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Ecological Assessment of Restored Rock Phosphate Mine Spoils in the Maldevta Area of Garhwal Himalayas

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This research explores the complex interaction between vegetation restoration and soil recovery, with a particular focus on the ecological restoration of an area in Maldevta, Garhwal Himalayas, that was once mined. The Himalayan ecology, which is abundant in minerals and biodiversity, is under a great deal of stress from mining, building roads, and grazing. The research area experienced open-pit mining, which degraded the soil and eliminated vegetation from what had once been a tropical dry mixed deciduous forest. Analyzing the restored soil's physical and chemical properties reveals a varied profile that affects fertility, structure, and nutrient composition. The loamy sand is made up of different percentages of sand (72.4%), silt (16.96%), and clay (9.89%). The chemical characteristics of the soil include potassium (5.10%), phosphorus (0.33%), nitrogen (0.042%), and electrical conductivity (EC) of 0.21 ohms/cm. The pH of the soil is 7.80. Employing the quadrat method for vegetation analysis, the study underscores the dominance of key plant species like Lantana camara, Mallotus philippensis, and Bombax ceiba in the restored ecosystem. The results

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demonstrate how restoration initiatives improve soil conditions, vegetation structure, and species diversity. By highlighting the crucial relationship between soil and vegetation dynamics, this study adds insightful information that can improve the effectiveness of ecological restoration projects. The work supports the long-term establishment of self-sustaining ecosystems by offering a thorough grasp of the intricate biological mechanisms leading to the rehabilitation of degraded landscapes in the fragile Himalayan region.

Keywords: Bidens pilosa; bombax ceiba; ecological restoration; eupatorium adenophorum; forest restoration; lantana camara; mallotus philippensis; murraya koenigii; soil characteristics.

1. INTRODUCTION

The Himalayas extend over 2500km in length and have a width varying from 230 to 320 km from north to south. They are rich in natural resources concerning both animal and plant diversity. They are also a treasure house of various minerals such as dolomite, marble, gypsum, magnesite, high-grade limestone, and rock phosphate [46]. The Himalayan region is under stress due to various degrading factors such as road construction, grazing, landslides, and mining. Disturbance of land surface due to mining results in the loss of soil [1] reduction of water holding capacity, low moisture [2,43], high surface temperature, and insufficient supplies of plant nutrients [3]. The Mussoorie forest of the Garhwal Himalayas has been attracting scientists from both home and abroad from various fields including soil, ecology, and geology since the nineteenth century. Mining continues to be an important economic activity in India. Even though reliable estimates of mining area and production are not documented, TERI [4] estimates that India produces as many as 84 minerals, including 4 fuels, 11 metallic, 49 nonmetallic industrial, and 20 minor minerals. Interestingly, 80 % of the total mineral production comes from open-cast mines, which results in large quantities of overburden [50]. 9,244 mines have been leased out and are spread over 21 states, and about 13,000 mineral deposits occupy about 0.7 million hectares, which equates to 0.21 % of the total land mass of the country. In India, the total value of mineral production accounts for $10 billion approximately per year. However, these estimates are difficult to reconcile to take into account small-scale mining, which has seen a large increase concerning area and the production of minerals [5].

Mine spoils that are left to natural restoration on their own may take hundreds of years to develop any vegetation cover. However, carefully planned artificial interventions that mimic natural processes can accelerate the process and reduce this period [6]. For the management of forest vegetation in these mine spoils, soil, geology, and biota are important factors that can be manipulated for desired results (Puri et al, 1956). Understanding the process of natural colonization and plant succession in disturbed sites is a prerequisite for expedient eco-restoration and biodiversity conservation [37, 39,40]. Studying the vegetation and soil characteristics of abandoned mine spoil may help analyze the factors responsible for the distribution and establishment of vegetation in such derelict ecosystems. Keeping in mind the importance of such a study, this study was carried out in the Maldevta area of the Mussoorie forest division of the Garhwal Himalayas. Limestone quarrying in the absence of rehabilitation plans in Mussoorie hills was held by many as a landmark ruling [51].

Traditionally, the assessment of restoration success has heavily focused on vegetation recovery, providing insights into ecosystem productivity, habitat stability, and successional pathways [7-10]. Saxena's study emphasizes the pivotal role of soil organic carbon (OC) in determining soil fertility and defining soil quality thresholds [44]. The impact of soil properties on moisture content, pH, and electrical conductivity (EC) is evident, particularly in mined areas with high stone and sand content [11,12]. Bulk density variations, nitrogen concentration, and nutrient availability are critical factors influencing vegetation growth and overall ecosystem health [13,14]. Discriminant analysis, as employed by [30], becomes a valuable tool for assessing soil suitability for afforestation based on key discriminators such as available N, organic matter, and total K. Diverse Forest ecosystems in the Garhwal Himalayas, highlight the considerable impact of disturbances on analytical characters, with dominance and diversity indices varying between sites [35]. Studies in the Doon Valley [23] further assess soil productivity indices, linking them to the mean annual increment of crops. These findings echo the broader understanding that successful restoration involves a comprehensive evaluation of soil-vegetation relationships, underscoring the ecological significance of soil health in rejuvenating degraded landscapes [31, 36]. Long-term studies [15] emphasize the importance of continuous monitoring and analysis in gauging the effectiveness of restoration initiatives, providing valuable insights into the evolution of soil chemical properties over time. In essence, these interconnected studies collectively contribute to a comprehensive understanding of the intricate dynamics between soil and vegetation in the context of ecological restoration.

This paper focuses on the study of the interaction between vegetation restoration and soil recovery in the ecologically fragile Maldevta area of the Garhwal Himalayas and how restoration initiatives improve soil conditions, vegetation structure, and species diversity, providing insightful information to improve the effectiveness of ecological restoration projects.

2. MATERIALS AND METHODS

2.1 Study Area

The study site, situated in Maldevta within the Garhwal Himalayas at coordinates 30.21°N 78.08°E, was selected based on altitudinal variation, encompassing three subsites with elevations of 780m, 750m, and 720m. Positioned 18 km northeast of Dehradun in the Doon Valley, Maldevta spans an elevation range of 750 to 1050 m above sea level. Surrounded by the Ganga to the east and Yamuna to the west, it lies within the longitudinal synclinal valley, with the northern and southern boundaries formed by the Mussoorie and Shivalik ranges, respectively. Known for its mineral wealth, the region holds an estimated 10.64 million tons of minerals, primarily phosphate ore, with a history of open-cast mining impacting around 10 hectares along the western Bindal River.

Maldevta experiences a typical monsoon climate, characterized by severe winters in December-January and hot temperatures in May-June. Temperature ranges from 3.6°C to 35.3°C, and annual rainfall averages 1805.0 mm, peaking at 625.0 mm in August. Monsoons prevail from mid-June to September, followed by dry weather from October to December, with winter rains in January and early February. Physiographically, Maldevta falls within the Mussoorie forest division, featuring a mountainous terrain confined to the Lesser Himalayas. The Raipur range to the north exhibits high peaks, gradually decreasing in elevation as one moves southward. The alignment of the division is from north to south, showcasing rugged landscapes intersected by crisscrossing streams.

