ASSESSMENT OF THE RECLAIMED MINED AREA OF SAHASTRADHARA,DEHRADUNBY SOIL AND VEGETATION ANALYSIS

Abstract

This study investigates the impact of forest area mining on reclaimed limestone mined areas in Sahastradhara, Uttarakhand, India. Initiated in 1989-90, eco-restoration efforts aimed at rehabilitating the mined areas resulted in restoration ages of 25, 24, and 23 years across different sites. The study comprehensively examined vegetation and soil physicochemical properties at various depths, revealing the dominance of species like Murrayakoenigii, Acacia catechu, Vitex negundo, Eupatorium adenophorum, Grevillea robusta, and Lantana camara. Soil analyses unveiled variations in moisture content, bulk density, and coarse fragment percentage across the sites, a rise in organic carbon, phosphorous, and nitrogen levels, showcasing soil improvement post-restoration. Correlation analyses unveiled interrelationships between soil properties, emphasizing the importance of organic matter in influencing soil acidity. Vegetation analyses at different sites revealed evolving plant communities, with prominent species contributing to the ecological richness. The Importance Value Index (IVI) and Shannon Weiner Index (H') provided insights into species dominance and biodiversity. The results showed that the soil pH was slightly basic, and the available phosphorus and nitrogen levels were within the optimal range for plant growth. However, the bulk density and electrical conductivity values were higher than the recommended range.This study contributes valuable insights into the intricate interplay between mining activities, vegetation dynamics, and soil health, guiding future ecological restoration endeavors in similar contexts. The study concluded that the eco-restoration work carried out in the area has been successful in restoring the vegetation, but further assessment is required to ensure the long-term success of the restoration efforts.

Keywords:Doon valley, Mined area, Sahastradhara, Soil analysis, Vegetation analysis

INTRODUCTION

The recent surge in forest area mining has underscored the critical need for effective restoration initiatives. Restoring mine spoils is a protracted process, demanding continuous assessment during and after ecosystem restoration. A study in Sahastradhara, Dehradun, Uttarakhand, examined vegetation and soil physicochemical properties at different depths (0-30 and 30-60 cm) in reclaimed limestone mined areas. Prominent species included *Murrayakoenigii*, *Acacia catechu*, *Vitexnegundo*, *Eupatorium adenophorum*, *Grevillea robusta*, and *Lantana camara*, while various soil properties were tested within specific ranges. Mining, an intensive land-use practice, extracts minerals from the Earth's crust to supply raw materials for industries, leaving lasting environmental impacts. In India, nearly 1 million hectares face mining-related stress, disrupting ecosystems and causing environmental harm. The Doon Valley in Uttarakhand faced severe threats due to extensive limestone quarrying, resulting in the depletion of forest vegetation, landscape degradation, and habitat loss. Increasing tourism further exacerbated the decline in floristic diversity.

The Sahastradhara mined area, situated along the Baldi River banks, underwent limestone extraction for 30 years through surface mining. Eco-restoration efforts commenced in 1989-90, and 1990-91, resulting in restoration ages of 25, 24, and 23 years, respectively. Mining disturbances alter organism-habitat relationships, leading to soil property destruction, disruption of surface water resources, and accelerated soil erosion. Harsh conditions in mine spoils, with low organic matter, unfavorable pH, and soil compaction, limit plant and microbial growth. Furthermore, the majority of contemporary mining methods require a lot of water for waste disposal, extraction, and processing. Wastewater from these operations has the potential to contaminate neighboring water sources and reduce the availability of fresh water in the area around the mine [1].Restoring mined areas involves ecosystem reconstruction and soil reclamation to capture and retain fundamental resources. However, uncertainties in assessment, monitoring, and management complicate restoration planning. Ecological restoration can involve managing various physical, chemical, and biological disturbances of the soil, such as soil pH, fertility, microbial community, and different soil nutrient cycles. This turns the degraded land into a productive ecosystem, which in turn provides the dependent population with tangible resources (fuel, fodder, timber, medicine), as well as intangibles (cleaning the air and water, detoxifying and breaking down wastes, regulating the climate)[2].This study emphasizes the critical need for effective reclamation strategies to mitigate the environmental impact of limestone extraction and other mining activities in India, which have led to deforestation, biodiversity loss, water quality deterioration, and soil erosion. Understanding plant community composition is crucial for successful reclamation, as vegetation plays a key role in carbon build-up. The extensive mining footprint in India requires diverse efforts for ecological restoration across various mineral types, highlighting the importance of comprehensive and sustainable approaches.

