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and Colin D. Hills

RECLAMATION OF MINE-IMPACTED LAND FOR ECOSYSTEM RECOVERY

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Preface

Mining activities significantly impact upon the environment. Across the world, the mining activities generate huge quantities of spoil, promote deforestation and the loss of agricultural production, and the release of contaminants that mean that valuable soil resources are being lost while minerals are being won.

As the effects of the disturbance of ecosystems and loss of valuable land by extractive industries are now being recognized, it is important to show how corrective action can be taken. The introduction of sustainable mining activities does not mean a quantum leap in the technology utilized in mining, but the simple introduction of considered planning and mitigation strategies, that start before mining takes place and extend to after mining has ceased and post-closure activities are being executed.

In this book, the authors have attempted to show how mining impacts on the properties of soil and how soil carbon reserves/soil fertility can be restored when mining has ceased. Restoration involves a coordinated approach that recognizes the importance of key soil properties to enable re-vegetation to take place rapidly and ecosystems to be established in a low cost and sustainable way.

About the authors

Nimisha Tripathi is an Australian Endeavour Fellow, presently working as a visiting academic at the University of Greenwich, UK. Her broad area of research includes restoration and microbial ecology of damaged terrestrial ecosystems. She has worked as a project leader on the rejuvenation of contaminated mine wastelands; has carried out pioneering work on modified chitosan for soil remediation and carbon sequestration. Dr Nimisha has extensive publications in international peer-reviewed journals and a copyright on a novel method developed for estimation of nitrogen in soil and plant materials. She has won several prestigious awards and prizes, including, the Endeavour Research Award (Gov. of Australia), Young Scientist Award (Gov. of India) and, the Green Scientist Award (Hindustan Times and Dainik Jagran Group). Her bio-data is cited in International Biographical Centre, Cambridge, England (2009) and the Marquis 'Who's Who in the World' USA 26th Edition (2009).

Raj Shekhar Singh is Principal Scientist and Associate Professor at CSIR-Central Institute of Mining and Fuel Research, Dhanbad. Dr Raj is specialized in restoration ecology and has extensive research experience on restoration of alternate land uses and damaged ecosystems, remediation of contaminated wastelands, environmental impact assessment and management plan. He has, to his credit, publications in more than 150 journals including *Nature* (London) and books, patents and copyright. Dr. Raj was awarded the UK Commonwealth Fellowship (2012), and had attended the UK House of Parliament to discuss waste recycling (2013) apart from winning several awards and honors for his research contribution, including Whitaker Award (1998), Advisor (Research & Development), Green Earth Citizen, Sweden (2013) and CSIR patent prizes (2006, 2007). His Bio-data was cited in the Dictionary of International Biography Centre, Cambridge, England (1997). Dr Raj has edited more than 10 proceedings and is the advisor and editorial board member of a number of peer-reviewed journals.

Colin D. Hills is Professor of Environment and Materials Engineering at the University of Greenwich. Professor Hills has an extensive research and publishing record on the treatment and valorisation of hazardous wastes and contaminated soils. He has authored national guidance on stabilisation/solidification technology for the Environment Agency, is Academic Lead for the CO_2-Chemistry KTN (Utilisation Cluster), is European Contributor to the UN EP Global Environment Outlook (GEO6) for Waste and Chemicals and is a contributor to the EU road map for CO_2 mineralisation. Professor Hills has won a number of major awards for his work, including: the Green Chemical Technology Prize (IChemE), National Winner of the Shell Springboard Challenge (2008), winner of the Times Higher Award for his Outstanding Contribution to Innovation and Technology (2008). Professor Hills is Founder Director, Technical Director of Carbon8 Systems Ltd, and a Founder of Carbon8 Aggregates Ltd, sister companies that are pioneering the use of waste CO_2 gas for the engineering of waste materials.

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Finally, we are indebted to our family members who have provided unselfish support during the writing of this book. Dr Raj S. Singh wishes to express much gratitude to his late father, and Dr Nimisha Tripathi to her late grandfather for his inspiration throughout this endeavour.

Contents

1 Introduction

1.1 Background and purpose

Since Palaeolithic times (ca. 450 000 years ago), mining has been an integral part of the human existence (Hartman, 1987). Mining is fundamental to technological development and there is evidence of subsurface mining dating back to 15 000 BC (Kennedy, 1990).

Throughout the world, the most common form of mineral extraction is surface or open-pit mining. Minerals with a low stripping ratio generate large amounts of overburden or spoil, which are discarded on adjacent land surface.

The discarded overburden is disposed of in surface dumps, which significantly impact upon both flora and fauna. Spoil dumps occupy large areas of productive land and contaminate surface and subsurface water resources, upon impacting ecological pools and biological processes (Tripathi et al., 2012). The loss of key components of an ecosystem directly results in land degradation.

Surface mining disrupts the environment by disturbing the landscape, despoiling agricultural land and through deforestation. The consequence of mining is a loss of plant biomass and land productivity. The environmental impacts caused by mining, based on Richards (2002), are:

- Ecosystem disturbance and degradation
- Habitat destruction
- Adverse chemical impacts (from improperly treated wastes); and
- Loss of soil-bound carbon (to the atmosphere)

The management of mine spoil/degraded land is a major issue throughout the world. The ecological and environmental impacts of mining warrant a corrective action supported by appropriate post-closure

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management strategies. By managing environmental impacts, the long-term viability of mining operations can be secured.

