Heliyon 10 (2024) e29877

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Review and assessment of the potential restoration of ecosystem services through the implementation of the biodiversity management plans for SDG-15 localization

Hishmi Jamil Husain [a,b], Xiuqing Wang [a,*], Saied Pirasteh [a,c], Davood Mafi-Gholami [a,d], Bhavesh Chouhan [e], Mohammed Latif Khan [f], Mehdi Gheisari [a]

[a] Institute of Artificial Intelligence, Shaoxing University, Shaoxing, 508 West Huancheng Road, Yuecheng District, Zhejiang Province, Postal Code, 312000, China
[b] Classification, Saudi Aramco, Company General Use, G5RF+JPJ, Arafat, Al Andalus, Jeddah, 23324, Saudi Arabia
[c] Department of Geotechnics and Geomatics, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India
[d] Department of Forest Sciences, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord, Iran
[e] Indian Institute of Forest Management, Bhopal, 462002, India
[f] Department of Botany Dr. Hari Singh Gour Vishwavidyalaya (A Central University), Sagar, 470003, Madhya Pradesh, India

A R T I C L E I N F O

Keywords:
Ecosystem services
Noamundi iron ore mine
West Bokaro colliery
Restoration
TATA steel

A B S T R A C T

Effective restoration strategies play a crucial role in mitigating the environmental impact of mining and colliery activities while promoting ecological resilience and rejuvenating ecosystem services. However, many organizations find it challenging to understand and balance their efforts in restoring degraded lands. For example, their restoration plans lack clarity and overlook relevant ecosystem services. This study reviews and focuses on the potential restoration of ecosystem services at TATA Steel's Noamundi Iron Ore Mine and West Bokaro Colliery to contribute to Sustainable Development Goals (SDGs), particularly SDG-15, for localization. The approach involved assessing the number of preventive measures being implemented to restore a particular ecosystem service. Moreover, the potential of each preventive measure is to restore that ecosystem service. The findings underscore the significance of preventive measures and comprehensive restoration plans in enhancing carbon sequestration, soil fertility, habitat creation, and genetic diversity conservation. Our results showed that the impact scores and ranks of various ecosystem services demonstrate the positive effects of restoration efforts, emphasizing the importance of reestablishing forests, restoring water bodies and wetlands, and allocating land for agriculture and public use. The research provides valuable insights for decision-makers in developing sustainable land management strategies, ensuring biodiversity conservation and local communities' well-being. By prioritizing ecosystem services in restoration initiatives, stakeholders can contribute to the sustainable management of natural resources and foster a harmonious coexistence between human activities and the environment.

* Corresponding author.
E-mail addresses: hishmi.husain@gmail.com (H.J. Husain), wxq@usx.edu.cn (X. Wang), sapirasteh1@usx.edu.cn (S. Pirasteh), d.mafigholami@nres.sku.ac.ir (D. Mafi-Gholami), bhbh13.nmh@gmail.com, bchouhanpsm24@iifmbhopal.edu.in (B. Chouhan), khanml61@gmail.com (M.L. Khan), mehdi.gheisari61@gmail.com (M. Gheisari).

https://doi.org/10.1016/j.heliyon.2024.e29877
Received 1 December 2023; Received in revised form 6 April 2024; Accepted 16 April 2024
Available online 18 April 2024

1. Introduction

As defined by Fisher et al. [1], ecosystem services encompass the benefits humans derive from the proper functioning of natural ecosystems. These services encompass provisioning services like food, water, and raw materials; regulating services such as climate control, water purification, and pest management; cultural services like recreational opportunities and aesthetic enjoyment; and supporting services which involve processes like nutrient cycling and soil formation [2–5]. Given their vital role in human well-being and sustainable development, ecosystem services are integral to our economic, social, and environmental prosperity [6,7]. However, human activities, notably mining and industrial operations, can exert significant impacts on ecosystems, potentially leading to the degradation or loss of these invaluable services [8]. Hence, it is imperative to diligently evaluate and mitigate these impacts to safeguard the long-term sustainability of ecosystems and the essential services they afford.

TATA Steel's Noamundi Iron Ore Mine and the West Bokaro Colliery are major mining operations located in West Singhbhum District and Bokaro District of the Jharkhand State in India. These operations involve the extraction of iron ore and coal, respectively, which are essential raw materials for the steel industry. While these activities contribute to economic development, they can also adversely affect the surrounding ecosystems. Mining operations often involve land clearing, excavation, and waste disposal, which can lead to deforestation, habitat fragmentation, and soil erosion. Additionally, releasing pollutants and sediments into nearby water bodies can negatively impact water quality and aquatic ecosystems. Such disturbances can result in the loss of biodiversity, disruption of ecological processes, and a decline in ecosystem services [9–11]. TATA Steel has implemented biodiversity management plans to mitigate these impacts, aiming to restore and conserve the affected ecosystems and their services. These plans include measures such as habitat restoration, reforestation, and water management strategies.

The purpose of this study is to assess the potential restoration of ecosystem services through the implementation of TATA Steel's biodiversity management plans at the Noamundi Iron Ore Mine and the West Bokaro Colliery. The study aims to evaluate the effectiveness of these plans in mitigating the negative impacts of mining operations on local ecosystems and their services and to support Sustainable Development Goals (SDGs) localization, particularly SDG-15. Having said that, the authors hold significant importance for several stakeholders. In addition, first and foremost, it provides valuable insights for TATA Steel in evaluating the effectiveness of its biodiversity management plans and identifying areas for improvement. The linkage between the study's evaluation of biodiversity management plans and SDG 15, Life on Land, is profound and multifaceted. SDG 15 specifically targets the protection, restoration, and sustainable use of terrestrial ecosystems, including forests, wetlands, mountains, and drylands, as well as their biodiversity. By assessing the effectiveness of these plans in mitigating the negative impacts of mining operations on local ecosystems, the study directly contributes to the overarching goal of preserving and restoring biodiversity.

