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Revegetaion at Restored Disturbed Mining Area of Giral Mines, Barmer, Rajasthan, India.

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ABSTRACT

Wide-ranging lignite mining in the Indian (Thar) Desert inaugurated within the historical time. Associated mining of this treasured resource there have been noticeable, important environmental impacts. The subsequent land degradation has provoked concern from both public community and governing bodies. This research evaluates the success of restoration plans applied to revegetate a restored disturbed lignite mine area, near the village of Giral in western Rajasthan State. Restoration success was attained within the present environmental factors and their limitations of this northwest Indian hot-desert ecosystem using a combine method of: (1) backfilling (abandoned pits) the area with mine dumps and cover the backfilled-surfaces with fresh topsoil to a thickness of about 0.30 m; (2) use of rain water storage system; (3) soil profile alteration methods; (4) plant establishment methodologies; and (5) the selection of appropriate native species (trees, shrubs and grasses). Initial results indicate that the resulting vegetative cover will be capable of self-perpetuation under natural conditions. The mine spoil is alkaline in nature and has high electrical conductance. The average content of organic carbon, N, P and K is lower than in the regional topsoil. This study established approaches for the renovation of restored disturbed lignite mine areas and has also resulted in an understanding of restoration developments in arid regions with an importance on the long-term intensive care of restoration success.

Keywords: Lignite mining, revegetation, backfilling, restoration, environment, restoration success, rain water harvesting system.

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INTRODUCTION

Mining includes destruction in the environment, construction of deep swallow holes, damage biodiversity, contamination of soil, groundwater, and soil surface by chemicals from mining processes. Mining disturbs the natural environment and soil strata. Mining areas stored by few methods like revegetation, preserving the topsoil during mining and leveling of the excavated overburden and restoring them, etc. Mining procedures usually require the removal of vegetative cover combined with the stripping of topsoil, overburden, and indulge materials. These activities, along with the construction of access roads, usually result in severe disturbance or destruction of soil structure, landscapes, and vegetation. Without proper management and regulation, additional adverse impacts change the habitat. India ranks third in the world in coal and lignite production and mined 316 million tonnes of this energy resource between 1998 and 1999; about 7 per cent of the total annual global production [1].

Vegetation cover is a critical component of terrestrial ecosystems, especially in arid and semi-arid regions, which must be sustained by sufficient water [2]. The vegetation dynamics concerning space and time are, therefore, primarily dominated by the availability of water [3]. Due to the exaggerated mining activities during the most recent 10 years, the Giral area is mostly had dried up after excavation, which, consequently, led to a severe decline of vegetation cover and drastic changes in plant community structures along the underground water and artificial pond area of Giral [4]. Natural vegetation cover plays a critical role as the primary producer of organic matter; the status of ecosystem recovery can primarily affect the ultimate environmental conditions in Giral backfilled region.

STUDY OBJECTIVES

The objective of the restoration work was the production of a sustainable native plant species and different combination of trees, shrubs, grasses and herbaceous species, which balanced the requirements of the local population by providing a farming and grazing resource. Our study examined the importance of conducting pre-mining soil and mine spoil inventories in order to anticipate potential restoration difficulties. These lists help in assessing the possible construction of ecosystem stability. Particular emphasis was placed on understanding the characteristics of successful native plant species selection, characterizing the physical and chemical properties of overburden and mining soils, restoring land capability, topographic landscaping for the conservation and maximization of existing soil moisture through rainwater harvesting, creating suitable rooting medium, use of rehabilitated surfaces for short-term cropping or long-term revegetation, and evaluating plant-community sustainability. Successful restoration can be evaluated using two main criteria: (1) stabilization of surface materials through suitable site reconstruction; and (2) formation of long-term sustainable vegetation communities.

METHODS AND MATERIALS

Study area and background

RSMML started lignite mining in the year 1994 at Giral, and till the demand of lignite in Rajasthan, part of Punjab, Gujrat, and U.P. met by the Giral mine. Giral lignite mine is situated 45 Km near the town of Barmer city. Giral lignite mine is opencast mining, with heavy earth moving machinery but without drilling and blasting. The Giral lignite mine represents a restricted sub-basin covering an about 15 sq. km area within the Barmer basin, represents the sediments of lower tertiary period (Paleocene-lower Eocene) age.

