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ARTICLE

Restoration Planning of Mining Wastelands : A Case Study

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ABSTRACT

Mining plays an important role in the economic development of a country. But the consequences of the mining can be seen in the form of degradation of soil, water, and native vegetation, which ultimately results in the disturbance of the local ecosystem. The ecological restoration of such disturbed ecosystems involves the reclamation of soil, conservation of water, erosion control, and re-vegetation of native vegetation. This can be achieved by improving the physical properties of soil, enhancing the nutrient status of soil, selecting appropriate plant species for re-vegetation, providing provision of irrigation facilities for re-vegetated mining wasteland, and so on. The present study was conducted in the Kota district of Rajasthan, where stone mining is one of the major industrial activities. The paper provides a scientific assessment of the existing vegetation of limestone mining wastelands through field surveys and physicochemical analysis of soil and water. Loss of natural vegetation and excessive stoniness of the substratum were major hurdles that restrict the easy recovery of vegetation on mining wastelands but there is almost no negative impact on the water quality. The study summarizes the holistic technology including the vegetational approach to the restoration of mining wastelands and puts forward some existing problems and their solutions.

Keywords: Mining; Wasteland; Reclamation; Vegetation

1. Introduction

SER defines restoration as "The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." [1]. Restoration aims to guide a degraded ecosystem to a pre-disturbance state; and is generally based on the successional establishment of a stable climax community [2]. In most cases of restoration, ecological outcomes such as vegetation structure, species diversity and abundance, and ecological processes are used as ma-

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jor attributes as these are the most commonly used indicators of the ecological condition of any system [3,4]. The ultimate and often exclusive goal of any restoration project is to create an ecosystem that can support itself and is resilient i.e., does not need further assistance [1,5].

1.1 Study rational and objectives

Ecological restoration in areas of environmental degradation can help reverse global biodiversity losses, as well as promote the recovery of ecosystem services [6]. Thus knowledge of ecosystem diversity and distribution is important in the conservation of biodiversity [7-10].

Usually natural restoration process can take hundreds of years. The main objective behind the present research work is to find out the most suitable plans to mitigate and manage the negative impact of mining in the study area and to suggest ways to intervene in such a way that helps to accelerate the restoration process.

1.2 Study area

The study was conducted in the Ramganjmandi area of the Kota district of Rajasthan which is famous worldwide for building limestones. Kota district lies in the southeastern part of Rajasthan. The limestone deposits are found between 24°32' and 24°48' N latitudes and 75°50' and 76°05' E longitudes. Geographically, Kota stone is part of semi series of the lower Vindhyan group and has a vast reserve of limestone deposits spread over 150 sqkm area with a total probable reserve up to mineral limits of about 100 million tonnes. In the study area the average yield of Kota stone per hectare of the land area is 1 Lakh MT and with the current trend of yearly production level, 55 to 60-hectare land is brought under mining each year. It is estimated that to date 900 hectares of prime agricultural land has been lost to limestone mining in Kota and Jhalawar district. Kota, with 22.13 sqkm of mining wasteland ranks third in land area under mining waste after Rajsamand (46.20 sqkm), Jodhpur (33.56 sqkm), and Bikaner (28.50 sqkm) in Rajasthan (**Figure 1**).

2. Material and method

Characterization of the mining waste dump was also done to identify the fertility status and identify the factor that may cause hindrance to the establishment of the plant species. Physico-chemical characterization of the soil of mining wastelands, the water of mined-out and abandoned mining pits and existing flora in the study area were analyzed as a starting point in a strategy aimed at selecting suitable restoration planning of abandoned mine spoils and degraded land along with post-mining alternative land use objectives.

2.1 Analysis of soil

Soil texture was determined by mechanical analysis, a method commonly known as the hydrometer method [11]. The electrical conductivity (EC) was measured with the help of a conductivity meter in soil water extract in a ratio of 1:2. The pH was determined in the soil-water suspension of a ratio of 1:2 using a pH meter. For the measurement of soil organic carbon (SOC), the titration method was followed [12]. The extraction method [13] was adopted to determine available phosphorus. The Ammonium acetate method [14] was used to determine available potassium. For a rapid and accurate analysis of available Zn, Cu, Fe, and Mn, the DTPA method [15] is used.

2.2 Analysis of water

Water samples were collected twice during the study period from ten locations each of unmined and mined areas. Alkalinity was estimated by titration method. Total hardness and Calcium hardness were determined by the EDTA method. Sulphate was estimated by the Turbidimetric method and Chloride by titration method using $AgNO_3$. Nitrate and Flourides were also estimated by the titration method.