This study contributes to the broader scientific community by advancing our understanding of the restoration potential of ecosystem services in heavily impacted areas. Furthermore, the study benefits local communities and the environment by assessing the restoration of ecosystem services essential for their well-being and sustainability. The findings can inform decision-making processes related to land use planning, conservation strategies, and sustainable resource management. Ultimately, this study promotes the integration of biodiversity management plans into industrial operations, ensuring the preservation of ecosystems and the services they provide while facilitating responsible economic development.

The contribution of this study is summarized as follows.

a. Creating a structural framework approach to improve the understanding of ecosystem services as a part of restoration efforts.
b. Supporting SDG-15 for localization to impact policy on integrated development planning.
c. Assisting in aligning restoration efforts with ecosystem services.

The rest of the paper organizes related works in **Section 2**. **Section 3** explains the methodology of the proposed research framework. The study findings are given in **Section 4**, followed by a discussion, and then we wrap up the paper with a conclusion followed by suggestions in **Section 5**.

2. Related works

Mining activities exert significant environmental and health impacts, causing ecosystem degradation and pollution of water and air sources [12,13]. To mitigate these adverse effects, restoration and reclamation efforts are gaining momentum within the field of restoration ecology. These endeavors aim not only to rehabilitate ecosystems but also to restore their biodiversity and ecosystem services [12,14]. However, the process of restoration and reclamation is complex and time-consuming, necessitating the implementation of robust biodiversity management plans [15,16].

In addition, incorporating biodiversity assessments and indicators into forest management planning is increasingly important for ensuring forest ecosystems' resilience and sustainable functioning [17–19]. Research has identified stand and landscape-level biodiversity indicators, with stand-level ones being particularly practical and valuable for management plans. Notably, structural indicators like large trees and old forest stands are easily observable and obtainable through forest inventories. However, compositional indicators pose challenges in identification. To enhance the practicality of these indicators, leveraging existing databases and technology, including remote sensing and smartphone applications, can be highly effective [17]. For further insights on this topic, refer to studies by Ayazi et al. [20], Pirasteh and Varshosaz [21], Amanehalsadat et al. [22], Pirasteh et al. [23], Mafi-Gholami et al. [24], and Li et al. [25].

Understanding the intricate relationships among ecosystem services is pivotal for effective ecosystem management [26]. These services often interact, forming neural, synergic, and trade-off relationships. Simply quantifying them is insufficient; analyzing the drivers behind these interactions is imperative. A suggested typology based on drivers and interactions can enhance comprehension, ultimately aiding the sustainable management of landscapes to provide multiple ecosystem services [26]. Moreover, progress in ecosystem production functions and service mapping, coupled with developing appropriate finance, policy, and governance systems, is crucial for guiding significant investments in natural capital [27]. Despite improving scientific understanding in this area, it still poses a limitation in decision-making processes. Establishing innovative institutional structures for ecosystem services allows for systematic assessment and evaluation, creating opportunities for more effective management [27]. Collaborative sharing of experiences and setting future priorities can expedite innovation and the adoption of new approaches.

The Millennium Ecosystem Assessment (MEA) scenarios have illuminated the consequences of various policies on human well-being, stressing the integration of biodiversity and adaptive management practices to enhance resilience and combat ecosystem degradation [28]. Understanding the impacts of mining activities on ecosystem services and human well-being is crucial for effective management. While limited literature examines mining impacts on ecosystem services, existing studies highlight various negative impacts, including pollution, soil erosion, and loss of biodiversity. Implementing biodiversity management plans at TATA Steel's Noamundi Iron Ore Mine and the West Bokaro Colliery offers promise for restoring ecosystem services. These plans should include a comprehensive biodiversity assessment, covering both flora and fauna, and utilize practical indicators for monitoring restoration progress. Understanding the relationships between ecosystem services is crucial for informing decision-making and optimizing service provision [21,24].

Progress in ecosystem production functions and service mapping is essential for informed decision-making and wise investments in natural capital [27]. Developing innovative institutional structures and sharing experiences can accelerate progress in managing mining ecosystem services in mining regions [27]. Implementing biodiversity management plans in mining sites presents an opportunity to restore ecosystem services and improve human well-being. By conducting comprehensive biodiversity assessments, utilizing practical indicators, and integrating advances in ecosystem science, restoration efforts can be effectively guided, leading to sustainable management practices and enhanced human well-being.

3. Data and methodology

3.1. Profile of the study area

3.1.1. Noamundi Iron Ore Mine

The Noamundi Iron Ore Mine, operated by Tata Steel Limited, is situated in the West Singhbhum district of Jharkhand, India,