The Rajasthan State Mines & Minerals Limited (RSMML) is the major mining organization in the state of Rajasthan, which extracts the various mineral in different districts of the country. The organization is involved in the mining of multiple metals, including Limestone, Rock Phosphate, Gypsum, Fluorspar, Lignite, Steel grade Limestone, Multi-metal, and Granite. The present study deals with study for lignite mining in sub-blocks Giral, Jalilo, and Thumbli of Giral Lignite mine, District Barmer. Motorable Pucca Road can approach the tunnel, and it connected to the metal road of Bhadka-Thumbli Road. NH no. 15 is transitory about 12 km. away from the area. Barmer railway station is the nearest railway station to the Jodhpur- Munabao section of the N-W railway. The current lignite demand in the state of Rajasthan met by Giral mine. The mine is operational since 1994. Giral mine was the first operational opencast lignite mine in the Rajasthan state. To meet the ever-increasing lignite demand for generation of power through existing power plant of M/s RVUNL (State PSU) and meet the industrial application and also to generate additional revenue, RSMML commenced lignite mining in the state. The mining activities could lead to significant environmental problems if its operations not adequately planned. There could be problems of air pollution during excavation or dumping of overburden, increased noise levels, and vibrations, loss of valuable topsoil, topographical changes, increase in traffic, adverse impact on ecology, etc.

Methodology Applied for the Floral Study

To achieved restoration success, we can use a combination of rainwater harvesting, soil amendments, and plant establishment methods using trees, shrubs, and grasses. For assessing the floral diversity in the study area, both floristic survey and quantitative analysis of vegetation undertaken. Information regarding local names and locality of the plants recorded with the help of the local people and forest staff. The quantitative analysis of vegetation done by using quadrats as sampling units. The quadrats were laid randomly in identified sites of the project area. Vegetation indices have been developed to qualitatively and quantitively assess vegetation covers using spectral measurements [5]. Besides, vegetation activity has a vital seasonality.

Methodology Applied for the Faunal study

Ground surveys were carried out in different phases by trekking the impact areas for identification of faunal species inhabiting the area, including village land, adjoining forest on the slopes of hillocks and dunes, artificial ponds, and agricultural fields. Apart from direct sightings and primary data generated through transects and trails. However, to gain an insight in the following respects for species of carnivore, ungulates, non-human primates, mammals, birds, reptiles, and other fauna, the survey was conducted in the Giral restored mining area and nearer areas of Giral.

Experimental Design

A mine-land rehabilitation plan should make logical and effective use of the natural resources available at the site. Such resources include precipitation, topography, topsoil, soil amendments and locally adapted plant species [6]. Also, the rehabilitation effort should have some evaluation of cost–benefit based on land-use considerations. Our study involved backfilling the abandoned pits with a heterogeneous mixture of bentonitic clays, shale, and weathered lignite. The backfilled areas were then covered with fresh topsoil (a mixture of fine sand and $CaCO_3$ concretions, i.e., caliche´ spread to a thickness of 0.25 to 0.30m depending upon reserves of usable soil) and land-shaping to create basins for harvesting precipitation and surfaces for transplanting the revegetation species. The rainwater harvesting system [7] was utilized since it was found to perform well in a related gypsum-mine rehabilitation study within the same region

[8]. The rainwater harvesting treatment was replicated six times in a randomized block design; the area of each plot was 1 ha. Deep ripping broke the interface between the compacted, backfilled mine spoil and the topsoil. This procedure may minimize the capillary movement of potentially acidic water from the backfill into the topsoil [9].

Figure 2. Rain water storage system in Giral mines, Barmer

Topsoil and Mine dump Analyses

Topsoil and mine spoil (dump material used for backfill—a heterogeneous mixture of bentonitic clays, shale, weathered lignite sampling was conducted in the summer of 1997 in order to assess the soil parameters directly affecting revegetation. Mine spoil cores were dug manually to a depth of 0.30m at Giral mine. All sites selected randomly at restored disturbed locations. Representative samples were obtained by mixing the samples from different restored disturbed sites. The composite samples were sieved (<2 mm), air-dried and stored in plastic containers. Physical parameters measured were particle size distribution, $CaCO_3$ content, moisture equivalent, and water holding capacity. The particle-size analysis was conducted using the International Pipette Method [10].