2.2 Collection of Soil Sample

For the soil sampling process, various tools like an auger, hoe, core sampler, measuring tape, polythene bags, aluminum tags, and thread were employed. Soil samples from different depths underwent a meticulous analysis, encompassing drying, crushing, sieving, and subsequent testing for multiple physical and chemical parameters. The process included estimating bulk density, coarse fragments, pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, and exchangeable potassium, sodium, and calcium. These analyses collectively provided crucial insights into the soil's fertility, structure, and nutrient composition, essential for understanding the ecosystem dynamics in the study area.

2.3 Soil Analysis

The soil texture of Maldevta varies from sandy loam to loamy sand. Soils are neutral in reaction. The soil color varies according to profile, but generally, the color was observed to be dark brown to olive brown. The soil texture of the mind site after reclamation is recorded as loamy sand. The composition of sand, silt, and clay was reported in the order of 72.40%, 16.96%, and 9.89, respectively. Similarly, the chemical properties of mine spoil show that it is slightly alkaline with a pH value of 7.8. Physicochemical characteristics of mine spoil:

Table 1. Soil sample analysis

Parameters	Mine Spoil
Sand (%)	72.4
Silt (%)	16.96
Clay (%)	9.89
Textural Class	Loamy sand
pH	7.80
EC ohms/cm	0.21
N (%)	0.042
P (%)	0.33
K (%)	5.10

(Source: Negi. M. 1998)

2.4 Methods of Vegetation Study

For the vegetation study, various materials such as quadrat ropes, poles, tree calipers, digital calipers, and plastic bags for soil sample collection were utilized. The quadrat method, with sizes of 1 * 1 m for herbs and 5 * 5 m for woody vegetation, was employed at three different altitudes for quantitative analysis of abundance, basal cover, frequency, and density. The importance value index (IVI) was calculated, and species diversity was assessed using the Shannon-Weiner Diversity Index. Soil samples, collected at two depths (0-15 cm and 15-30 cm), underwent drying, crushing, and sieving. Physicochemical properties of the soil were analyzed, including moisture content, bulk density, pH, electrical conductivity, soil organic carbon, available nitrogen, available phosphorus, exchangeable potassium, sodium, and calcium. The estimation of bulk density and coarse fragments percentage, as well as the determination of pH, electrical conductivity, organic carbon, nitrogen, and cation concentrations, contributed to a comprehensive understanding of the soil's characteristics. Organic matter was estimated by the Walkley and black method (Jackson, 1973), total nitrogen was estimated by the Kjeldahl method (Wilde *et al*., 1985), available phosphorous was determined by (Olsen *et al*., 1954) using a spectrophotometer and extractable K, Na and Ca were estimated by using Flame photometer according to Misra [16]. The moisture content of the soil is a percentage of the dry soil weight (Huque and Alam, 2005). Bulk density is a measure of the weight of the soil per unit volume (gm/cc) method (Huque and Alam, 2005) [17].

2.5 Vegetation Analysis

Although Sal (*Shorearobusta*) forests are generally the climax type of forest in different localities of the Doon Valley, the types of forest vary greatly, ranging from temperate moist forests to tropical dry-deciduous under Northern tropical dry mixed deciduous types (Champion and Seth, 1968). At Maldevta, before being mined, the area was represented by tropical dry mixed deciduous forest types (5b/C_2). In the natural forest areas of the Maldevta site, the forest still occurs with the predominating species of silver fir (*Grevillea robusta*), Eucalyptus, Amaltas (*Cassia fistula*), Klair (*Acacia catechu*), silk cotton (*Bombaxceiba*), Toon (*Toonaciliare*), and Haldu (*Adina cordifolia*). Other species found scattered with these are Eugenia dalbergioides Basinga (*Adhatodavasica*), Gandhala (*Murrayakoenigii*), Ziziphus. Opuntia, Agave, Boerhaavia, Karonda (*Carissa congesta*), Lantana, and Parthenium. The undergrowth consists of Dhaula (*Woodfordiafruticosa*), Rumex, Doodhi (*Euphobiahirta*), *Eupatorium*, and *Pogostemon*. The main grasses are *Cynodon* and *Eriophorum comosum*. The forest is open and heavily grazed.

3. RESULTS AND DISCUSSION

3.1 Soil Analysis

Mostly, soils are noncalcareous; however, certain soils developed on limestone had calcareous leaching. Fauna was almost absent in the soil mass. The faunal community structure of reclaimed sites bears little resemblance to those of pre-disturbance or nearby undisturbed faunas [41]. The soil was stony with efflorescence, moderate erosion, no deposition, moist subsoil, light plant litter, and high organic matter. The soil color is generally dark olive brown, which is directly related to the organic matter content. The dark brown color indicates the accumulation of humus on the surface layer. The effect of different land uses subjected to various levels of erosion depending on slope and management practices, fire, grazing, felling, etc., could not be ruled out [47]. Two different soil samples were collected at two different depths from the same site. These samples were analyzed separately, and the average of the two soil samples was taken for each parameter at, a particular depth. The soil profile showed a pH range of 7.3-8.1. The basic pH of the soil is due to the limestone and sandstone deposits in the area. Coarse fragments in the soil ranged from 52-75%. The moisture content in the soil ranged from 1-7%. The average bulk density of the soils ranged from 1-1.3gm/cm^3. The organic carbon content was generally high. The contents of exchangeable Ca, Na, and K are greater at the surface and decrease with depth. Similarly, the content of phosphorous and nitrogen decreases with depth. The evidence of decreasing moisture content with the increase in soil depth was also revealed by Haque (1997); Chowdhury et al., (2007); Shaifullah et al., (2008). Jonston and Alongi (1995) also analyzed that the soil moisture content was higher due to the presence of vegetation [17].