MATERIALAND METHODS

Study Area

In the restored limestone mine area of Sahastradhara, Doon Valley, Uttarakhand, samples were collected from three sites at different altitudes—875 m, 850 m, and 825 m. Sahastradhara, situated 18 km from Dehradun on the Baldi River, has an average elevation of 900 meters, with a valley-like topography surrounded by hills on three sides. After being quarried for limestone, the slopes were restored 29 years ago by the Forest Research Institute, Dehradun, through surface mining cessation. Sahastradhara experiences distinct seasons, with moderate summers and heavy monsoon rains contributing 80% of the average annual rainfall of 3000 mm. The soil texture varies, supporting diverse floral and faunal biodiversity despite anthropogenic pressures and forest degradation. Presently, Sahastradhara serves as a popular tourist destination, featuring natural springs, amusement parks, and eateries, attracting visitors while grappling with increased pollution levels and ongoing construction activities. The region's subtropical climate fosters lush mixed deciduous vegetation, highlighting the ecosystem's resilience amidst developmental challenges.

Vegetation analysisand soil properties

For this present study, the soil samples were collected with the help of a hoe and core sampler, from predetermined depths i.e., 0 to 15 cm and 15 to 30 cm.

Collection of vegetation data

Vegetation data collection involved a systematic process at three representative sites within the study area. Initially, a site representative of the field was chosen, and the necessary sampling equipment was brought to the location. A quadrat rope, marked at diagonal lengths of 10x10 m, 3x3 m, and 1x1 m, was placed on the site, with quadrats demarcated using poles. Woody species, encompassing trees and shrubs, were recorded within the 10x10 m and 3x3 m quadrats, with their diameters measured using a tree caliper. Additionally, herbs, seedlings, and grasses within the 1x1 m quadrat were recorded, and their diameters were measured using a digital caliper. This process was repeated at two other sites at different altitudes in the area.

Methods of Analysis

The study was conducted using the quadrat method [3]. Quadrats of 3 sizes, i.e., 10 x 10 m and 3 x 3 m for woody vegetation (shrubs and trees), and 1 x 1 m for herbs, grasses, and seedlings, were laid.Three quadrats were laid randomly at each site. The species, their numbers, and diameters were recorded. Quantitative analysis of vegetation for frequency percentage, density (plant/m^2), abundance, and basal cover (cm^2 or m^2) was calculated following [3]. The Importance Value Index (IVI) was calculated by summing up the values of relative frequency, relative density, and relative dominance. Species Diversity Index (H') was calculated based on IVI, using the Shannon-Weiner Diversity Index [4] (Shannon-Weiner, 1963).

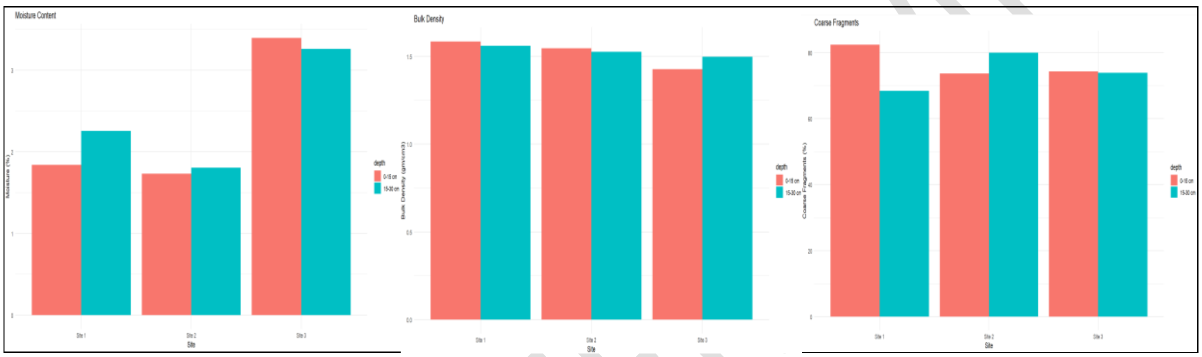
RESULTS AND DISCUSSION

Soil analysis

The range for soil moisture content was calculated to be 1.73 - 3.94% with an average of 2.47%. The soil moisture is considerably low but has been maintained since the restoration was conducted. However, such low values could be due to the dumping of spoils, and overburden during limestone extraction. The average bulk density was 1.52 g/cm^3. Earlier studies have shown the bulk density readings to be within the range of 1.65 - 1.66 gm/cm^3[5]. Bulk density with depth. This trend was observed in the study. Although a bulk density level up to 1.5 gm/cm^3 indicates good soil quality, the soil in this area does harbor numerous plant species. In another study, soil bulk density recorded increases with the increase of soil depth. The bulk density of soils ≤ 1.5 gm/cm3 indicates good soil quality and more than 1.5gm/cm3 leads to adverse impacts [2](Rout, 2018). The coarse fragment percentage was calculated to be 75.436%, which is fairly high and suggests that the area still has adversely affected soil.