2.3 Analysis of vegetation

Vegetation sampling was done by five 10000 m^2

(1 hectare) areas selected for sampling trees. Each 10000 m^2 plot was divided into 100 equal nested quadrats of 10 × 10 m^2 and 10 such quadrats were selected for shrubs, woody climbers + saplings based on randomized block design. Further two 100 m^2 quadrat was divided into 100 nested quadrats of 1 × 1 m^2 and herbs + seedling were sampled from 10 such quadrats based on randomized block design. The vegetation data were quantitatively analyzed for frequency, density, basal area, and IVI (Importance Value Index) following the studies [16,17]. Basal areas of the trees and shrubs were expressed as m^2/hectare and herbs were expressed as cm^2/m^2.

3. Observation and results

3.1 Survey of mining wastelands

Open cast mining creates huge mining wastes which are dumped in nearby cultivable land. Many mines are abandoned after exhaustive excavations and the pits remain unfilled. Other mining-related activities such as cutting and polishing also create wastes in the form of slurry which is disposed of directly into the water courses or in nearby agricultural fields. Every year about 2.5 to 3 lakh MT of stone polish is discharged which affects about 5-10 Ha of land every year. In the study area, most of the mine leases are large (4 Ha to 25 Ha), so side by side pit filling is not possible. Large quantity of blasted wastes is dumped over prime agricultural fields. The present trend of production level is likely to generate about 138 lakh m^3 of waste material every year. Presently only 35% of waste material is filled back in the mined-out pits, leaving behind 90 lakh m^3 of waste dumped over prime agricultural land, requiring 40-50 Ha of fresh land for waste dumping per year. Presently it is estimated that about 1800 lakh m^3 of waste material is dumped in adjacent agricultural land covering about 900-1000 Ha area. Overburden accounts for 80% of total solid waste generated in "*Kota stone*" mining. Excavation and disposal of large quantities of waste cost about 25-30% of the total cost of production. In "*Kota stone*" mining the mineral recovery has never been more than 25%. The mineral-to-waste ratio has varied between 1:10 to 1:8.

Figure 1. View of the study site (mining wastelands in Ramganjmandi, Kota).

3.2 Physical features of mining wastelands

Mining wastelands in the study area feature huge waste dumps with a very large amount of pieces of limestone. The physiography of the surface is a slope with a very low content of clay and silt. Mining causes a loss of valuable topsoil at the rate of 8-8.5 m^3 per year. The texture of the soil is dependent on the parent rock material by weathering, of which the soil is formed. But disturbances in soil may change the physical properties of soil including texture. There exists a change in the ratio of components of soil defining a textural class of soil around mining wastelands and of waste dumps. Excessive stoniness of the substratum and lack of clay is the major problem in the study area (**Figure 2**).

3.3 Characteristic of soil

Chemical analysis of soil in mining wasteland areas shows reduced organic content and low nutrient level. Change in physico-chemical properties includes increased pH, texture, reduced organic carbon, and reduced macro as well as micronutrients (Iron, Copper and Manganese) [18]. Among micronutrients Iron and Manganese show more than 70% decrease from control. There is no remarkable change in Available potassium, the level of which is above the reference value in both the non-mining and mining areas (**Figure 3**).

3.4 Vegetation characteristic of mining waste dumps

A preliminary survey of the study area shows the dominance of shrubby flora in the mining waste dumps. Floristic inventory of the reference vegetation is represented by a total of 171 plant species belonging to 50 families comprising 45 dicotyledonous and 5 monocotyledonous families. Whereas in areas around mines and on waste dumps only 42 plant species belonging to 20 families comprising 19 dicotyledonous families and 1 monocotyledonous family got representation. Dicotyledons contribute mainly to the characteristic flora of protected vegetation in terms of families (**Table 1**). 65 plant species belonging to 29 families form the tree and shrub layer of the vegetation in control sites whereas 111 plant species including seedlings of a few trees and shrub species belonging to 33 families form the ground cover (**Table 2**). Trees and shrubs are represented by 11 families with 14 species and herbaceous plant cover is represented by 28 plant species belonging to 13 families in mining wastelands (**Table 2**).