The $CaCO_3$ content was estimated in a Collins' calcimeter [11]. Moisture equivalent was estimated using the centrifugation method described by Piper (1966). Water-holding capacity was determined gravimetrically after completely saturating the soil with water using Ryczowsky boxes with perforated bottoms [12]. Chemical parameters measured included pH, electrical conductivity (EC), organic matter content, nutrient content, and major and minor element content. The pH and EC of samples were determined using a glass electrode in a 1:2 soil–water mixture. Organic matter was measured by determining the loss on ignition of samples at 500^0C for eight hours. Total available N present in the samples was determined by extraction with potassium chloride followed by flow injection analysis [13, 14].

The exchangeable cations, such as Ca, K, Mg and Na, were extracted with neutral–normal ammonium acetate solution and their concentrations were determined by flame photometry [12]. Phosphorus concentrations were determined by means of spectrophotometry following digestion in sulfuric acid at 370^oC for 135 minutes [13]. Total S was extracted by fusion and oxidation with sodium carbonate and its concentration was determined turbidimetrically [15]. The SO_4–S was determined by means of extraction with 0.15 per cent calcium chloride solution followed by the turbidimetric method [16]. Alkaline-phosphatase was assayed using the borax–NaOH buffer method (pH 9.4) [17]. Dehydrogenase, a measure of total microbial activity, was assayed by the method of Tabatabai (1982). The alkaline-phosphatase and dehydrogenase measurements are expressed on an oven-dry basis.

Mine spoil Water Content

Percentage mine spoil water content was obtained using a calibrated neutron moisture-gauge (RSMML Head Office, Lab Jaipur). Measurements were made at two locations selected randomly within each plot at 0.20m intervals to a depth of 1m. The access tubes were 51mm diameter electro-mechanical tubing and were installed in 1997. During current study, actual measurements were made in 2019 and 2020 at the end of the rainy season (the last week of September).

Plant Survival and Growth

Individual species survival was assessed by simple individual counts. Growth of revegetated trees and shrubs was measured in terms of height, cover, and collar girth and was recorded every year at the end of the rainy season.