Physical properties of soil

The soil profile data from three distinct sites (Site 1, Site 2, and Site 3) reveal variations in key parameters at two depths, 0-15 cm and 15-30 cm. At Site 1, at a depth of 0-15 cm, the soil exhibits a moisture content of 1.84%, a bulk density of 1.5850 gm/cm^3, and a substantial presence of coarse fragments at 82.440%. Progressing to 15-30 cm, the moisture content increases to 2.255%, while the bulk density slightly decreases to 1.5595 gm/cm^3, and the percentage of coarse fragments reduces to 68.395%. At Site 2, the 0-15 cm depth exhibits a moisture content of 1.73%, a bulk density of 1.5450 gm/cm^3, and 73.655% coarse fragments. At 15-30 cm, the moisture content slightly increases to 1.803%, while the bulk density decreases to 1.5260 gm/cm^3, and the percentage of coarse fragments rises to 79.940%. Site 3 demonstrates higher moisture content values, with 3.395% at 0-15 cm and 3.26% at 15-30 cm. Bulk density at these depths is 1.4275 gm/cm^3 and 1.4970 gm/cm^3, respectively, while the percentage of coarse fragments ranges from 74.325% to 73.865% (Fig 1). These variations in soil characteristics underscore the importance of comprehensive soil profiling for understanding and managing soil quality in diverse environments.



(a) (b) (c)

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

Chemical properties of the soil

The soil pH of the study area was in the range of 7.8 - 8.3, with an average of 8.0. The pH of the study is from previous studies and was found to be 7.3. While the pH for optimum plant nutrient availability is 6.5 - 7.5, the slightly alkaline pH still shows good concentrations of nutrients and hence, fairly good growth of plant species. The average soil EC in the upper depth (0-15 cm) was found to be 190 microS and in the lower depth (15-30 cm) was 180 microS which has increased greatly sinceDubey *et al*,[5] estimated it to be 54.90 microS. This indicates that nutrients are being conducted efficiently in the soil, increasing the rate of plant uptake. Also indicates that the soil samples contain an elevated number of soluble salts when it comes in contact with water. The earlier studies showed the OC level to be 1.10%. In this study, it was found to be increasing with an increase in soil depth, with the levels being 3.91% in the upper depth and 5.42% in the lower level. Soil of good quality has OC greater than 0.8% and of poor quality if the level is less than 0.4% [6]. The increased level of organic carbon shows that soil quality is improving in the restored area. The average phosphorous content percentage was found to be 0.112% which is higher than the value of 0.0026% recorded in the earlier study of the area. Different soil nutrient levels at different locations may result from human activity or natural and human-driven processes [7]. This indicates the restoration of the phosphorous levels in the soil since the mining ended in the area.

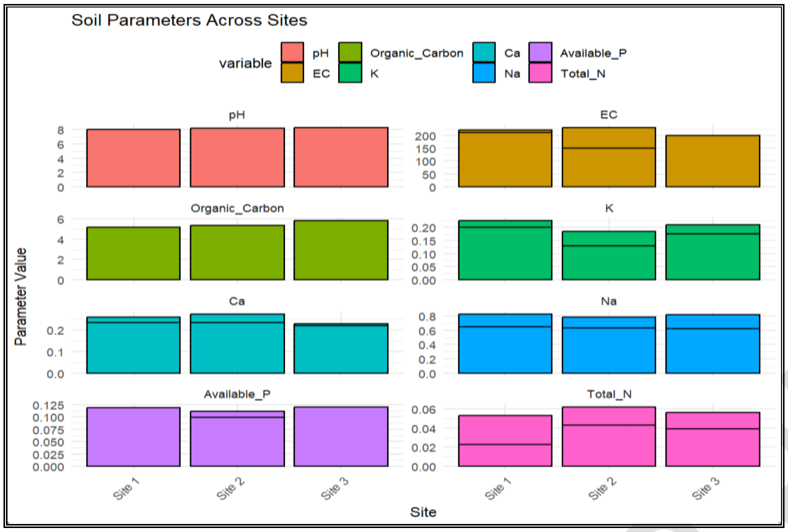


Fig 2: Chemical Properties of soil *viz,* Site 1, Site 2, Site 3 at depth (0-15) and (15-30) cm