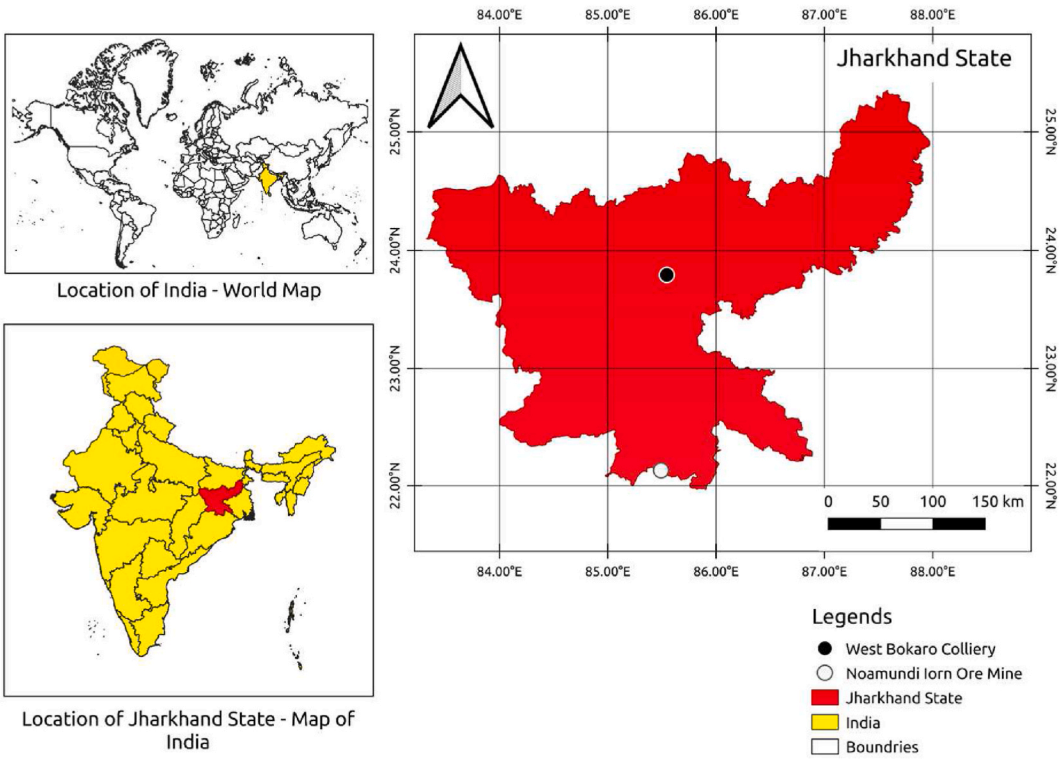

Fig. 1. Regional location of Noamundi Iron Ore Mine and the West Bokaro Colliery.

positioned between 22°04′14″ N to 22°10′41″ N latitude and 85°27′09″ E to 85°30′06″ E longitude [29,30] (Fig. 1). Boasting a production capacity of 10.00 million tonnes annually, it holds a significant position in the local iron ore industry [30]. The mine lies in proximity to Noamundi town, near the Odisha border, and approximately 64 km from Chaibasa. Other adjacent towns include Padapahar, Barajamda, Jagannathpur, Kharsawan, Gua, and Kiriburu [31].

The Noamundi Iron Ore Mine achieved a 5-Star rating from the Indian Bureau of Mines for 2021-22 due to its commitment to sustainable practices, facilitated by advanced technologies such as mining software, drones, fleet management systems, and remote-controlled drills [31]. Collaborating with the International Union for Conservation of Nature (IUCN), Tata Steel developed a comprehensive Biodiversity Management Plan (BMP) covering 1160.06 ha to restore local biodiversity within and around the mine site, with regular annual reviews for continual improvement. For mine closure, the Noamundi Mine Closure Plan outlines reclaiming 1019.81 ha out of 1230.42 ha, relinquishing 210.61 ha for government and community use. Table 1 provides a detailed view of the potential reclamation and restoration of the Noamundi Iron Ore Mine.

3.1.2. West Bokaro Colliery

The West Bokaro Colliery is a captive opencast mine operated by Tata Steel in the Ramgarh district of Jharkhand, India. Its main purpose is to produce 1.9 million tonnes of coal annually for Tata Steel's steel plants. The colliery is situated at coordinates 23.699974 N, 86.081045 E. It is part of the larger West Bokaro coalfield, which spans an area of 259 square kilometers (Fig. 1). The coalfield contains significant coal reserves amounting to 4246.30 million tonnes [31].

The BMP provides practical guidance to Tata Steel for the progressive restoration and enhancement of biodiversity in the West Bokaro Colliery and its surrounding areas. By following the plan's recommendations, Tata Steel can mitigate the ongoing net loss of biodiversity caused by mining operations and contribute to the restoration of local ecosystems [31]. Table 2 depicts a detailed view of the reclamation and restoration of the West Bokaro Colliery.

The biodiversity management plan of both the sites aims to meticulously survey and assess the existing flora and fauna within and around the mine site to establish a baseline understanding of biodiversity. Subsequently, it seeks to implement targeted conservation measures, including habitat restoration, reforestation initiatives, and the establishment of wildlife corridors to facilitate the movement of species. Additionally, the BMP emphasizes the importance of community engagement and participation in biodiversity conservation efforts, fostering partnerships with local stakeholders to ensure sustainable outcomes.

3.2. Theoretical framework of the proposed research

The theoretical framework for this study is grounded in established ecosystem services frameworks, particularly drawing upon the Millennium Ecosystem Assessment (MEA) and the Common International Classification of Ecosystem Services (CICES). This framework, which recognizes and categorizes the various benefits that ecosystems provide to humanity, forms the basis for understanding the diverse services ecosystems offer, ranging from provisioning services (e.g., food and raw materials) to regulating services (e.g., climate regulation and water purification), supporting services (e.g., habitat provision and genetic diversity maintenance), and cultural services (e.g., recreation and spiritual experiences). The following ecosystem services frameworks are suggested in this study.

a. Millennium ecosystem assessment (MEA): The MEA framework, widely recognized in the field of ecosystem services, provides a comprehensive structure for understanding the interconnectedness of ecosystem processes and human well-being. The classification of restoration areas into afforestation/forested areas, water storage and wetlands, and public spaces/parks and agricultural land aligns with the MEA framework's recognition of ecosystems' diverse services [32].
b. Common international classification of ecosystem services (CICES): The CICES framework contributes to the theoretical underpinning by offering a standardized classification system for ecosystem services. This framework ensures consistency in terminology and understanding, facilitating a more coherent assessment of the impact of preventive measures on ecosystem services in different restoration areas. The alignment with these frameworks ensures that the study evaluates the impact of preventive measures on distinct ecosystem services within the context of the restoration areas, providing a solid theoretical foundation [6].
c. Biodiversity management plans: The study integrates the BMPs specific to Tata Steel's Noamundi Iron Ore Mine and West Bokaro Coal Mine. BMPs are comprehensive strategies designed to conserve and enhance biodiversity within industrial landscapes, complementing the broader ecosystem services frameworks. The incorporation of BMPs provides a practical and site-specific

Table 1
Land restoration as per Approved mine closure plan.