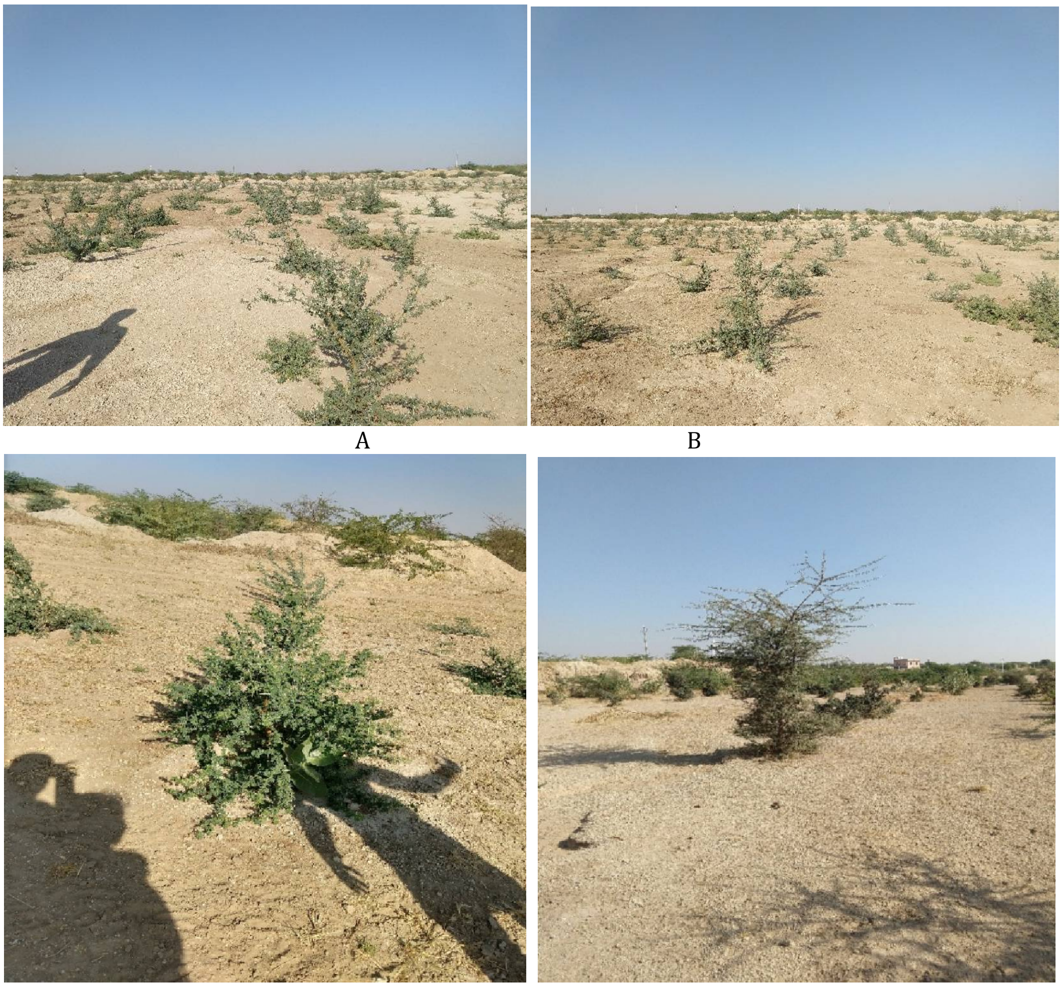
Vegetation Succession

Species presence and abundance was investigated quantitatively in 2020 at the end of the study. Ten 100m2 quadrats, diagonally abutting each other, were positioned in each plot using the method of Kent and Coker [18]. Woody perennials in each quadrate were counted. The herbaceous vegetation was sampled for frequency and density in a 1m2 area nested in one corner of each of the 100m2 quadrats. Further, the cover of herbaceous vegetation was measured along a line transect [19].

RESULTS AND DISCUSSION

Evaluation of progressive improvements:

With the discussion concerning Figure 3 (a) to (d), it can be observed that the flora can slowly be recover after nearly four years of environmental degradation due to mining and the limitation of underground water availability. During this process, the yearly retrieval of vegetation level may be helpful to elucidate the fluctuations of the ecosystem recovery relative to the last stable state. Vegetation activity has a vital seasonality, and the growing season usually occurs between April and October in this study area. Coefficient of Variation (CoV) is a simple statistic calculated from the average, or mean (μ) and the standard deviation (σ) of the time series during the restoration. This statistic has been widely used to determine the spatial difference of progressive variability in the vegetation activity at different arid and semi-arid regions of the world.



A B (C) (D)

Figure 3 (a to d): Flora can slowly be recovering after nearly four years (2016-2020) of environmental degradation due to mining at Giral mine, Barmer, Raj., India

Chemical and Physical Characteristics of the Soil Used for Backfill

A representative section of the strata exposed in the pit walls and used for backfill is shown in Figure 3 and 4. The section measured is 53m thick, and with the exception of 3.2m of superficial material, is presumably entirely within the akli Formation. For the section shown, approximately 4.6m of lignite is mined and not used for backfill, along with some strata that are discarded due to expansion. The seven mined seams were sampled for detailed coal analysis, and selected samples of inter-burden and overburden were sampled for palynology and basic geochemistry. Two possible unconformities (depositional hiatuses) are indicated in the table. These are sharp breaks in bedding, the lower of which shows slight discordance, and the upper is marked by a burrowed surface in the coal.

Figure 3 Giral mine seam and backfilled areas.