The practice of ecological restoration of disturbed and degraded land is a primary action in ecosystem recovery. This is achieved by ensuring a nutrient cycling is re-established, which in turn fosters increasing biodiversity.

The introduction of a progressive post-mining plan, which considers the ecological condition of the land (to be mined) and the suitability of native plants for reclamation activities is an important step as this:

- Minimizes the overall impact of mining at a site
- Ensures an appropriate post-mining closure design is implemented
- Reduces overall cost
- Enhances environmental protection and restoration of soil-based carbon
- Reduces the time frame for completing the reclamation strategy

Post-closure reclamation actions can be implemented immediately after the cessation of mining and should utilize the best available technology options available.

Thus, by using appropriate management strategies, such as mulches and organic matter-based additions, re-vegetation can be effectively carried out post mine closure. Reclamation will re-establish the soil carbon reserve lost during mining that is essential for the correct functioning of vegetation. The reintroduction of soil organic matter is achieved via the removal of CO_2 from the atmosphere into root mass and leaf litter. The growth of biomass reduces the amount of CO_2 in the atmosphere, and therefore mitigates the effects of climate change.

This work provides a comprehensive description of impacts arising from land degradation caused by mining activities. It provides insight into the technical aspects of the restoration and reclamation of mining-impacted land and the reintroduction of soil-based carbon reserves that are so important to the re-establishment of self-sustaining ecosystems. Key ecological concepts are explored, and the major ecological pools and biological processes functioning in disturbed or degraded ecosystems are presented.

The successful repair of degraded land and reintroduction of a sustainable ecosystem requires a multidisciplinary approach, and this is reflected in the content of this book. All the stages of land reclamation from the initial policy decisions to management and outcomes are presented. As such, this work will provide key insights to undergraduate and postgraduate students, researchers, mine managers, policymakers and professionals dealing with contaminated mine land reclamation and management issues.

1.2 Key concepts and definitions

A number of key concepts and definitions are presented which underpin the understanding of ecological restoration. A number of these are as follows:

Biogeochemical cycles	The pathway by which a chemical substance moves through both biotic (biosphere) and abiotic (lithosphere, atmosphere and hydrosphere) components of Earth.
Carbon sequestration	This is the process of naturally or artificially storing carbon dioxide for a longer-term out of the atmosphere, where it contributes to the greenhouse effect.
Carbon sink	A natural or artificial reservoir that accumulates and stores carbon-containing chemical compounds (e.g. CO_2) for an indefinite period.
Decomposition	Conversion or decay of chemically unstable material to simpler forms by the natural action of air, water, light and microorganisms.
Disturbance	The major cause of long-term changes in the structure and functioning of ecosystems. Disturbance may be natural, involving fire, wind, disease, insect outbreaks and landslides, or anthropogenic from human impacts (e.g. clear cutting, deforestation, habitat destruction, introduction of invasive species).
Ecology	A branch of biology dealing with the interactions among organisms and their abiotic environment: the study of 'the structure and function of nature, which includes the living world' (Odum, 1959). In terms of disturbance, ecology encompasses the study of interrelationships between biotic and abiotic components of the existing disturbed ecosystems.
Ecosystem	A biological community of interacting organisms and their physical environment. Ecosystems are characterized as complex systems with abiotic and biotic processes interacting between the various components. In simple terms, Odum's ecosystem is the fundamental unit of ecology.
Ecological processes	The key processes regulating the ecological system (ecosystem) – nutrient processing, productivity, decomposition, nutrient turnover, hydrological flux.
Ecological restoration	The practice of renewing and returning a degraded, damaged or destroyed ecosystems to its original (prior to disturbance) condition.
Ecosystem development	The development of pools and processes of an ecosystem culminating in a stabilized ecosystem. Ecosystem development is the part of ecological succession. The concepts of ecosystem development are often based on assumptions and extrapolations with respect to structural–functional interactions in the initial stage of ecosystem development.