Activity	Conceptual Land Degradation	Reclamation Measures		
	Area in ha.	Measures	Area in ha.	% of the total area
Mining Excavation	957.51	Afforestation/Plantation	874.51	85.75 %
		Water Storage/Wetland	65.00	6.37 %
		Parks/Public Spaces	18.00	1.77 %
OB Dumps, Tailing Dam	62.30	Afforestation/Plantation	62.30	6.11 %
Total	**1019.81**	**Area under restoration**	**1019.81**	**100.00 %**

Table 2
Land use and land restoration plan.

Activity	Conceptual Land Degradation	Reclamation Measures		
	Area in ha.	Measures	Area in ha.	% of the total area
Soil Storage Area	Nil	–	Nil	–
Excavation area	1487	Afforestation/ Plantation	1270	72.99 %
		Water Storage/Wetland	32	1.84 %
		Agriculture	160	9.19 %
		Parks/Public Use	25	1.44 %
External O.B. dumps	Nil	–	Nil	–
Infra Area (Workshop, administrative building, washery etc.)	63	Afforestation/ Plantation	63	3.62 %
Township & habitation	Nil	–	Nil	–
Roads in mines	Nil	–	Nil	–
Village	25	Parks/Public Use	25	1.44 %
Water Bodies	42	Water Storage/Wetland	42	2.41 %
Greenbelt along mine barrier	83	Afforestation/ Plantation	83	4.77 %
Garland drains	10	Parks/Public Use	10	0.57 %
Embankment	10	Parks/Public Use	10	0.57 %
Peripheral roads on barrier	20	Parks/Public Use	20	1.15 %
Total	1740	Area under restoration	1740	100.00 %

dimension to the theoretical framework, ensuring that the proposed preventive measures align with established conservation strategies.

d. Preventive measures and impact assessment: The methodology delves into categorizing preventive measures and assigning impact levels based on potential effects on ecosystem services. This categorization, rooted in the MEA and CICES frameworks, emphasizes nuanced evaluation of ecological restoration.
e. Aggregation and comparative analysis: The aggregation of impact scores across different preventive measures, restoration areas, and ecosystem services allows for a comprehensive analysis consistent with the principles outlined in ecosystem services frameworks. This framework aligns with the theoretical premise that the cumulative impact of multiple measures influences the overall restoration outcome, reflecting the holistic approach advocated by the MEA.

The first step of the research involves identifying the restoration measures that actively contribute to the restoration of degraded areas. These measures are categorized based on their potential to restore the particular degraded land into three types of restoration areas, as defined in Table 3.

Next, we will evaluate the impact of these restoration measures on the 18 ecosystem services as defined by the Food and Agriculture Organisation (FAO) of the United Nations, outlined in Table 4. This assessment is vital for comprehending how each measure influences individual ecosystem services.

Next, we selected each preventive measure and assigned an impact level to each ecosystem service based on the Impact Levels defined in Table 5. These impact levels, quantified on a scale from 1 to 5, reflect the potential effects of the preventive measures on the respective ecosystem services. A comprehensive evaluation of the potential repercussions can be obtained by assigning impact scores to each ecosystem service across all preventive measures. This proposed assessment provides insights into the broader implications and consequences of implementing preventive measures on ecosystem services.

Now, to aggregate the impact scores, the corresponding scores for a specific ecosystem service are combined from all preventive measures. This aggregation process is conducted for each of the three types of restoration areas, resulting in comprehensive scores representing the overall impact on ecosystem services for each mentioned type of restoration area (as shown in Table 1). This analysis allows for a deeper understanding of the ecosystem services that are restored when degraded land is transformed into a Forest Area, a

Table 3
Classification of restoration areas.

Type of Area	Explanation
Afforestation/Forested Areas	The deliberate and systematic planting of a variety of native tree species in previously non-forested or degraded areas with the intention of establishing new forests or restoring forest cover. This process typically includes selecting appropriate tree species based on factors such as soil type, climate conditions, and local ecological considerations.
Water Storage and Wetlands	These are the areas that are being subjected to a deliberate and systematic process of revitalizing or transforming degraded or altered landscapes into functional ecosystems, with the specific aim of supporting water retention, conservation, and the re-establishment of wetland habitats or similar efforts that support improving and enhancing the water quality and availability in the area.
Public Spaces or Parks and Agricultural Land	These areas are designated to serve the specific purpose of promoting public use and enjoyment, preserving and enhancing biodiversity, and promoting various measures to protect species such as butterflies and reptiles. Some of these areas have also been converted into agricultural land, and for this research, agricultural areas have been included in this category.

Table 4
Ecosystem services.