The rocks (Figure 3 and 4) are generally typical of lignitic sequences of similar age in other areas of the world, except that they are considerably less sandy. The clay stones in the lower, lignitic part of the section are typical under clays (coal seat rock) that show fossil root traces and slickensides internal surfaces. The intercalations of coal and under clay exposed in the pit walls are remarkably regular and appear to be cyclic. The depth of weathering in the study area is generally down to the highest lignite bed and may be influenced by the postulated overlying unconformity. The rocks above seams are difficult to describe due to the effects of weathering, but they do not appear to be compositionally much different from the coal-bearing unit. The clays are much more fissile and probably less bentonitic than the under clays, and they are somewhat siltier and sandier. No thick sandstone beds were observed below the aeolian sands, which is highly unusual for a coal-bearing section of this type. The main features of reclamation significance above the zone of weathering are abundant secondary evaporitic and solution deposits. These include bedded and bladed selenite gypsum several centimetres thick, caliche´ beds and nodules in excess of 40 cm thick, and nodular ironstone bands or lag that may be sideritic and/or limonitic in composition and several centimetres thick.

Figure 4: Lignite Seams during mining and dumps at Giral mine, Barmer, Rajasthan

Table 1: Physicochemical characteristics of modified soil profile and lignite mine spoil (n=9)

Parameter	Modified soil	Mine Dump Profile
$CaCO_3$ (%)	5.5 ± 1.0	3.9 ± 4.0
Moisture equivalent (%)	9.1 ± 1.8	10.9 ± 2.2
Water-holding capacity (%)	28.9 ± 2.9	48.0 ± 13.8
pH	8.6 ± 0.3	7.8 ± 1.2
Electrolytic conductance (d S m-1)	1.1 ± 0.3	5.7 ± 3.6
Organic carbon (%)	1.2 ± 0.2	0.6 ± 0.2
N (kg ha-1)	657 ± 35	259 ± 39
P (kg ha-1)	300 ± 95	67 ± 39
K (kg ha-1)	222 ± 85	152 ± 27
Ca (ppm)	1600 ± 100	3900 ± 1200
Mg (ppm)	400 ± 100	1000 ± 200
Na (ppm)	63.8 ± 23.4	222.4 ± 68.9
Total S (ppm)	800 ± 100	6400 ± 700

Survival and Growth Performance of Plant Species

There have been recurring instances of plant and their leaf damage was manifested by leaf drop and in the mortality of newly grown shoots. It's due to layer of dust and mining soil covered the whole plant and its leaf. So, damage in terms of the percentage of plants affected, was at a maximum in Tamarix aphylla (88 per cent), followed by Colophospermum mopane (78 per cent), Senna angustifolia (77 per cent), Pithecellobium dulce (68 per cent), Acacia nubica (56 per cent), Tecomella undulata (52 per cent), Salvadora persica (31 per cent), Azadirachta indica (26 per cent), Acacia tortilis (6 per cent) and Dichrostachys nutans (2 per cent).

The remaining tree and shrub species, such as *Prosopis cineraria, Capparis decidua and Zizyphus nummularia,* did not show significant damage.

Figure 4: Leaf is covered with mine dust and layer of mining soil. Its lead to damage the plant growth.

Between 2016 and 2020, the *Azadirachta indica* gained significant (p<0_01) maximum height (471 per cent) followed by *Salvadora persica* (267 per cent), *Colophospermum mopane* (180 per cent), *Tamarix aphylla* (132 per cent), *Prosopis cineraria* (111 per cent), *Tecomella undulata* (71 per cent), *Acacia tortilis* (63 per cent), and *Pithecellobium dulce* (31 per cent) compared to 352 per cent, 262 per cent, 20 per cent, 45 per cent, 79 per cent, 10 per cent, 26 per cent, and 17 per cent, respectively, under control growth conditions. Among shrubs, *Dichrostachys nutans* gained significant (p<0_01) maximum height (235 per cent) followed by *Acacia nubica* (154 per cent), *Senna angustifolia* (95 per cent), *Zizyphus nummularia* (42 per cent), and *Capparis decidua* (37 per cent) compared to 180 per cent, 102 per cent, 65 per cent, 31 per cent and 19 per cent, respectively, under control growth conditions. When compared to the control-grown plants, maximum significant ($p<0.01$) increase in plant cover for rain water harvesting system was observed for *Dichrostachys nutans* (3610 per cent) followed by *Colophospermum mopane* (2970 per cent), *Tecomella undulata* (2100 per cent), *Azadirachta indica* (1450 per cent), *Prosopis cineraria* (1150 per cent) and *Salvadora persica* (110 per cent). The remaining tree and shrub species gained >100 per cent cover over the control. At the end of the study in 2020, grass showed the greatest abundance of all plant types in terms of percentage coverage (45 per cent).