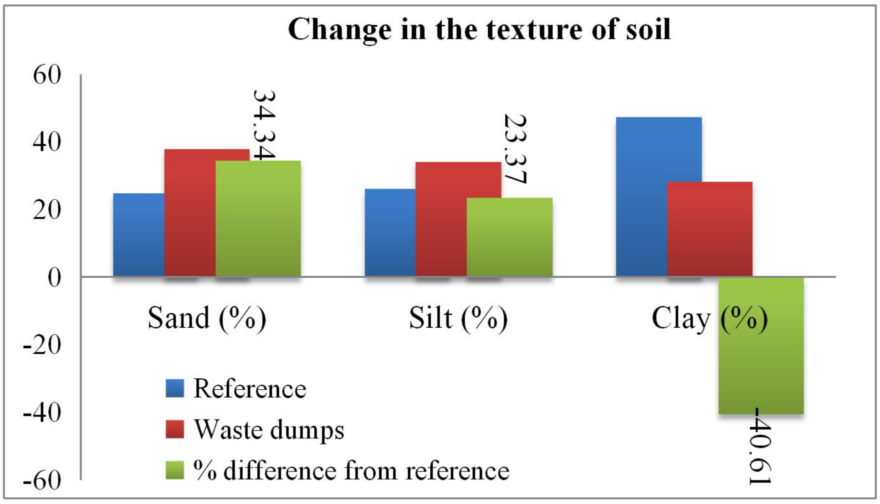

Figure 2. A graphical presentation of the change in components of soil determining texture.

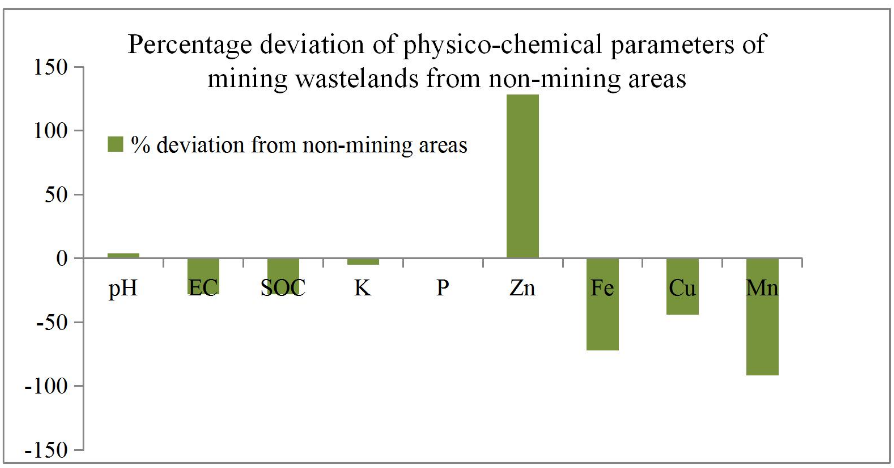

Figure 3. Physico-chemical analysis of the soil from control and experimental areas.

Table 1. Statistical synopsis of the flora of two different sites (non-mining area and 5-10 years old abandoned waste dump) in the study area.

Taxonomic group	Protected vegetation (Control)			Abandoned waste dump (5-20 years old)		
Angiosperms	Families	Genera	Species	Families	Genera	Species
Dicotyledons	45	120	140	19	34	35
Monocotyledons	05	23	31	01	06	07
Total	50	143	171	20	40	42

Table 2. General floristic and diversity characteristic of vegetation in non-mining area and mining waste dumps in RamganjMandi.

Parameters	Values	
	Protected vegetation stands	Mining waste dumps
Plant species forming tree+shrub layer	65	14
Plant species forming ground layer	111	28
Families forming tree+shrub layer	29	11
Families forming ground layer	33	13
Total density of trees/hectare	5.22	3.2
Total density of shrub/hectare	793.7	328
Total density of herbs/m^2	72.184	9.04
Total basal area of trees (m^2/hectare)	0.244	0.060
Total basal area of shrubs (m^2/hectare)	2.495	1.08
Total basal area of herbs (cm^2/m^2)	69.201	17.182

Shrubs form the characteristic vegetation in the protected as well as exploited habitats (**Figure 4**) because they are represented by higher density per hectare and basal area (m^2/hectare) in both the sites as compared to trees among individuals having cbh > 10.5 cm. There is a decrease in density and basal area of all the growth forms (trees, shrubs and herbs) in the exploited areas as compared to control sites. There exists a considerable decrease in species/family ratio and species/genus ratio in exploited areas as compared to protected vegetation sites.