Sr. No.	Type of Ecosystem Service	Name of the Ecosystem Service	Description
1	**Provisioning Services**	Food	Ecosystems provide a variety of food resources, including crops, livestock, fish, and wild game. These resources form the basis of human diets and contribute to food security.
2		Raw Material – wood, biofuels, and fibres	Ecosystems provide raw materials for various human needs, such as timber for construction, fuelwood for heating and cooking, and fibres for clothing and paper production. Biofuels, such as ethanol and biodiesel, can also be derived from plants grown in ecosystems.
3		Fresh Water	Ecosystems play a critical role in regulating the water cycle, which includes the provision of fresh water for human consumption, agriculture, and industrial activities. Wetlands and forests act as natural water filters and help maintain water quality.
4		Medicinal Resources	Many plants and animals found in ecosystems are used in traditional medicine and pharmaceuticals. Ecosystems are an important source of new drugs, and their conservation is critical for maintaining the potential of future discoveries.
5	**Regulating Service**	Local Climate Air Quality	Ecosystems have a significant impact on local climate and air quality. Trees, for instance, offer shade, and forests can influence rainfall and water availability at both local and regional scales. Trees and other vegetation also play a crucial role in purifying the air by extracting pollutants from the atmosphere.
6		Carbon Sequestration and Storage	Ecosystems play a critical role in global climate regulation by acting as reservoirs for greenhouse gases. As trees and plants grow, they actively extract carbon dioxide from the atmosphere, sequestering it within their tissues.
7		Moderation of extreme events	Ecosystems play a crucial role in mitigating the effects of extreme weather events like floods, droughts, and storms. Wetlands and forests, for example, serve as natural buffers against floods by absorbing and retaining excess water, gradually releasing it to maintain a steady flow.
8		Water Purification	Ecosystems provide a natural filtration system that helps to purify water. Wetlands and forests act as natural water filters, removing pollutants and contaminants before they enter waterways.
9		Erosion prevention- soil fertility maintenance	Vegetation cover is instrumental in averting soil erosion and preserving soil fertility through vital biological processes like nitrogen fixation. Soil erosion is a primary driver of land degradation, leading to diminished soil fertility, desertification, and a subsequent decline in the productivity of downstream fisheries.
10		Pollination	Insects and wind are vital for pollinating plants and trees, crucial for fruit, vegetable, and seed development. This service is mainly provided by insects, with some input from birds and bats. In agroecosystems, pollinators are essential for orchard, horticultural, forage production, and seed production for various crops. Bees, birds, and bats influence roughly 35 % of global crop production, leading to increased yields for approximately 75 % of the world's primary food crops.
11		Biological Control	Ecosystems provide natural pest control through the regulation of predator-prey relationships. Many beneficial insects, birds, and other animals feed on pests and help to control their populations.
12		Regulation of Water Flow	Ecosystems regulate water flow by storing, releasing, and filtering water. Wetlands, for example, can absorb and store large amounts of water during heavy rain events and release it slowly over time to maintain a steady water flow.
13	**Supporting Services**	Habitat for species	Ecosystems serve as habitats for plants and animals, hosting a variety of intricate processes that support various ecosystem services. Certain habitats, known as 'biodiversity hotspots,' boast an exceptionally high number of species, making them genetically diverse compared to others.
14		Maintenance of genetic diversity	Genetic diversity, encompassing gene variations within and between species populations, delineates distinct breeds or races. This diversity forms the foundation for locally well-adapted cultivars and serves as a vital gene pool for commercial crops and livestock development.
15	**Cultural Services**	Recreation, mental and physical health	Ecosystems offer spaces for recreation and physical activity, crucial for both mental and physical well-being. Time spent in nature has demonstrated benefits in reducing stress and enhancing overall health.
16		Tourism	Nature's allure draws millions of global travelers, offering a cultural ecosystem service that encompasses benefits for visitors and income opportunities for nature tourism providers.
17		Aesthetic appreciation and inspiration for culture, art and design	Ecosystems inspire cultural and artistic expression, fueling creativity and imagination in literature, music, and visual arts. This influence extends to both science and culture, with animals, plants, and ecosystems providing enduring wellsprings of inspiration.
18		Spiritual experience and sense of place	Nature holds a prominent place in many major religions. It encompasses natural heritage, instilling a deep spiritual connection and fostering traditional knowledge and customs, all contributing to a profound sense of belonging.

(Source: Food and Agriculture Organisation of the United Nations).

Table 5
Impact levels.

Impact Score	Impact Level	Description
1	Negligible Impact	Measures that do not contribute significantly to restoring the ecosystem service. They may not make any noticeable difference in the ecosystem, and their effects may not be easily measurable or observable.
2	Low Impact	Measures that have a low impact are those that contribute slightly to restoring the ecosystem service. They may have some positive effects, but these effects are limited in scope and duration. They may not be enough to restore the ecosystem service.
3	Moderate Impact	Measures that have a moderate impact are those that contribute significantly to restoring ecosystem service. They have positive effects that are observable and measurable. These effects may be noticeable in the ecosystem and may last for some time.
4	High Impact	Measures that have a high impact are those that contribute substantially to restoring ecosystem service. They have significant positive effects that are easily observable and measurable. These effects have a considerable impact on the ecosystem and may last for a long time.
5	Very High Impact	Measures that have a very high impact are those that contribute immensely to restoring ecosystem service. They have profound positive effects that are easily observable and measurable. These effects have a transformative impact on the ecosystem and may have the potential to contribute to the restoration of ecosystem service to a great extent.

water body/wetland, or a Public Space/Park.

Impact Score Calculation for each ecosystem service:

$$\text{Impact Score} = \sum \left\{ (n_{vh} * 5\Big) + (n_h * 4) + (n_m * 3) + (n_l * 2) + (n_n * 1) \right\}$$

where.

n_{vh} = number of preventive measures that have a very high impact on the ecosystem service.
N_h = number of preventive measures that have a high impact on the ecosystem service.
N_m = number of preventive measures that have a moderate impact on the ecosystem service.
n_l = number of preventive measures that have a low impact on the ecosystem service.
n_n = number of preventive measures that have a negligible impact on the ecosystem service.