Status of earlier to present plantation growth

Restoration generally considered as accelerated succession[20]. The vegetation analysis undertaken by collecting numerical community data for trees, shrubs, and herbs from the randomly laid quadrats. *Acacia Senegal* found as the dominant tree species at this site. The dominance of *Prosopis juliflora* may be due to its non-palatable nature and drought-tolerant species. The other competing species in the shrub strata were *Calotropis procera, Capparis decidua, Aerva javanica,* and *Acacia jacqemontii.* Changes in ecosystem structure and function may not be gradual but show sudden changes. The macro-nutrients develop satisfactory success in the plantation. The plant covers 60%-70% of land in the backfilled areas of Giral mines. Gradually the plants include the land year by year. It gives satisfactory growth.

Natural Succession and Community Sustainability

The rehabilitation efforts of this study have initiated the process of natural succession of favourable plant species on the lignite mine-disturbed area at Giral. This is evidenced by changes in the vegetative composition in 2000 compared to the original transplanted species used in 1997 (Previous data collected from Giral mining). With successional progression, dynamic changes occurred in the ecological diversity over the course of the study in terms of abundance, frequency and density of desirable invasive plant species (Table 2). Diversity (i.e., species richness) increased rapidly following rehabilitation.

Table 2. Plant species used in the rehabilitation of lignite mine disturbed area at Giral, India

Life form	Indigenous		Naturalized leguminous	Exotic leguminous
	Leguminous	Non-leguminous		
Tree	***Prosopis cineraria***	***Azadirachta indica*** ***Salvadora persica*** ***Tamarix aphylla*** ***Tecomella undulate***	***Acacia tortilis*** ***Pithecellobium dulce***	***Colophospermum mopane***
Shrub		***Capparis decidua*** ***Zizyphus nummularia***	***Dichrostachys nutans*** ***Senna angustifolia***	***Acacia nubica***
Grass		**Cenchrus ciliaris** **Cymbopogon jwarancusa**		

The increase was most evident with the annual species, a characteristic of early plant succession. The early successional species contribute organic matter to the mine spoil, especially at the end of the growing season, which is of special ecological importance. The presence of organic matter, even at <1 per cent in these mine soils, enhances nutrient and moisture availability and is a starting point for soil microbial activity [8]. The restored disturbed agro-ecosystem created appears to be self-perpetuating but in order for it to become sustainable (for an indefinite length of time) it must not experience heavy grazing pressure during the initial years [21].

CONCLUSIONS

There are many rehabilitation techniques used throughout the mining industry; however, the technique employed at the Giral Lignite Project since 1997, 2016-2020, in the arid Indian northwest, has proved particularly successful. This technique involves backfilling the mined pits, covering the undesirable spoils with fresh topsoil to a thickness of 0.2- 0.30 m, and shaping and battering the slopes to 5%. This latter procedure creates micro-catchments where rainwater harvesting can occur and where transplanting container-grown 4-month-old tree and shrub saplings can be undertaken at 9m-5m spacing. A restored disturbed mine land-use was chosen for the rehabilitated surfaces because this type of sustainable agro-ecosystem meets the needs of the local population by providing both an agricultural and a grazing resource. The following types of rehabilitation plant species were selected: eight tree species (selected because of their use as top-feed for animal browsers); five shrub species (used for animal browsing and nitrogen fixation); and two grass species (used for land stabilization and animal grazing).

At the end of study, in 2020, the vegetation composition differed from that which was originally planted during 1997 indicating that the rehabilitation effort had in fact facilitated the process of natural succession. Although the rehabilitation strategy used in this study appears to have been successful, much research remains on processes that affect the long-term sustainability of lignite-mine rehabilitation. Long-term sustainability (>10 years) and quality of the revegetated plant community are key issues. This is mainly due to the uncertainty of the impact of intense and long-term animal grazing. Nevertheless, the outlook for restoring and enhancing the potential for producing vegetation useful to humankind appears promising, if the technology developed to date is properly used.

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