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Ecosystem productivity	In ecology, productivity refers to the rate of generation of biomass in an ecosystem.
Endemic (or native) plants	The plant species indigenous and unique to a specific geographic region over a given period of time.
Exotic plants	The plant species living outside its native distributional range, which has arrived there either by deliberate or accidental human activity.
Functional components	The components of ecosystem having specific roles in regulating the functioning (e.g. biogeochemical processes, disturbance regimes) of an ecosystem but governed by the structural components. Four functional components of an ecosystem include: • Abiotic factors • Producers • Consumers • Decomposers Odum (1959) termed the three 'functional kingdoms of nature' for latter three living components.
Greenhouse effect	The phenomenon by which the sun's thermal radiation is trapped by the gases (e.g. carbon dioxide, methane, water vapour) of a planetary surface and is re-radiated back from the planet causing atmospheric heating.
Greenhouse emission	The emission of gases, for example, chlorofluorocarbon, carbon dioxide, perfluorocarbon, sulphur hexafluoride, that contributes to the greenhouse effect by absorbing infrared radiation.
Habitat alteration	The process making changes to the environment that adversely affects ecosystem function. However, the effects are not permanent (Dodd and Smith, 2003).
Habitat destruction	The process in which natural habitat is rendered functionally unable to support the existing species. In this process, the regional ecosystem is completely eliminated resulting into the total removal of its former biological function and loss of biodiversity (Dodd and Smith, 2003). Habitat destruction is the primary cause of species extinction worldwide.
Habitat fragmentation	A secondary affect of habitat destruction, which occurs when the remaining species populations after habitat destruction are isolated due to destroyed linkages between habitat patches after disturbance.
Land disturbance	Changes of land use and land forms, soil moisture regulation, loss of biodiversity, loss of soil organic matter pool and altered nutrient cycling.
Land degradation	As defined by the UN Environment Programme, land degradation is 'a long-term loss of ecosystem functions and services, caused by disturbances from which the system cannot recover unaided' (Dent, 2007).
Land reclamation	The act of returning a land to a former, better state. In terms of a wasteland, land reclamation refers to the conversion of wasteland into useful land.
Land rehabilitation	The act of returning a damaged land to some degree of its former state.

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Litter	Fallen leaves and other decaying organic matter that make up the top layer of a terrestrial ecosystem.
Mine spoil/overburden	Miner's definition: Any loose or consolidated material lying over a mineral deposit of ore or coal. Civil engineer or soil scientist definition: loose soil, sand, or gravel lying above the bedrock.
Natural disturbance regime	This is a concept that describes the pattern of disturbances that shape an ecosystem over a long timescale. It describes a spatial disturbance pattern, a frequency and intensity of disturbances, and a resulting ecological pattern over space and time. These disturbances do not include the anthropogenic disturbances.
Resilience	The capacity of an ecosystem to respond to a disturbance by resisting damage and recovering quickly.
Standing biomass	The total dried biomass of the living organisms present in a given environment.
Soil amendments	Soil amendments are the materials added to soil to improve the quality of soil, especially its ability to provide nutrients to plants. They also act as the soil conditioners.
Soil microbes	Microorganisms for which the soil is the natural habitat. Examples include bacteria, actinomycetes, fungi, algae and protozoa.
Stripping ratio	The unit amount of overburden that needs to be removed to access/extract a similar unit of coal, mineral/metal ore.
Structural components	The structural components of an ecosystem are constituted by living (biotic) and nonliving (abiotic) components. Living components: populations of organisms (species diversity) and the living resources they use. Nonliving components: nonliving resources (e.g. space) and the nonliving physical characteristics of habitats (e.g. temperature, humidity, habitat complexity).
Succession	The process by which the structure of a biological community evolves over time.
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development promotes the idea that social, environmental and economic progresses are all attainable within the limits of earth's natural resources.

1.3 Supporting information

The mitigation of environmental impacts from mining activities is a complex subject. In order for the reader to access more information on particular aspects of mine restoration, a number of information sources are given below in Tables 1.1, 1.2 and 1.3. These include the addresses of organizations involved in mine restoration in India and elsewhere, useful websites and a list of NGOs involved with restoration activities (Tables 1.4 and 1.5).

Table 1.1 List of relevant organizations.

India
Banaras Hindu University (BHU), Varanasi
Central Institute of Mining and Fuel Research (CIMFR), Dhanbad
Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun
Forest Research Institute (FRI), Dehradun
Indian School of Mines (ISM), Dhanbad
National Environmental Engineering Research Institute (NEERI), Nagpur
Tropical Forest Research Institute (TFRI), Jabalpur
International
International Affiliation of Land Reclamationists (IALR): an umbrella organization, which encompasses restoration groups in the United Kingdom, the United States, Australia, Canada and China:
• The British Land Reclamation Society
• American Society for Surface Mining and Reclamation
• Mineral Council of Australia
• Canadian Land Reclamation Association (Association Canadienne de Rehabilitation des Sites Degrades)
• China Land Reclamation Society
UK Environment Agency (EA)
American Society of Mining and Reclamation (ASMR), Virginia
Intergovernmental Panel on Climate Change (IPCC), Switzerland
International Union for Conservation of Nature (IUCN), Switzerland
Interstate Mining Compact Commission (IMCC), New York
National Association of State Land Reclamationists (NASLR), New York
Office of Surface Mining, Reclamation and Enforcement (OSMRE), New York
United Nations Environment Program (UNEP), Geneva
The United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris
Western Pennsylvania Coalition for Abandoned Mine Reclamation, Pennsylvania
World Wide Fund for Nature (WWF), Switzerland

1.4 Structure/layout of the book

To address the impact of surface mining on terrestrial ecosystem and its management, the authors have used India as the prime model while discussing the general reclamation practices and underlying policies worldwide.

The book is organized in seven chapters to cover the ecological principles of land restoration, adequate management of degraded mine lands and the consequent environmental and societal benefits. Included is a synthesis of the authors experience for more than 20 years of research on mine-degraded lands and their environmental impact and subsequent reclamation.