Once the impact scores are obtained, these scores are compared for the iron ore mine and the colliery. This provides insights into which of the ecosystem services would be restored and where efforts need to be made to restore the other ecosystem services with a low score.

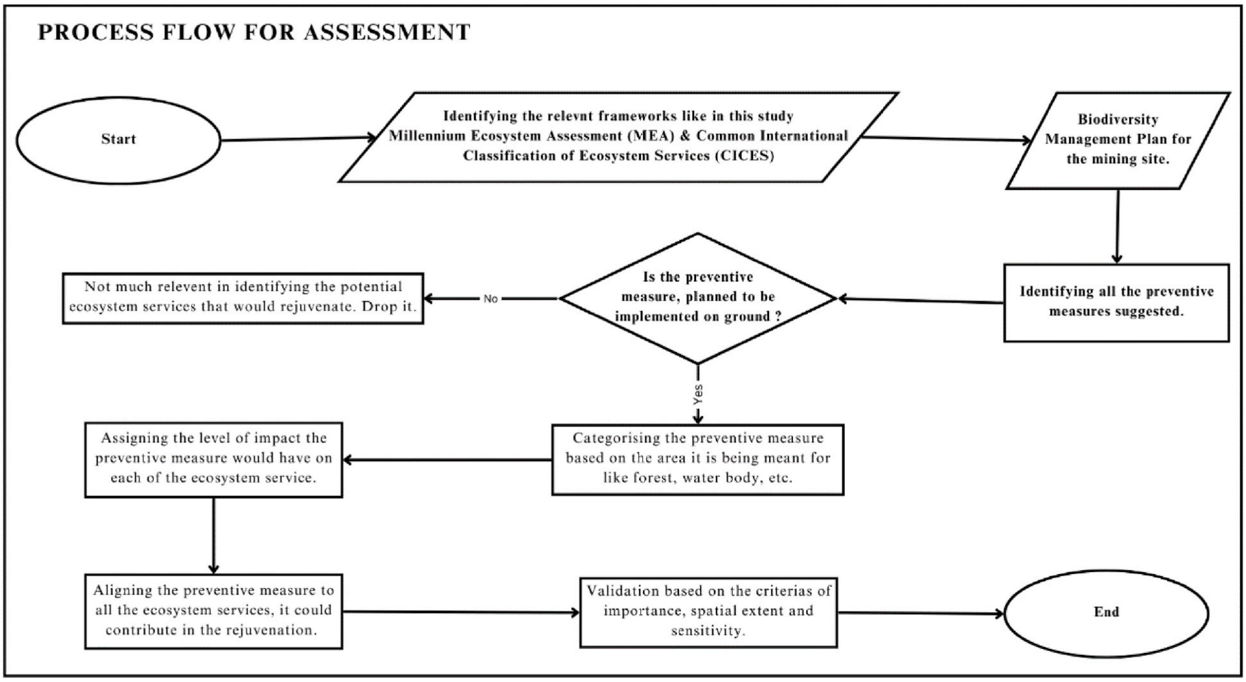

Fig. 2. Process flow diagram for the assessment.

3.3. Validation

The validation process, acknowledging the importance of expert opinions in assessing the spatial extents and sensitivity of ecosystem services, is depicted in Fig. 2. The consultation process involved soliciting expert opinions on various aspects of ecosystem services, including their spatial extents and sensitivity. Experts were provided with pertinent information and data regarding the ecosystems under study, allowing them to evaluate and provide insights based on their expertise. The use of the Borda Method in assigning importance values ensures a theoretically grounded validation process that considers the diverse perspectives of experts in the field, in line with the principles of the MEA. Finally, using Z-scores for standardization, aligning with statistical principles and enhancing the comparability of results across different ecosystem services. This step ensures that the impact scores are normalized, reflecting a methodological rigour consistent with the overarching principles of ecosystem services frameworks.

The equation employed is as follows:

$$\text{Impact Score} = (\text{Importance of Ecosystem Service}) \times (\text{Spatial Extent}) \times (\text{Sensitivity})$$

Where the importance of the ecosystem service is determined by a normalized value based on expert opinions, utilizing the Borda Method [33] to assess the degree of importance. Spatial extent represents the value derived from the reclaimed areas pertinent to the specific ecosystem service. Sensitivity denotes the value derived from various reports and surveys conducted by Tata Steel, incorporating expert opinions through the Borda Method [33] to ascertain sensitivity.

Scores are standardized using the Z-score, also known as the standard score. This statistical measure quantifies the deviation of a data point from the mean of a dataset in terms of standard deviations. It provides insight into how a data point relates to the overall distribution of the data. The formula to calculate the Z-score is as follows:

$$Z = (X - \mu) / \sigma$$

where, Z = Z-score, X = the data point you want to standardize, μ (mu) = the mean (average) of the dataset, σ (sigma) = the standard deviation of the dataset.

The Z-score for a data point (X) is calculated by subtracting the mean (μ) and dividing by the standard deviation (σ) of the dataset. This score indicates how many standard deviations the data point deviates from the mean. A positive Z-score signifies a data point above the mean, while a negative Z-score indicates a point below it. The magnitude of the Z-score reflects the extent of deviation from the mean in terms of standard deviations.

This research methodology expects to focus on implementing preventive measures to restore ecosystem services in the Noamundi Iron Ore Mine and the West Bokaro Coal Mine. By evaluating the impact of these measures on various ecosystem services, valuable insights can be gained regarding the potential outcomes of restoration efforts in different types of environments.