3.5 Hydrological characteristics of mining wastelands

Physico-chemical analysis of water shows no major impact on water quality when compared with the water quality from non-mining areas (**Table 3**). All the parameters remain within the limits of the reference values. Whereas pH, Alkalinity, Total hardness, Calcium hardness, Chloride, Sulphate, Total dissolved solids, and even Fluoride are decreased as compared to non-mining areas [18]. The study area

Figure 4. General floristic and diversity characteristics of natural vegetation and mining waste dumps in RamganjMandi.

faces water scarcity during summer and opens abandoned pits are reservoirs of water that are used as drinking water at places (**Figure 5**).

All these have resulted in a negative impact on the natural environment with total disruption and modification of landscape, changed hydrology, drainage patterns and altered vegetation. The impacts of mining can be seen in the form of deforestation, water, and air pollution, changing patterns of rainfall and the local climate, depleting water balance, and many others [19,20]. Based on an extensive survey and study of mining wastelands in the study area, a restoration plan of the same is presented.

4. Discussion

The results show lower diversity in both the growth forms i.e. trees + shrubs and ground flora in areas of mining wastelands. Results indicate increased competition between species which in turn has narrowed down the number of species able to make a living in exploited areas. The abundance of very dissimilar species in exploited areas whereas the somewhat similar proportion of constituent species in the protected sites. The condition is reversed in the case of herbaceous species. Majumdar [21] has reported 700 species occurring in the Hadoti region**.** Sharma and Tyagi [22] reported 619 species from the same region whereas Sharma [23] reported 1098 species. Losing biodiversity not only affects the environment in very close vicinity but affects the ecosystem as a whole [24]. State of Environment Report India [25], states that extensive mining is causing severe fragmentation (landscape discontinuities) of habitats and forest areas. The natural successional process is usually slow, taking 50-100 years, at least a human lifetime [26]. A minimum period of 50 years to a century is required to establish advanced specific plant species in denuded, mining overburden-filled land [27]. In areas of degraded ecosystems due to mining appropriate intervention may be required to initiate and enhance the succession process.

Table 3. Characteristic of water from the non-mining areas and abandoned mines.

Sr. No.	Parameters (all results in mg/L except pH)	Reference values	Control (non-mining areas)	Experimental (mining pits)
1.	pH	6.5-8.5	7.8	7.33
2.	Alkalinity (methyl orange)	200	326.5	112
3.	Total hardness ($CaCO_3$)	300	257.5	146.5
4.	Calcium hardness ($CaCO_3$)	187	114	91.5
5.	Chloride (Cl^-)	250	160.5	66
6.	Sulphate (SO_4^{-2})	200	84	2.7
7.	Nitrate (NO_3^-)	45	30.7	4.8
8.	Total dissolved solids	500	1119.6	419.2
9.	Fluoride	1.0	0.79	0.313

Figure 5. Abandoned mining pits in the study area.

4.1 Restoration of mining wastelands in the study area

Restoration of the mined-out wastelands includes approaches; management of mining wastes, reclamation of abandoned waste dumps, and re-vegetation of the waste dump.

Management of the mining waste dumps

Reuse and Recycle the mining waste for producing commercial products: Recycling and reusing waste to produce a commercial product may be the best option to sustain the future economy not only by generating additional employment in the region but also by releasing lands locked in the storage of mining waste. In a study conducted by CBRI, Roorkee in the early 90s Sand Lime Brick can be manufactured by blending Polish Waste (Slurry) and Calcined Kota Stone quarry waste which has a strength of 150-180 kg/cm^2 as compared to normal clay brick of 20-30 kg/cm^2 strength. The manufacturing process involves calcination and hydration of Kota stone waste to yield low-grade lime powder, mixing this Lime powder with polish waste and river sand in different proportions, hydraulic pressing, and passing saturated steam at about 14-15 kg/cm^2 pressure in autoclave then curing for 4-6 hrs.

Studies carried out by Civil Engineering Department, Engineering College, Kota prove that Kota Stone waste aggregate can be used to make cement concrete and the loss in compressive strength when compared with cement concrete (Sandstone) is only 15.7% and cement can be replaced up to 30% by Kota Stone Slurry in cement concrete with loss in compressive strength only up to 6%.

Lately, an Italian Company has come up with technology to produce Compound Stone involving compaction by vibro-compression under vacuum of a mixture formed by stone aggregate and binding paste to produce high-density Compound Stone wherein 84%-91%, by overall weight, will be the stone aggregate from Kota Stone quarries. The Compound Stone so produced will have outstanding geo-mechanical properties such as high compressive strength, low water absorption, mechanical resistance, resistance to chemical agents, heavy density, etc., which are compatible with natural stone.