The exchangeable cation concentration of exchangeable K^+ decreased with increasing depth of soil. It was 0.207% in the upper depth and 0.168% in the lower depth of soil, an average of 0.188%. Although the previous recorded value was 0.024%, there has been an increase in the concentration of potassium in the soil of the area. The concentration of Na^+ was again found to decrease with increasing soil depth, i.e., it was 0.81% in the upper depth and 0.634% in the lower depth of the soil profile. The concentration of Ca^{2+} also showed the same trend, the percentage content slightly differing in the upper (0.255%) and lower depths (0.23%). The available nitrogen content in the soil samples was estimated to be 0.0572% in the upper depth and 0.0351% in the lower depth with an average of 0.0462%, which is again an increase from the previous recorded readings of 0.027%.

Hence, we can see here that even though the soil bulk density and pH levels were not fully optimum for ideal plant growth, the other properties have shown a significant improvement in the concentrations toward good quality soil and therefore, have contributed to the cause of the thriving species diversity of the restored mined area, which is discussed in the section below.

Correlation between physical and chemical properties of soil

The correlation matrix provides valuable insights into the interrelationships among various soil properties. Firstly, a strong negative correlation (-0.82577) between moisture content and bulk density indicates that as soil moisture increases, bulk density tends to decrease, pointing towards a connection between higher moisture and reduced soil compaction. Additionally, a noteworthy positive correlation (0.910948) between pH and organic carbon highlights that soils with elevated organic carbon levels tend to exhibit higher pH values, emphasizing the influence of organic matter on soil acidity. The negative correlation (-0.42275) between electrical conductivity (EC) and organic carbon suggests that higher organic carbon content might be associated with lower EC in the soil solution.

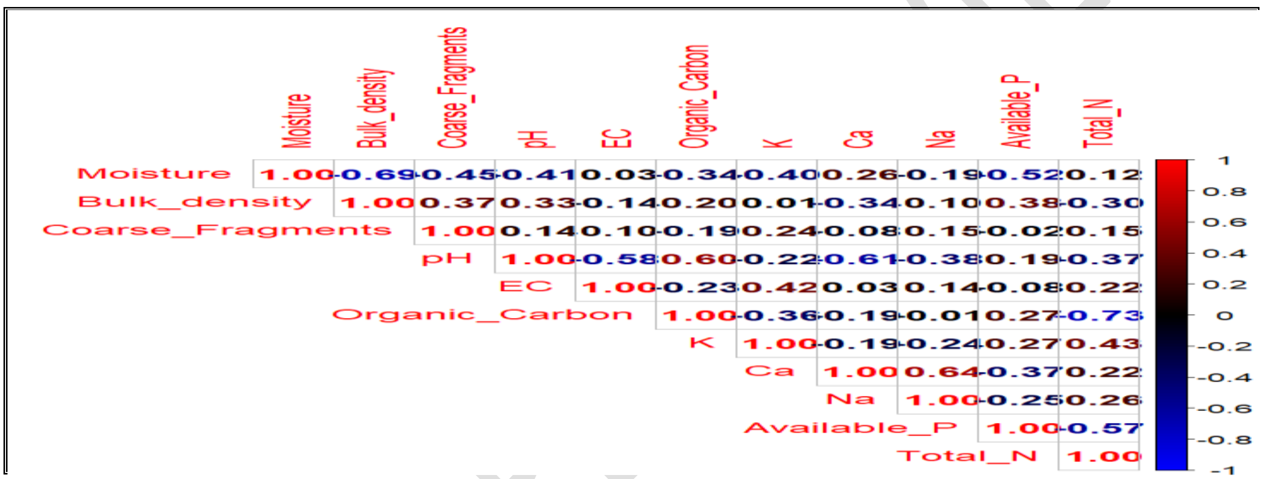


Fig 3: Pearson's Correlation Coefficient between physical and chemical properties of soil

In terms of nutrient content, positive correlations between potassium (K), calcium (Ca), sodium (Na), and total nitrogen (Total N) imply a tendency for these nutrients to co-occur in the soil. Furthermore, the negative correlation (-0.5775) between available phosphorus (Available P) and total nitrogen suggests an inverse relationship, indicating that as available phosphorus levels rise, total nitrogen levels may decrease. These findings underscore the intricate connections between soil properties, providing valuable insights for informed agricultural practices such as irrigation management, nutrient optimization, and overall soil health enhancement.