3.2 Physical Properties of Soil

Fig. 1 presents soil profile data for three different sites, including moisture content, bulk density, and the percentage of coarse fragments at two depth intervals (0-15 cm and 15-30 cm). At Site 1, the moisture content ranges from 2.80% to 2.25%, with corresponding bulk densities of

1.171 gm/cm^3 and 1.204 gm/cm^3 at the respective depths. The percentage of coarse

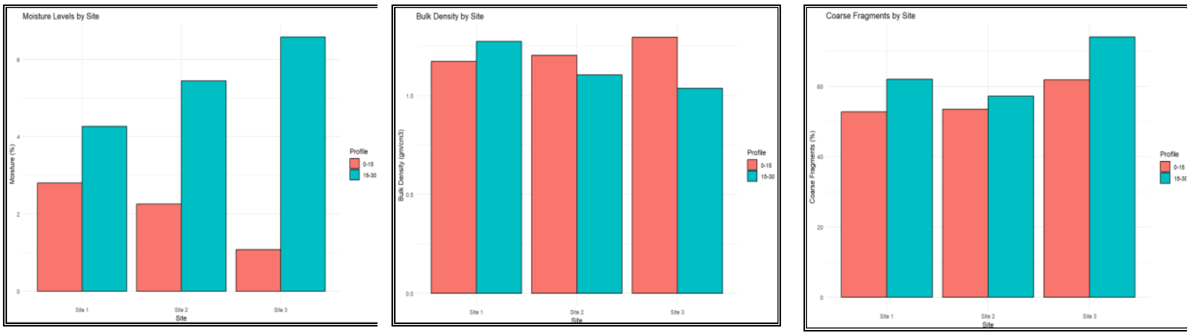


Fig. 1. Physical Properties of soil i.e. Moisture Content (a), and Bulk Density (b), Coarse Fragments (c), by all 3 sites at depth (0-15) and (15-30) cm

fragments is 52.695% at 0-15 cm and slightly higher at 53.49% at 15-30 cm. Site 2 displays the lowest moisture content, ranging from 1.08% to 4.26%, with bulk densities of 1.295 gm/cm^3 and 1.273 gm/cm^3 at 0-15 cm and 15-30 cm. Coarse fragments constitute 61.815% and 62.03% at these depths. Site 3 exhibits the highest moisture content, ranging from 5.44% to 6.58%, with bulk densities of 1.104 gm/cm^3 and 1.036 gm/cm^3 at 0-15 cm and 15-30 cm, respectively. The percentage of coarse fragments is notably higher at 57.125% and 74.055% at the corresponding depths. The variations in these soil characteristics across the sites and depths provide insights into the diverse soil profiles and conditions at the specified locations.

3.3 Chemical Properties of Soil

The essential soil profile information for three different sites, focusing on pH, organic carbon content, exchangeable cations (K^+, Ca^{2+}, Na^+), available phosphorous (P), and total nitrogen (N) at two depth intervals (0-15 cm and 15-30 cm) shown in Fig. 3. At Site 1, the pH ranges from 7.3 to 7.6, indicating a slightly basic soil environment. Organic carbon content varies from 2.92% to 4.71%, with higher values in the deeper layer. Exchangeable cations show concentrations of K+ (0.11% to 0.135%), Ca2+ (0.205% to 0.255%), and Na+ (0.525% to 0.91%). Available P ranges from 0.359% to 0.525%, and total N ranges from 0.048% to 0.069%. Site 2 exhibits pH levels of 7.7 to 7.8, organic carbon content from 3.52% to 4.7%, and exchangeable cations with concentrations similar to Site 1. Available P varies from 0.328% to 0.78%, and total N ranges from 0.032% to 0.072%. Site 3 displays higher pH values (7.8 to 8.1) and elevated organic carbon content (6.26% to 9.86%), with exchangeable cations, available P, and total N concentrations showing similar trends to the other sites. These findings offer insights into the soil characteristics, helping understand the nutrient status and acidity levels at different depths across the specified site.

3.4 Correlation between Physical and Chemical Properties of Soil

The correlation matrix provided offers insights into the relationships between various physicochemical properties of soil in Fig 3. Moisture content exhibits a positive correlation with bulk density (r = 1), suggesting that as moisture increases, bulk density tends to rise consistently. This relationship is intuitive, as higher moisture levels typically lead to more compacted soils. Bulk density also shows a negative correlation with coarse fragments (r = -0.63), indicating that as bulk density increases, the presence of coarse fragments decreases.

This implies that denser soils are less likely to contain large, coarse particles [33]. The pH level of the soil exhibits a negative correlation with most other properties, such as organic carbon (r = -0.90), potassium (K, r = -0.48), calcium (Ca, r = -0.71), sodium (Na, r = -0.08), and available phosphorus (r = -0.04). This suggests that more acidic soils (lower pH) tend to have higher levels of these properties. Organic carbon content is positively correlated with pH (r = 0.89), indicating that as the pH of the soil increases, organic carbon content also tends to rise. This association is consistent with the fact that organic matter decomposition contributes to soil acidity. Potassium (K) is negatively correlated with bulk density (r = -0.19), suggesting that denser soils tend to have lower potassium levels. Calcium (Ca) exhibits a positive correlation with bulk density (r = 0.60), implying that denser soils are more likely to have higher calcium content. The relationship between sodium (Na) and bulk density is negative (r = -0.21), indicating that as bulk density increases, sodium levels tend to decrease. Available phosphorus is positively correlated with calcium (r = 0.31) and negatively correlated with total nitrogen (r = -0.05).

3.5 Vegetation Morphology

Fig. 4 to 6 shows frequency distribution, variations among the morphological characteristics, and IVI of all the species at all sites. Similarly, the plant species diversity, similarity, and Importance Value Index (IVI) were compared with mine spoils and natural forest sites [48]. In the first site, *Eupatorium adenophorum* has maximum abundance [42], whereas *Bombax ceiba* has maximum IVI. Shannon Weiner Index Of first site H'=2.26. In the second site *Bidens pilosa* has maximum abundance while *Mallotus philippensis* has maximum IVI. Shannon Weiner Index of second site H'=1.545. In the third site *Lantana camara* has maximum abundance while *Bombax ceiba* has maximum IVI. Shannon Weiner Index Of third site H'=2.2.

Frequency distribution, Variations among the Density, Hypothesized mean difference, Average Basal Area and Importance Value Index (IVI) of all the species at Site 1.

Each species exhibits a uniform frequency of 33.3%, indicating a consistent presence across the sampled plots. The density values vary, with *Eupatorium adenophorum, Murraya Koenigii, Lantana camara, Bidens pilosa, and Ageratum conyzoides* displaying higher densities, suggesting a more concentrated distribution. Abundance, representing the total number of individuals, ranges from 1 to 5, with *Eupatorium adenophorum* and *Ageratum conyzoides* being the most abundant. The average basal area provides insights into the plant size, with Bombax ceiba standing out with a substantial basal area of 813.91 cm². *Mallotus philippensis*, *Callicarpa macrophylla, Artemisisa absinthium, Pseudobombax ellipticum, and Bomarea Multiflora* also contribute to the vegetation structure, albeit with smaller basal areas. In summary, the table offers a comprehensive overview of the distribution, density, abundance, and size characteristics of diverse plant species within the study area.

