply chains. They will be forced to change from fast to slow or fair fashion chains. This discussion brings out clearly what are the triggering factors behind the usual behaviors of people sticking to fast fashion.

We can conclude that awareness, education, and urge to act are totally missing. People who know about it are also not willing to step up and do anything about it.

There are tools that we can use to bring about change in the behavior of people toward fast fashion. We need to place our focus on (1) how to build awareness amongst masses, (2) where to get education about our clothing, and (3) how to take action.

If you put our focus, energy, and effort on solving these three questions, then our environments' negative impact will surely start to shift to a less negative one. We need to be more humane. Let us try to understand the big difference between the fancy, fashionable lifestyles of people on one end and the poor the living conditions of the workers in the producing countries on the other end. Let us not get into the rotten cycle of buying quantities over quality.

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