4. Results and discussion

The total area under restoration for the Noamundi Iron Ore Mine and West Bokaro Colliery has been reported as classified as per Table 6, illustrated as follows.

The data from Table 6 reveals the planned restoration efforts for the Noamundi Iron Ore Mine and West Bokaro Colliery. After restoration, the Noamundi Iron Ore Mine is expected to have 936.81 ha (ha) of forest/plantation, accounting for 91.86 % of its total area. Similarly, the West Bokaro Colliery anticipates 1416 ha of forest/plantation, comprising 81.38 % of its total area. This indicates a significant commitment to reforesting both sites. Additionally, Noamundi is projected to have 65 ha of water body/wetland (6.37 % of total area), while West Bokaro Colliery expects 74 ha (4.25 % of total area), suggesting efforts to restore aquatic habitats and preserve water resources.

For agricultural and public use, Noamundi aims for 18 ha (1.77 % of restored area), while West Bokaro Colliery targets 250 ha (14.37 % of restored area), indicating a greater emphasis on agricultural land and public utilization at West Bokaro. However, both sites plan to restore 100 % of their total area, with Noamundi aiming for 1019.81 ha and West Bokaro Colliery for 1740 ha. These comprehensive restoration efforts focus on mitigating environmental impacts, promoting biodiversity, and enhancing ecological resilience in the respective regions.

Tables 7–9 list the net impact scores and ranks of each ecosystem service expected to be restored as preventive measures are being implemented to restore degraded land into Forest/Plantation, Waterbody/Wetland and Agriculture/Public Use for both the study areas.

Table 6
Expected land use area (in ha.) post restoration for the Noamundi Iron Ore Mine and West Bokaro Colliery.

Land Use	Noamundi Iron Ore Mine		West Bokaro Colliery	
	Area (in ha.)	% of the total area	Area (in ha.)	% of the total area
Forest/Plantation	936.81	91.86 %	1416	81.38 %
Waterbody/Wetland	65	6.37 %	74	4.25 %
Agriculture & Public Use	18	1.77 %	250	14.37 %
Total restored area	**1019.81**	**100.00 %**	**1740**	**100.00 %**

Table 7
Impact score of ecosystem services being restored as preventive measures are implemented to restore the degraded land into forests/plantations.

Sr. No.	Ecosystem Service	Noamundi Iron Ore Mine		West Bokaro Colliery	
		Impact Score	Impact Rank	Impact Score	Impact Rank
1	Food	114	13	86	6
2	Raw Material - wood, biofuels, and fibers	108	14	85	8
3	Fresh Water	123	9	69	15
4	Medicinal Resources	83	18	51	18
5	Local climate and air quality	125	8	83	11
6	Carbon sequestration and storage	171	1	124	1
7	Moderation of extreme events	134	6	85	8
8	Water Purification	123	9	72	14
9	Erosion prevention- soil fertility maintenance	162	3	110	3
10	Pollination	98	16	79	13
11	Biological Control	98	16	65	17
12	Regulation of Water flow	145	4	86	6
13	Habitat for species	168	2	123	2
14	Maintenance of genetic diversity	145	4	106	4
15	Recreation, mental and physical health	121	11	84	10
16	Tourism	99	15	69	15
17	Aesthetic appreciation- culture inspiration-art and design	134	6	92	5
18	Spiritual experience- a sense of place	119	12	80	12

Table 8
Impact score of ecosystem services being restored as preventive measures are implemented to restore the degraded land into waterbody/wetland.

Sr. No.	Ecosystem Service	Noamundi Iron Ore Mine		West Bokaro Colliery	
		Impact Score	Impact Rank	Impact Score	Impact Rank
1	Food	54	13	57	10
2	Raw Material - wood, biofuels, and fibers	34	18	35	15
3	Fresh Water	91	2	84	1
4	Medicinal Resources	35	16	29	17
5	Local climate and air quality	49	14	42	14
6	Carbon sequestration and storage	64	8	52	11
7	Moderation of extreme events	76	6	66	6
8	Water Purification	81	5	73	5
9	Erosion prevention and maintenance of soil fertility	88	3	74	4
10	Pollination	35	16	28	18
11	Biological Control	40	15	31	16
12	Regulation of Water flow	93	1	84	1
13	Habitat for species	82	4	76	3
14	Maintenance of genetic diversity	63	9	62	7
15	Recreation, mental and physical health	63	9	59	8
16	Tourism	55	12	49	13
17	Aesthetic appreciation- culture inspiration-art and design	65	7	59	8
18	Spiritual experience- a sense of place	60	11	52	11

The data presented in Tables 5–8 provide valuable insights into the restoration efforts and the impact on ecosystem services in the Noamundi Iron Ore Mine and West Bokaro Colliery areas. The findings indicate a significant emphasis on reestablishing forested ecosystems, restoring aquatic habitats, and allocating land for agricultural and public use. The restoration initiatives aim to mitigate the environmental impact of mining activities, promote biodiversity, and enhance ecological resilience in the respective regions.

In terms of restoration efforts, both mining sites have made substantial commitments to restore degraded land. The restoration targets for forest/plantation areas and water bodies/wetlands are notable, with a focus on creating a balanced ecosystem. The impact scores and ranks of ecosystem services demonstrate the positive effects of restoration efforts. This study underscores the significant impact of restoration measures on crucial ecological aspects at both mining sites, including carbon sequestration, erosion prevention, soil fertility maintenance, habitat provision, and genetic diversity preservation. Additionally, services like freshwater availability, local climate regulation, air quality maintenance, water purification, and moderation of extreme events demonstrate notable impact scores, highlighting their vital role in sustaining a resilient ecosystem. While certain services like food production, raw materials, medicinal resources, pollination, and biological control have lower impact scores, it is important to consider restoration efforts' specific context and focus. The study's impact scores and rankings for various ecosystem services in public spaces and agriculture offer valuable insights. The preservation of genetic diversity and habitat creation for species are consistently recognized as crucial services in both areas. Carbon sequestration and storage, food production, freshwater provision, erosion prevention and recreation, and mental and physical health are important aspects targeted for restoration, albeit with varying impact scores and ranks.