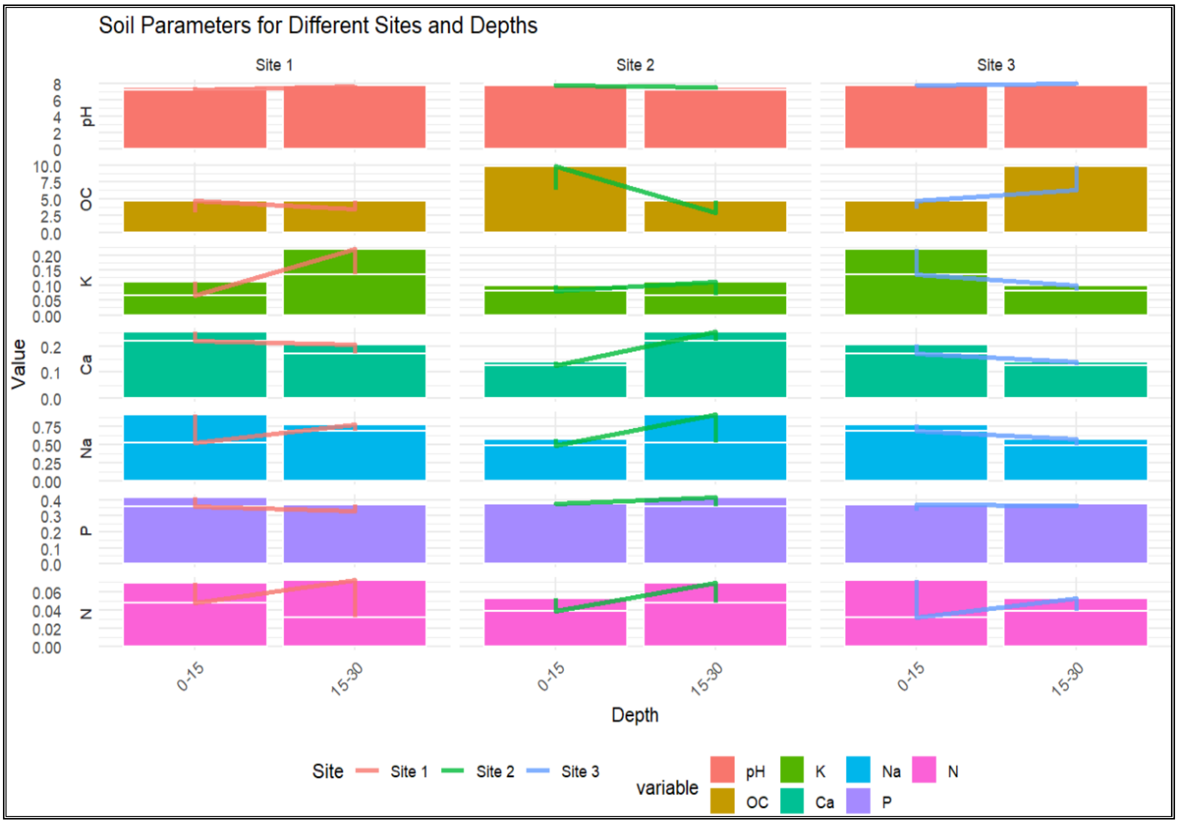


Fig. 2. Chemical Properties of soil *viz*, Site 1, Site 2, Site 3 at depth (0-15) and (15-30) cm

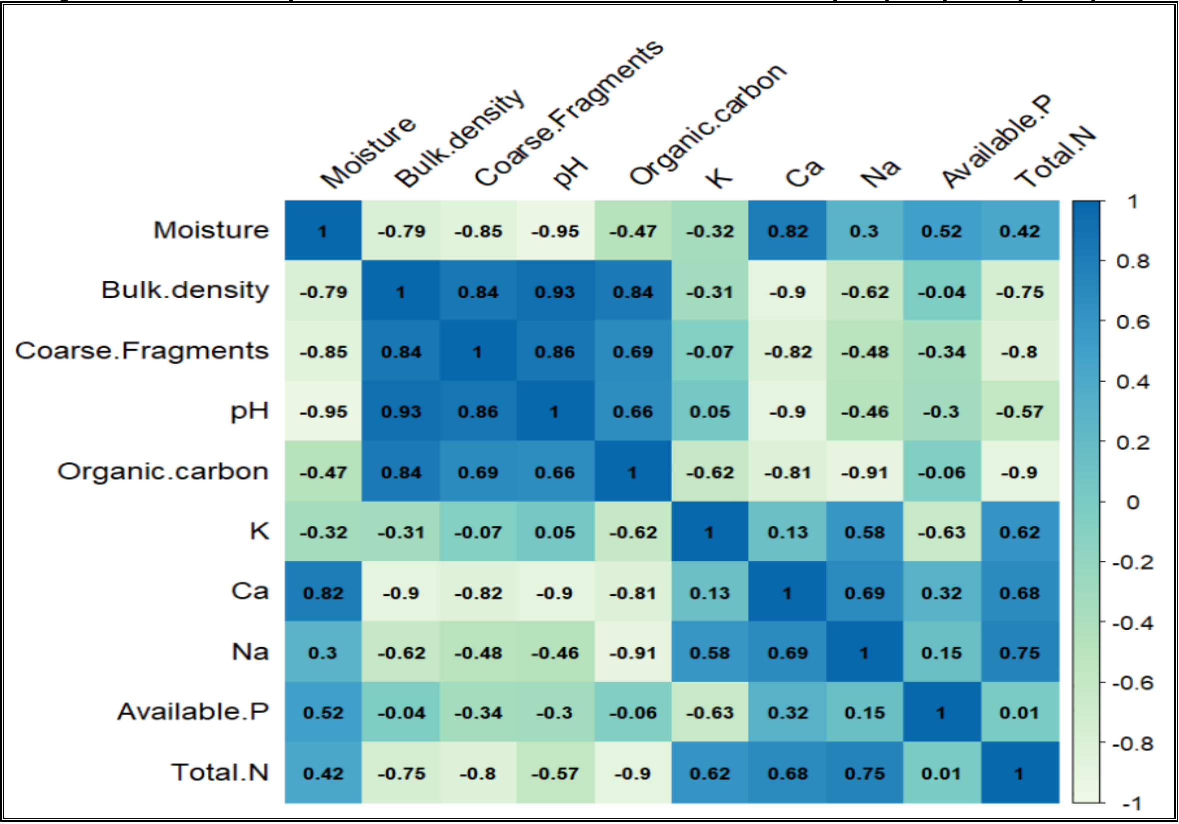
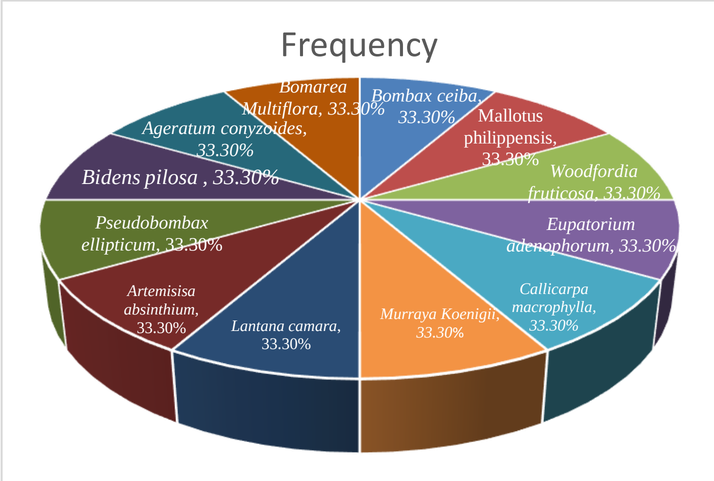