Vegetative Analysis

Table1 shows the results of the different parameters for theanalysis of vegetation growth in the restored area site-wise. They are namely, Frequency, Density, Abundance, and Average Basal Area while Fig 4 and 5 show the Importance Value Index(IVI), and Shannon Weiner's Index

(H’).Grevillea robusta, with a frequency of 33.3%, exhibited a density of 1.66 individuals per square meter, contributing to an overall abundance of 5 individuals. The average basal area for this species was measured at 352.81 cm². *Jacaranda mimosifolia*, with a frequency of 33.3%, displayed a density of 0.66 individuals per square meter, totaling an abundance of 2 individuals, and an average basal area of 331.50 cm². *Acrocarpusfraxinifolius*, found at a frequency of 33.3%, had a density of 0.33 individuals per square meter, contributing to an abundance of 1 individual, with an average basal area of 912.80 cm².*Justicia adhatoda* exhibited a frequency of 33.3%, displaying a density of 2.33 individuals per square meter, resulting in an abundance of 7 individuals, and an average basal area of 98.15 cm². *Murrayakoenigii*, with a frequency of 33.3%, showed a density of 1 individual per square meter, contributing to an abundance of 3 individuals, with an average basal area of 66.90 cm². *Eupatorium adenophorum* and *Vitex negundo* both had a frequency of 33.3%, each displaying a density of 1 individual per square meter and an abundance of 3 individuals. However, their average basal areas differed, with *Eupatorium adenophorum* at 5.74 cm² and *Vitex negundo* at 10.31 cm². Lastly, *Toona ciliate*, with a frequency of 33.3%, had a density of 0.33 individuals per square meter, resulting in an abundance of 1 individual, and an average basal area of 20.9 cm². Another study by Dhyani et al., (2016) [8],The Sahastradhra forest area's various communities' importance value index. 39, 27, and 19 species in total were found in the C1, C2, and C3 ecosystems, according to a floristic study. With an IVI value of 29.6, *Eupatorium adenophorum* is the most prominent plant species in the terrestrial community, followed by *Adhatodavasica*, which has an IVI value of 15.0. With IVI values of 42.58 and 44.04, respectively, *Triticum aestivum* and *Equisetum sps*. were the most prevalent species in aquatic and agricultural ecosystems, respectively.

Table 1: The Frequency distribution, Variations among the Density, Abundance, and Average Basal Area of all the species at Site 1

Name of the species	Frequency	Density	Abundance	Average Basal Area (cm^2)
Grevillea robusta	33.3%	1.66	5	352.81
Jacaranda mimosifolia	33.3%	0.66	2	331.50
Acrocarpusfraxinifolius	33.3%	0.33	1	912.80
Justicia adhatoda	33.3%	2.33	7	98.15
Murrayakoenigii	33.3%	1	3	66.90
Eupatorium adenophorum	33.3%	1	3	5.74

Vitex negundo	33.3%	0.66	2	10.31
Toona ciliate	33.3%	.33	1	20.9

Shannon Weiner Index of the first site (H')=1.84

Average Value of Importance Value Index of the first site (IVI)= 37.56

Grevillea robusta exhibited a relative frequency of 12.5%, indicating its presence in one-eighth of the sampled plots. With a relative density of 20.83%, the species demonstrated a concentrated distribution, contributing significantly to the overall vegetation structure. Its relative dominance of 19.8% highlighted its ecological importance, and the Importance Value Index (IVI) of 53.13 reinforced its significant role in the ecosystem.*Jacaranda mimosifolia*, with a relative frequency of 12.5%, displayed a moderate presence across the study site. The species exhibited a relative density of 8.33% and a relative dominance of 17.9%, indicating its relevance in the vegetation composition. The IVI of 38.75 underscored the ecological significance of *Jacaranda mimosifolia*.*Acrocarpusfraxinifolius*, with a relative frequency of 12.5%, showed a lower occurrence but stood out with a relative dominance of 49.45%. The IVI of 66.11 emphasized the species' dominance and ecological impact, contributing substantially to the overall vegetation structure. *Justicia adhatoda, Murrayakoenigii, Eupatorium adenophorum, Vitex negundo, and Toona ciliate* each played unique roles, contributing to the ecological diversity of the area. The IVI values provided a comprehensive assessment of their relative importance, showcasing the intricate dynamics of the plant community in the studied ecosystem.