Identification of post-closure land-use objectives: Sustainable land-use options and restoration/rehabilitation of these degraded ecosystems will control erosion, halt further degradation and preserve environmental quality [28]. The "commercial forest land" or "managed forest" plantation option provides an opportunity to achieve wood production, fuelwood, fodder, and other commercial forestry objectives. Establishing biofuel plantations (e.g., *Jatropha, Pongamia*) on degraded soils can be a win-win strategy provided that these soils are adequately restored and specific problems (e.g., nutrient and water imbalance, loss of topsoil, shallow rooting depth, drought stress, salinization, compaction, crusting) are alleviated [29]. In the post-mining landscapes, short-rotation tree plantations as a special form of energy forests have recently come into focus [30]. A large number of laticiferous plants like species of *Euphorbia* and *Calotropis procera* growing naturally on the mine spoils can be utilized for the production of biofuel [31] or as petro crops [32]. *Jatropha gossypifolia, Lantana camera,* and *Prospopis juliflora* which occur naturally in the study area produce a higher amount of biogas and are identified as biofuel crops [33].

Alternative use of abandoned mining pits: Shallow mining pits may be used for algal biomass cultivation to provide biofertilizers which may further be used for reclamation of the nearby mining wastelands and animal feed for the livestock reared by local inhabitants. Limestone mining operations are generally confined to 4-50 meters in depth and this is because there is a general scarcity of water in limestone areas [34]. Thus these pits can be best used for rainwater harvesting [35].

Reclamation of mining-affected soil

Physico-chemical analysis of overburdened material along with a sampling of the vegetation on mine spoils will help characterize mine waste materials as growth media and find out factors that could be limiting plant growth which will in turn help to evaluate the relationship between material properties and plant responses.

Physical amendment: Landscape designing (Re-sloping, Bunding, Terracing, etc.) will help erosion control. Mulching and the addition of organic matter to the soil will help to amend soil compaction. Grading and sloping the post-mine landscape to a 3% slope were the most effective and cost-effective reclamation approaches. Leveling or terracing to give the shape of a saucer may be adopted for soil and water conservation. Mulching and bundling along the contour of the waste dump can help in erosion control. Segregation and utilization of the waste stone pieces will lower the size and slope of waste dumps, and reduce excessive stoniness of substratum, and native soil trapped in the waste dumps will be made available for further amendment.

Amendment of mine-spoils (Identifying and, if necessary treating, any soil factors that are limiting): Finding out the most suitable soil working technique, remediation of soil fertility, amendment of mine-spoils with organic materials and bio-fertilizers.

4.2 Recovery of natural vegetation on mining wastelands

Phyto-sociological survey of the study area will help to find out suitable trees, shrubs, and grass species for site improvement through afforestation. Floristic analysis conducted to study the local flora and their interaction with the local climate has helped in the identification of pioneer species during the early stages of rehabilitation. Natural ecological processes such as colonization and population expansion in bare areas can be enhanced by planting native legumes [36]. Species to be used in restoration projects should be chosen from among the local vegetation [37]. Broadcasting the seeds of herbs and shrubs instead of going through the plantation of tree species is the best option [38]. Direct seeding of native species is a useful and cost-effective restoration method globally [39-42]. To increase the survival success of key shrubs and small tree species (thicket) planting of saplings is required [43].

Revegetation strategy, planning, and technique

Selection of appropriate species, Establishment of ground cover, shrub, and tree cover, planting techniques for establishing selected species for revegetation over mine spoils and overburdens will improve vegetation cover, type, vigour, and vitality of the species planted, and planting at the appropriate time and density will increase the survival of the plant. Finding out suitable planting techniques, time, and density of planting will increase the success rate of recovery of native vegetation.

Maintenance, evaluation of success criterion, and monitoring

Invasion by animals, weeds, and human activities can thwart rehabilitation efforts thus maintenance of the area being reclaimed is necessary to check the failure of the re-vegetation attempts. Maintenance might include replanting failed areas, repairing erosion problems, implementing fire management systems, controlling pests, weeds, and animal populations, using fertilizer, and applying amendments to the physico-chemical properties of the substratum.

5. Conclusions

The success of restoration planning of wastelands depends on a holistic approach integrating all aspects of restoration viz. evaluation of extent and type of degradation, management of waste, reclamation and physico-chemical amendment of wastelands substratum, selection of appropriate technique, time and plant species for re-vegetation.

Conflict of Interest

The author declares that there is no conflict of interest.

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