Fig. 3. Pearson's Correlation between physical and chemical properties of soil

Shannon Weiner Index of first site H'=2.26 Relative Frequency (R. Frequency), Relative Density (R. Density), Relative Dominance (R. Dominance), and Importance Value Index (IVI) for various plant species in the study area. *Bombax ceiba* stands out with the highest IVI of 108.09, driven by its high R. Dominance of 96.06%, indicating a dominant presence and substantial coverage. *Mallotus philippensis* follows with an IVI of 14.63, primarily due to its moderate R. Density of 3.7%, while *Eupatorium adenophorum* exhibits the highest R. Density at 18.5%, contributing to an IVI of 26.85. *Lantana camara, Bidens pilosa, and Ageratum conyzoides* also display notable IVI values (23.35, 19.43, and 23.13, respectively), suggesting their significance in the plant community. *Artemisisa absinthium, Pseudobombax ellipticum, and Bomarea Multiflora* exhibit lower IVI values, indicating a comparatively lesser impact on the overall vegetation structure. In summary, the IVI values provide a comprehensive assessment of the ecological importance and distribution patterns of each species, elucidating their respective roles in the studied plant community [34].

The Frequency distribution, Variations among the Density, Hypothesized mean difference, Average Basal Area and Importance Value Index (IVI) of all the species at Site 2 are shown in Fig. 5.

Moringa concanensis exhibits a frequency of 33.3%, a density of 0.66, and an abundance of 2, with an average basal area of 1133.54. *Mallotus philippensis*, with a frequency of 33.3%, a density of 0.33, and an abundance of 1, displays a substantial average basal area of 1297.78. *Lantana camara* and *Murraya Koenigii* both share a frequency and abundance of 66.6%, with densities of 2.33 and 2.33, respectively. *Lantana camara* has an average basal area of 1.87, while *Murraya Koenigii* has an average basal area of 0.78. *Bidens pilosa* stands out with a frequency of 33.3%, a high density of 6.66, an abundance of 20, and a minimal average basal area of 0.03. Other species, including *Bomarea Multiflora, Malvastrum coromandelianum, and Pseudobombax ellipticum*, also contribute to the botanical diversity with varying frequency, density, abundance, and average basal areas. This information provides insights into the ecological dynamics and distribution of plant species in the studied area [38,49].



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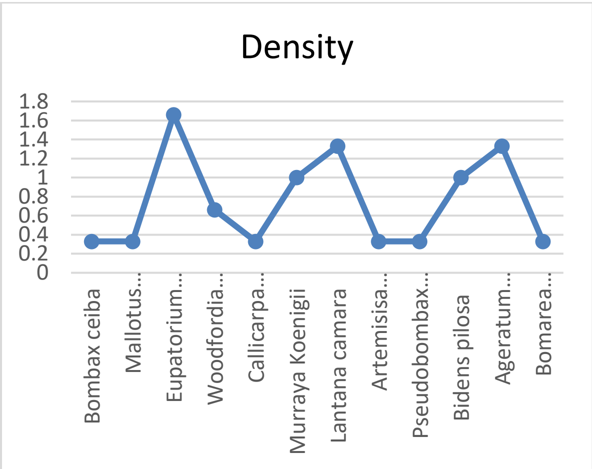

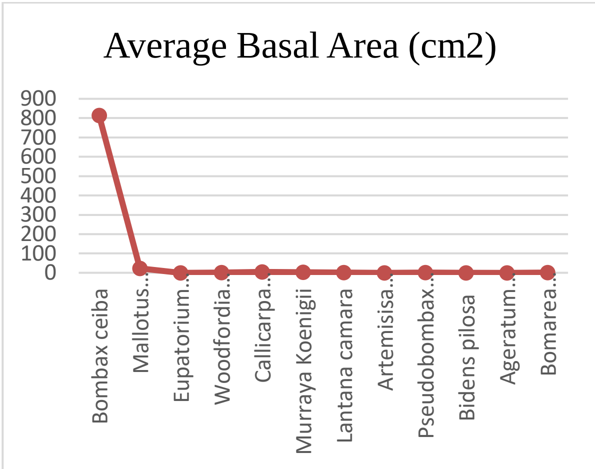

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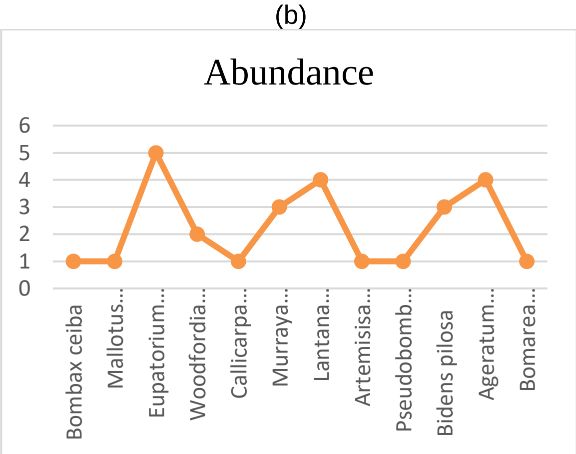
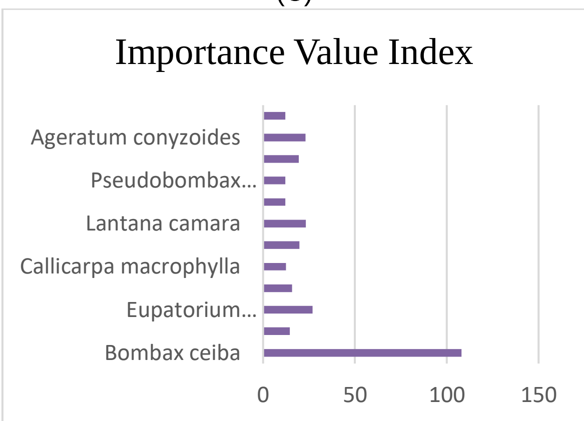
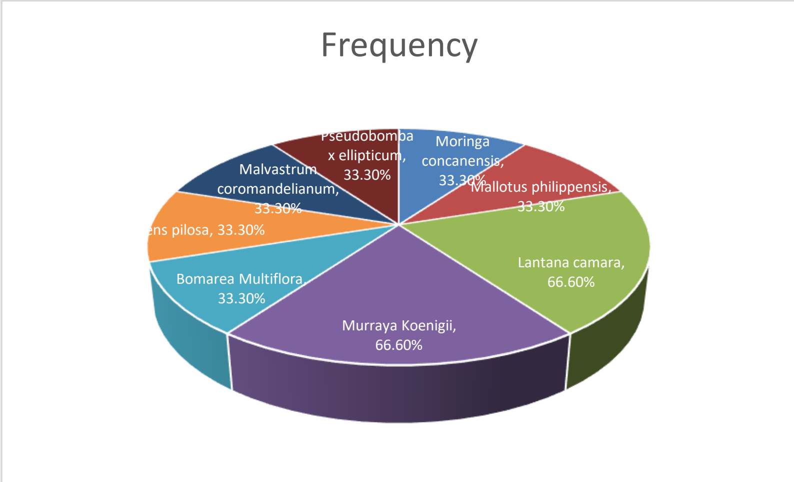