Acacia catechu, with a frequency of 33.3%, demonstrated a moderate presence across the sampled plots. The species exhibited a density of 1 and an abundance of 3, indicative of its relatively scattered distribution within the surveyed area. *Acacia catechu's* average basal area of 138.09 cm^2 highlighted its contribution to the overall vegetative cover, adding both structurally and ecologically to the landscape.*Murrayakoenigii* emerged as a dominant species with a 100% frequency, indicating its ubiquitous presence in all sampled plots. The species displayed a density of 3.33 and an abundance of 3.33, emphasizing its substantial role in shaping the local vegetation structure. Despite a lower average basal area of 4.81 cm2, *Murrayakoenigii's* high frequency underscored its ecological significance and potential influence on the surrounding ecosystem. Other species such as *Bauhinia variegata, Lantana camara, Solanum nigrum, Colebrookeaoppositifolia, Lepidagathis lutea, and Pseudobombaxellipticum* each contributed to the botanical diversity of the area. The varying frequencies, densities, and basal areas of these species collectively painted a nuanced picture of the vegetation dynamics, showcasing the ecological richness of the surveyed landscape.

Table 2: The Frequency distribution, Variations among the Density, Abundance, and Average Basal Area of all the species at Site 2

Name of the species	Frequency	Density	Abundance	Average Basal Area (cm^2)
Acacia catechu	33.3%	1	3	138.09
Murrayakoenigii	100%	3.33	3.33	4.81
Bauhinia variegata	33.3%	0.33	1	8.54
Lantana camara	66.6%	1	1.5	1.149
Solanum nigrum	33.3%	0.66	2	9.83
Colebrookeaoppositifolia	33.3%	0.33	1	48.49
Lepidagathis lutea	33.3%	0.33	1	176.62
Pseudobombaxellipticum	33.3%	0.33	1	154.63

Shannon Weiner Index of the second site (H')=1.662

Average Value of Importance Value Index of the second site (IVI)=37.39

Acacia catechu, with a relative frequency of 9%, demonstrated a moderate presence, particularly notable for its relatively high relative density of 13.63%. The species also exhibited a substantial relative dominance of 25.45%, resulting in an Importance Value Index (IVI) of 48.08. This suggests that Acacia catechu significantly influences the structure and composition of the vegetation within the surveyed plots.*Murrayakoenigii* emerged as a dominant species, commanding a notable relative frequency of 27.2%, the highest among the species considered. This was accompanied by a remarkably high relative density of 45.45%, indicating a dense and widespread distribution. Despite a lower relative dominance of 0.88%, the cumulative effect resulted in a substantial IVI of 73.58, underscoring the ecological significance of *Murrayakoenigii* in the surveyed ecosystem. Other species, including *Bauhinia variegate, Lantana camara, Solanum nigrum, Colebrookeaoppositifolia, Lepidagathis lutea,* and*Pseudobombaxellipticum*, exhibited varying degrees of relative frequency, density, and dominance. The comprehensive analysis of these parameters provides valuable insights into the ecological roles and interactions of each species, contributing to the biodiversity and overall health of the surveyed vegetation.

Bombax ceiba, with a frequency of 33.3%, exhibited a low but distinct presence, characterized by a density of 0.33 and an abundance of 1. Notably, this species displayed a considerable average basal area of 875.3 cm2, underscoring its ecological significance in terms of biomass and canopy cover.*Murrayakoenigii* emerged as a dominant species with a high frequency of 66.6%, indicating a widespread presence across the surveyed plots. It demonstrated a moderate density of 1.33 and an abundance of 1.5, showcasing a robust growth pattern. Acacia catechu, with a frequency of 33.3%, displayed a relatively higher density of 1.33 and an abundance of 4, contributing to its importance in terms of population density within the ecosystem. Other species, including *Justicia adhatoda*, *Colebrookeaoppositifolia, Solanum nigrum, Eupatorium adenophorum, Boehmariaplatyphylla, Lepidagathis lutea, Aplis census,* and *Kali bel*, exhibited varying degrees of frequency, density, and abundance. The cumulative analysis of these parameters provides valuable insights into the structural composition and ecological roles of each species, contributing to the overall biodiversity and ecological health of the surveyed vegetation.

Shannon Weiner Index of the third site (H')=2.39

Average Value of Importance Value Index of the third site (IVI)= 28.66

Table 3: The Frequency distribution, Variations among the Density, Abundance, and Average Basal Area of all the species at Site 2

Name of the species	**Frequency**	**Density**	**Abundance**	**Average Basal Area (cm^2)**
Bombax ceiba	33.3%	0.33	1	875.3
Murrayakoenigii	66.6%	1.33	1.5	46.13
Acacia catechu	33.3%	1.33	4	202.53
Justicia adhatoda	33.3%	0.66	2	50.24
Colebrookeaoppositifolia	33.3%	0.33	1	2.54
Solanum nigrum	33.3%	0.66	2	3.21
Eupatorium adenophorum	66.6%	1.33	2	0.49
Boehmariaplatyphylla	66.6%	0.66	2	1.13
Lepidagathis lutea	33.3%	0.33	1	18.08
Aplis census	33.3%	0.66	2	0.096
Kali bel	33.3%	0.33	1	0.031

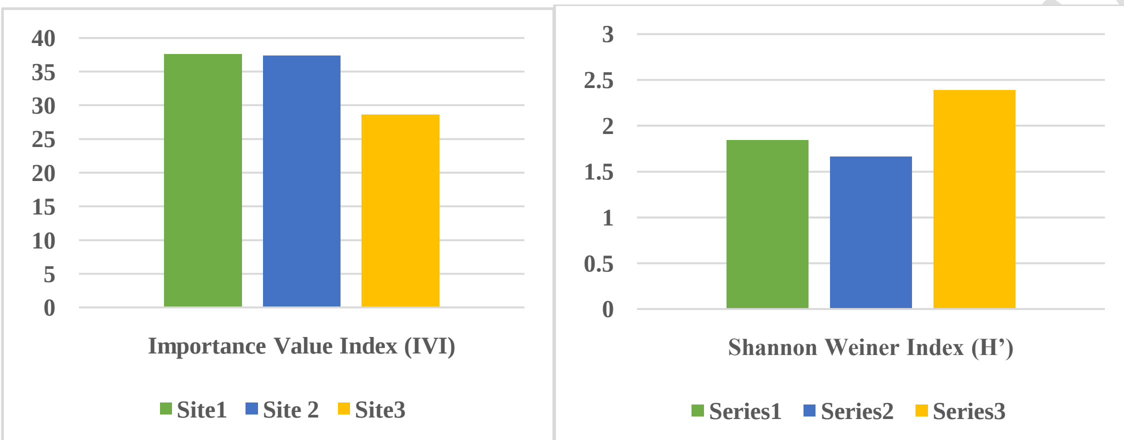
Bombax ceiba, with an R. Frequency of 7.14%, R. Density of 4.16%, and high Relative Dominance of 72.97%, emerges as a dominant species, contributing significantly to the vegetation structure with an IVI of 84.27. *Murrayakoenigii*, characterized by a 14.28% R. Frequency, 16.66% R.

Density, and 3.84% R. Dominance, demonstrates a substantial presence, yielding an IVI of 34.78. *Acacia catechu*, with a 7.14% R. Frequency, 16.66% R. Density, and 16.84% R. Dominance, represents a species with a balanced distribution and influence, contributing to the ecosystem with an IVI of 40.64. *Justicia adhatoda, Colebrookeaoppositifolia, Solanum nigrum, Eupatorium adenophorum, Boehmariaplatyphylla, Lepidagathis lutea, Aplis census, and Kali bel* display varying levels of relative frequency, density, and dominance, collectively shaping the biodiversity and ecological dynamics of the surveyed area. The IVI values offer a comprehensive metric for assessing the overall ecological importance of each species, facilitating informed conservation and management strategies for the studied vegetation.

The distribution and occurrence of trees, shrubs, herbs, and other ground flora are very sensitive to changes within a shortperiod. The major factors influencing these changes are edaphic factors and climatic factors [9]. We can see that *E. adenophorum* and *L. camara* have shown increased invasion in areas with higher IVI values. However, *G. robusta* shows similar levels of IVI and density as in previous studies (IVI = 53.13). The most dominant tree species in the study area were *G. robusta* (IVI = 53.13), *A. katechu* (IVI = 8.08), *J. mimosifolia*(IVI = 38.75), and *Bombax ceiba* (IVI = 84.27). These tree species show approaching values to the natural forest ecosystem, which shows that these species are the most aggressive and are the most frequent and abundant in limestone-mined areas [10].

Comparison of the Shannon Weiner Index (H') vs Importance Value Index (IVI)

The comparison of the Importance Value Index (IVI) and Shannon Weiner Index (H') across Sites 1, 2, and 3 (Fig 4) provides valuable insights into the ecological characteristics of the reclaimed limestone mined areas. Sites 1 and 2 exhibit similar IVI values, suggesting comparable ecological importance in terms of vegetation composition and dominance. However, the slight difference in IVI indicates nuanced variations in their contributions to the overall ecosystem. Notably, Site 1 surpasses Site 2 in species diversity, as evidenced by its higher Shannon Weiner Index (H') value of 1.84 compared to 1.662. This implies that Site 1 hosts a more diverse and evenly distributed plant community. Conversely, Site 3, with a lower IVI of 28.66, indicates a comparatively lesser ecological importance than Sites 1 and 2. However, the higher Shannon Weiner Index (H') of 2.39 for Site 3 suggests a richer and more evenly distributed species diversity.A species' high IVI demonstrated its ecological success and domination through improved regeneration and larger ecological amplitude [11]. This signifies that, despite a lower dominance of certain species, Site 3 supports a balanced and varied plant community. The contrasting patterns between IVI and H' underscore the need for a comprehensive evaluation of ecological restoration, considering both dominance and diversity metrics. Ultimately, these findings enhance our understanding of the complex interplay between vegetation dynamics and ecological health in restored mined areas, offering valuable guidance for future restoration strategies.