(d)

(e)

Fig. 4. Frequency distribution (a), Density (b), hypothesized mean difference (c), Average Basal Area (d), and IVI (e) of all the species at Site 1



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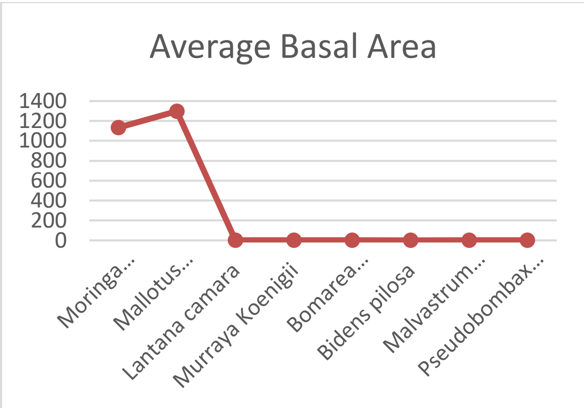

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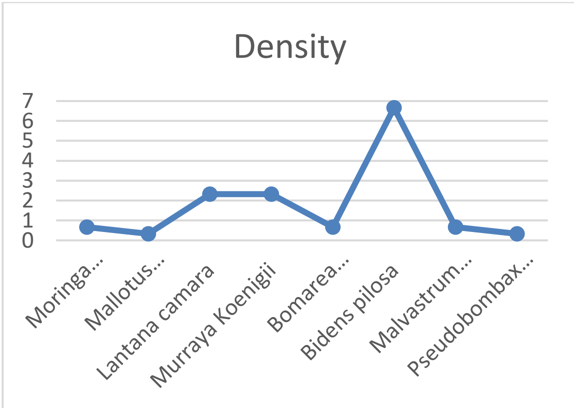

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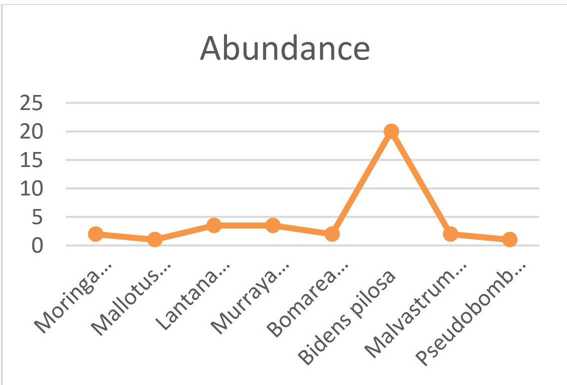

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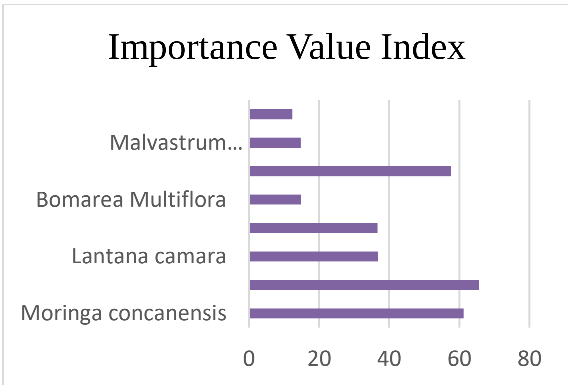
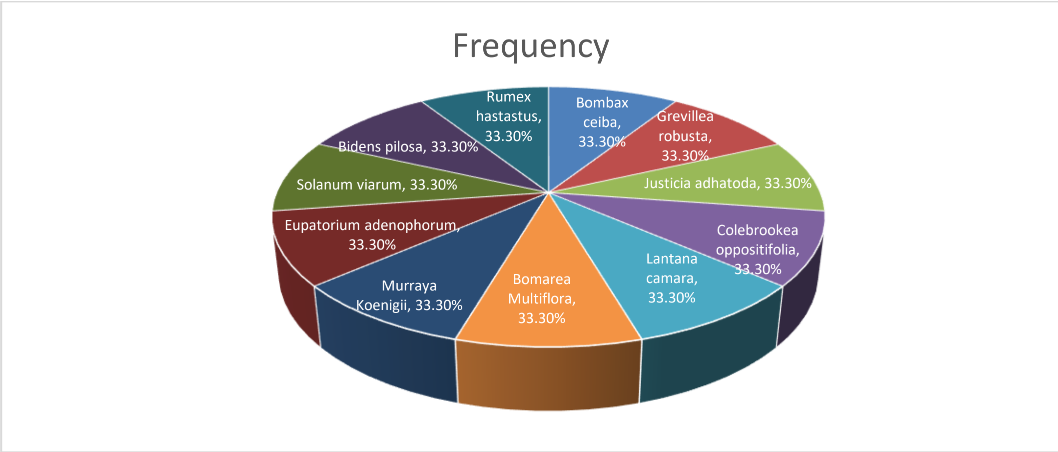


(e)

Fig. 5. Frequency distribution (a), Density (b), Hypothesized mean difference (c), Average Basal Area (d), and IVI (e) of all the species at Site 2



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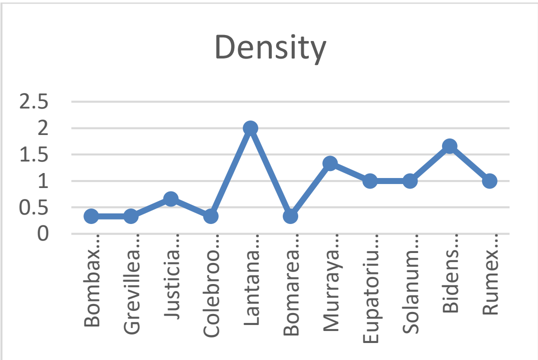

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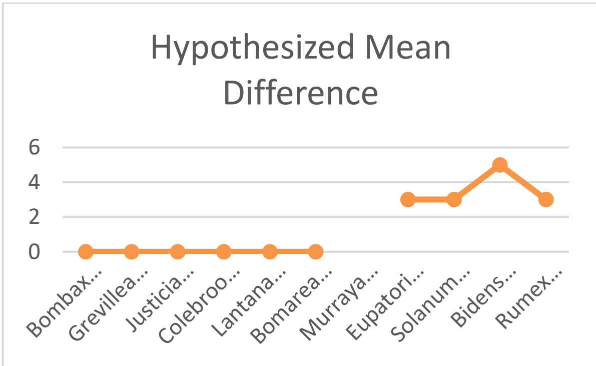