(a) (b)

Fig 4: The Importance Value Index, IVI (a), and Shannon Weiner's Index, H'(b) of all the 3 sites

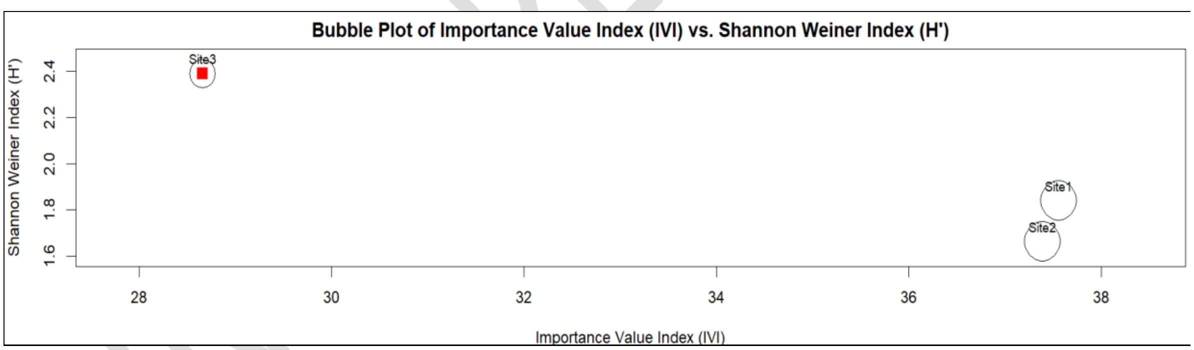


Fig 5: Representing the site (Site 3), supports a balanced and varied plant community comparatively based on their Shannon Weiner's Index (H') and Importance Value Index (IVI)

This present study shows that after 30 years, early successional species that were used during restoration have started to be replaced. The species mentioned above have begun invading the area. Natural invasion of trees into restored sites may be affected by the types of species already occurring in the site and resource availability. The establishment of tree species in degraded sites may facilitate the regeneration of native species that could not have otherwise been established in open sites or competition with herbaceous species. The species diversity of the three sites was 1.84, 1.662, and 2.39, respectively. This increase in biodiversity is of great importance because of the functional role of the ecosystem as a whole, especially of soil fauna, for soil properties and the self-regulation potential of intensive forest ecosystems [12].

CONCLUSION

A thorough investigation of the rehabilitated limestone mining region in Sahastradhara, Doon Valley, Uttarakhand, demonstrates the intricate relationship that exists between the health of the soil, plant development, and mining operations. The site has recovered well after over thirty years of restoration work, with the main colonizing plant species flourishing and diversity indices rising for tree, shrub, and herb species. The three altitudinal locations have different soil characteristics, with Site 3 having the most favorable conditions for plant development because of its greater soil moisture content, lower bulk density, fewer coarse pieces, slightly higher pH, and higher amounts of organic carbon. There were sufficient amounts of vital nutrients to enable plant development. With important species like *Bombax ceiba* present, Site 3 had the greatest species variety and dominance. Positive correlations were observed between certain nutrients, while a negative correlation existed between available phosphorus and total nitrogen, shedding light on soil nutrient dynamics. Considering these findings, Site 3 stands out as the most suitable for continued ecological restoration efforts, offering promising conditions for vegetation growth and biodiversity enhancement despite the emergence of some invasive species.

However, it's essential to acknowledge that the success of restoration is a complex interplay of various factors, and ongoing monitoring and adaptive management practices are crucial for the sustained health of the ecosystem. The study underscores the importance of holistic approaches in addressing the challenges posed by mining activities and emphasizes the need for effective reclamation strategies to mitigate environmental impacts. Eco-restoration studies are as important as the process of restoration itself. If the site is left unchecked or unmonitored, it may degrade and leave the soil even more harmed and degraded. Therefore, regular monitoring of the restored area is essential even if the area is not exposed to adverse human interference. Despite some construction work and various tourism activities increasing in the study area, the restoration is deemed to be successful overall. The restoration study of this area provides insight into the extent to which local factors and climatic factors affect the restoration process of limestone-mined areas. It is a perfect example and a good reference for studies in related fields.

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