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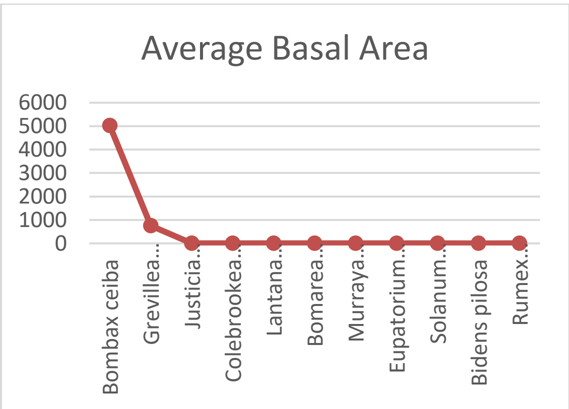

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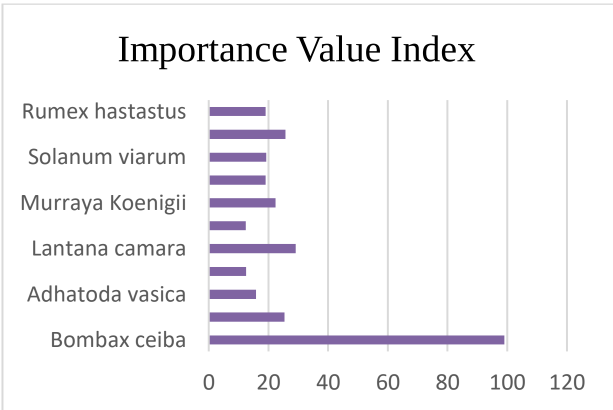

(e)

Fig. 6. Frequency distribution (a), Density (b), Hypothesized mean difference (c), Average Basal Area (d), and IVI (e) of all the species at Site 3

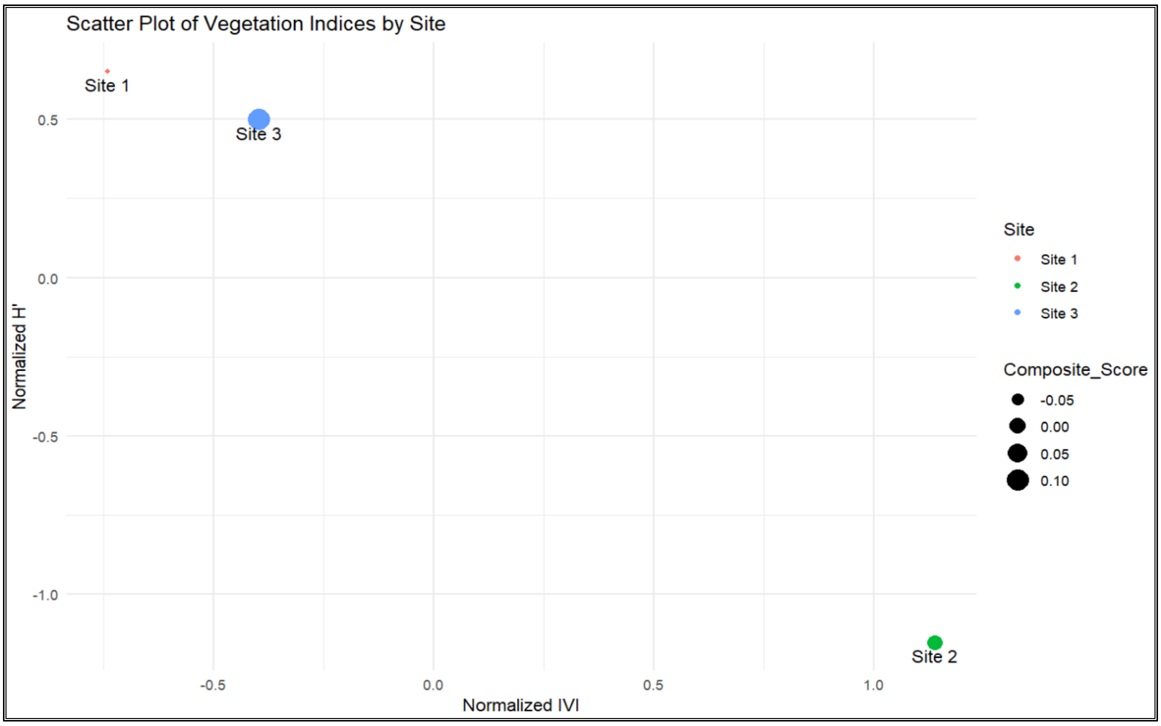

Fig 7. Representing the site (Site 3) that stands out to have better vegetation comparatively based on their Shannon Weiner Index (H') and Importance Value Index(IVI)

Shannon Weiner Index of second site H'=1.545

Moringa concanensis and *Mallotus philippensis* each contribute 10% to the relative frequency, with R. Density values of 4.76% and 2.38%, respectively. *Mallotus philippensis* stands out with a relatively high R. Dominance of 53.23%, resulting in an IVI of 65.61. *Lantana camara and Murraya Koenigii* share a relative frequency of 20%, with R. Density values of 16.66%. However, their R. Dominance values are minimal (0.07% and 0.03%, respectively), resulting in comparable IVI scores of 36.73 and 36.69. *Bomarea Multiflora*, with a 10% relative frequency, has an R. Density of 4.76% and a relatively low R. Dominance of 0.10%, yielding an IVI of 14.86. *Bidens pilosa,* with a 10% relative frequency, demonstrates a notably high R. Density of 47.60%, resulting in the highest IVI of 57.60. *Malvastrum coromandelianum* and *Pseudobombax ellipticum* also contribute to the plant community, each with a 10% relative frequency and comparable IVI scores of 14.77 and 12.41, respectively. This information provides a comprehensive assessment of the ecological significance and distribution of these plant species in the specified area.

The Frequency distribution, Variations among the Density, Hypothesized mean difference, Average Basal Area and Importance Value Index (IVI) of all the species at Site 3 are shown in Fig 6.

Bombax ceiba, Grevillea robusta, Justicia adhatoda, Colebrookea oppositifolia, Lantana camara, Bomarea Multiflora, Murraya Koenigii, Eupatorium adenohorum, Solanum viarum, Bidens pilosa, and Rumex hastastus each contribute 33.3% to the relative frequency. *Bombax ceiba* has a low Density of 0.33 and an Abundance of 1, but it stands out with a remarkably high Average Basal Area of 5024.00. *Grevillea robusta, Justicia adhatoda, and Colebrookea oppositifolia* each have a Density of 0.33, 0.66, and 0.33, respectively, with corresponding Abundance values of 1, 2, and 1. *Lantana camara* displays a higher Density of 2.00, contributing to an Abundance of 6, while maintaining an Average Basal Area of 1.87. *Bomarea Multiflora, Murraya Koenigii*, Eupatorium *adenophorum, Solanum viarum, Bidens pilosa*, and *Rumex hastastus* exhibit varying patterns in Density, Abundance, and Average Basal Area. *Solanum viarum* stands out with a significant Average Basal Area of 9.83. This information provides insights into the distribution and ecological importance of these plant species in the specified area.

Shannon Weiner Index of third site H’=2.2

Bombax ceiba exhibits a Relative Frequency of 9.09%, a Relative Density of 3.33%, and a substantial Relative Dominance of 86.62%, contributing to a high IVI of 99.04. *Grevillea robusta*, with a Relative Frequency of 9.09%, a Relative Density of 3.33%, and a Relative Dominance of 13.00%, has a lower IVI of 25.42. Other species, such as *Adhatoda vasica, Colebrookea oppositifolia, Lantana camara, Bomarea Multiflora, Murraya Koenigii, Eupatorium adenophorum, Solanum viarum, Bidens pilosa, and Rumex hastastus*, exhibit varying patterns in their ecological indices, contributing to the overall ecological dynamics of the studied ecosystem. The IVI values provide a comprehensive assessment of the ecological significance of each species, considering their relative frequency, density, and dominance in the specified area.

4. CONCLUSION AND DISCUSSION

The restoration project has improved the species diversity, vegetation structure, ecosystem processes, and overall soil condition. Revegetation was a multifactorial process dependent on the interaction of individual species ranges, dispersal efficiency, and edaphic/ climatic responses [25]. The relationship between soil and vegetation is crucial for natural woodland ecosystems. The established vegetation has modified the soil development processes [15]. The mutual relationship between vegetation and soil in the Maldevta area is governed by climate and other aspects [27]. The planting, growth, and colonization of woody plants enhanced above-ground ecological processes in the restored sites. The typical values of the Shannon-Weiner index are generally between 1.5-3.5 (Magurran *et al*, 2004). This area showed a Shannon-Weiner index well within the range [45]. The optimal range of pH varies among plants, but plants but most tree species will grow over a broad range of pH values [21]. The optimum range of nitrogen and phosphorous in forest soil ranges from 5-10 ppm and 30-50 ppm, respectively (Muller, 1977). The values of these nutrients were well within the range. Based on his study, [44] found that soil organic carbon is one of the vital parameters essential for determining soil productivity and fertility. He classified soil as of good quality when OC is greater than 0.8% and low-quality soil had OC less than 0.4%. Therefore, this soil can be considered good quality soil.

The thorough examination of the soil and the evaluation of the vegetation morphology offered insightful information about the biological dynamics of three different sites in the Maldevta region. The results of the soil study showed that the noncalcareous soils had a rocky texture, moderate erosion, high organic matter, and some calcareous leaching on limestone. A similar observation is given by [18], states that the waste product or overburden generated during mining contains major portions of shale, chert, and limestone. Humus buildup was suggested by the rich olive-brown color. The presence of sandstone and limestone deposits affected the pH, which varied from 7.3 to 8.1. Diverse soil profiles were highlighted by site variations in bulk density (1.1–1.3 gm/cm^3), moisture content (1-6%), and coarse fragments (52–75%). The evidence of decreasing moisture content with the increase in soil depth was also revealed by (17). (Johnston and Alongi, 1995) also analyzed that the soil moisture content was higher due to the presence of vegetation. Chemical characteristics varied between sites and depths in terms of pH, organic carbon, exchangeable cations, accessible phosphorus, and total nitrogen. The restored mine area has a slightly alkaline pH which is favorable for the release of nutrients (nitrogen, phosphorous, potassium) and enhancement of microbial occurrence [15] and this may be one of the reasons for higher available phosphorous in the restored mine area. With a greater moisture content, a lower bulk density, and noticeable coarse fragment percentages, Site 3 stood out in terms of physical characteristics, suggesting ideal growing conditions for flora. These variations were graphically shown, highlighting the importance of Site 3 in the physical characteristics of the soil that supports plants. Site 3 also showed noteworthy chemical features, including increased quantities of nutrients, organic carbon, and pH. These differences were illustrated graphically, which made it easier to determine that Site 3 had better chemical characteristics. Distributions of species, densities, basal areas, and significance values (IVI) were found among sites through an examination of vegetation morphology. With species including *Bombax ceiba, Lantana camara*, and *Bidens pilosa*, in particular, Site 3 had diversified and plentiful vegetation, which raised the Shannon Weiner Index (H'=2.2) and IVI. Yadav, R., [18] compared the microbial biomass and organic carbon of soil in restored and natural forest land, on some of the similar species and in the same area. The standing biomass of stem and root increased during development in all species [32]. The correlation matrix between physical and chemical properties provided insights into inter-relationships, enhancing our understanding of soil-vegetation dynamics. The statistical tests indicate significant differences in the pre-and post- mining land uses of the areas mined under the different statutory laws and amendments [28, 29].

Finally, with its rich vegetative morphology and exceptional physicochemical characteristics, Site 3 is the most ecologically relevant. Its rich soils, varied vegetation, and greater Shannon Weiner Index and IVI all point to improved resilience and health of the ecosystem. The Maldevta area's ecosystem has improved overall as a result of the restoration efforts, which have had a favorable effect on the quality of the soil and supported a variety of flourishing plants. Maldevta's restoration initiative has improved soil conditions, vegetation structure, and species variety. Good soil quality is indicated by the pH, nitrogen, phosphorus, and organic carbon values. The total nitrogen content in the soil around different restored plantations is comparable to the results of 0.78% total nitrogen in 12 years old naturally vegetated overburden [15]. The effectiveness of the restoration efforts demonstrates the interdependent interaction between soil and vegetation, which is essential for natural woodland ecosystems. The plant species varied in their ability to modify the soil properties of mine spoil [15]. It has commonly been accepted that the composition of vegetation is determined by its habitat- “vegetation is the best measure of environment” [26].

The enhanced species diversity, overall soil condition, and vegetation structure are clear results of the restoration initiative. The connection between soil and vegetation is emphasized, highlighting how important aspects and climate are in determining biological cycles. Ecological restoration involves living materials and reconstruction on a scale that far surpasses that of the repair of individual human beings [24]. Good soil quality is shown by the fact that all of the soil's parameters—pH, nitrogen, phosphorus, and organic carbon—fall within ideal ranges. A comprehensive picture of the ecology in Maldevta is provided by the integrated analysis of the vegetation and soil. The information obtained is crucial for sustainable land management practices, guiding further conservation efforts and supporting the continued success of the restoration project in promoting biodiversity and enhancing ecosystem health.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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