The data underscores the positive impact of restoration efforts in both mining sites, with significant improvements in various

Table 9
Impact score of ecosystem services being restored as preventive measures are implemented to restore the degraded land into public spaces and agriculture.

Sr. No.	Ecosystem Service	Noamundi Iron Ore Mine		West Bokaro Colliery	
		Impact Score	Impact Rank	Impact Score	Impact Rank
1	Food	9	9	16	3
2	Raw Material - wood, biofuels, and fibres	5	18	6	16
3	Fresh Water	7	11	5	17
4	Medicinal Resources	7	11	9	11
5	Local climate and air quality	7	11	9	11
6	Carbon sequestration and storage	11	6	10	8
7	Moderation of extreme events	7	11	7	14
8	Water Purification	7	11	5	17
9	Erosion prevention and maintenance of soil fertility	11	6	9	11
10	Pollination	7	11	13	6
11	Biological Control	7	11	12	7
12	Regulation of Water flow	8	10	7	14
13	Habitat for species	14	2	18	1
14	Maintenance of genetic diversity	15	1	17	2
15	Recreation, mental and physical health	12	4	15	4
16	Tourism	10	8	10	8
17	Aesthetic appreciation- culture inspiration-art and design	13	3	14	5
18	Spiritual experience- a sense of place	12	4	10	8

ecosystem services. The restoration of degraded land into forests, plantations, water bodies, wetlands, and agricultural areas has led to enhanced carbon sequestration, soil fertility, habitat creation, genetic diversity conservation, and other essential ecological functions. These findings highlight the success of preventive measures in restoring and conserving the ecosystems, promoting their resilience, and benefiting both local communities and the environment. However, understanding the impact scores and ranks could guide decision-making processes during restoration efforts, enabling the allocation of resources and prioritization of actions to maximize the positive effects on ecosystem services. Prioritizing essential services in restoration projects can promote sustainable natural resource management, bolster ecosystem resilience, and deliver a multitude of advantages to both local communities and the environment.

We compared the rankings of different ecosystem services based on the restoration of degraded land into three different types of areas. Figs. 3 and 4 compare the rankings of different ecosystem services for forest, waterbody/wetland, and public space/agriculture. These rankings reveal which ecosystem services are most susceptible to significant impacts based on the specific type of area where land restoration occurs. Thus, analyzing these rankings provides valuable insights into the potential effects on diverse ecosystem services.

The analysis of Figs. 3 and 4 reveals intriguing insights into the potential for ecosystem service restoration in the Noamundi Iron

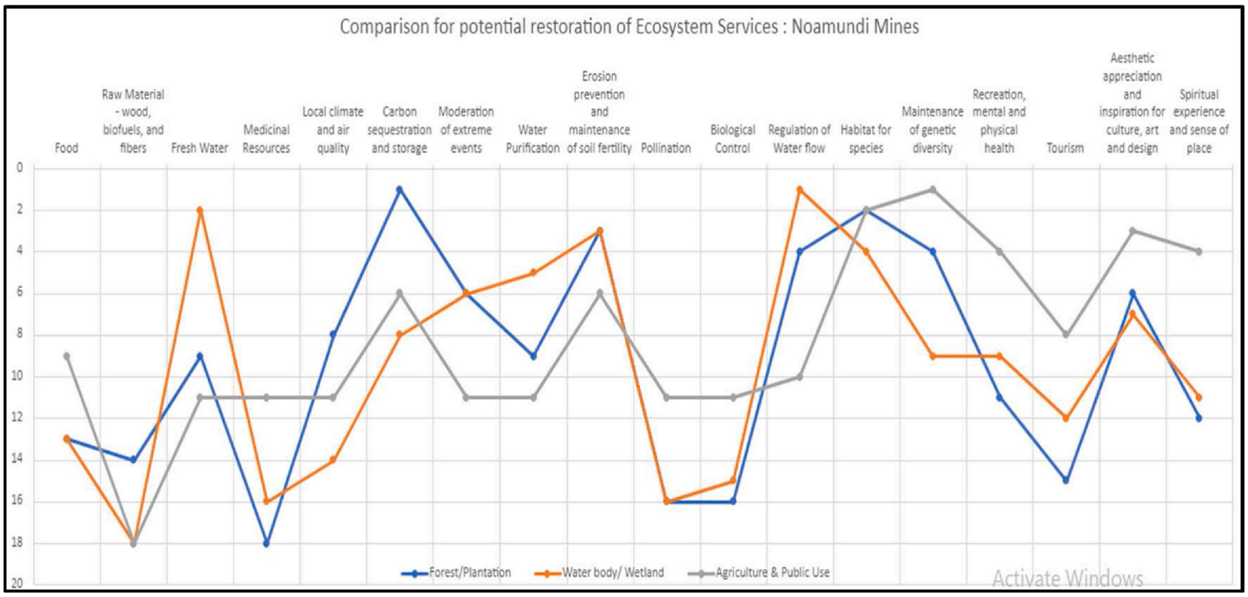

Fig. 3. Comparison of potential restoration of ecosystem services based on the type of area in which the degraded land has been restored for the Noamundi Iron Ore Mine.

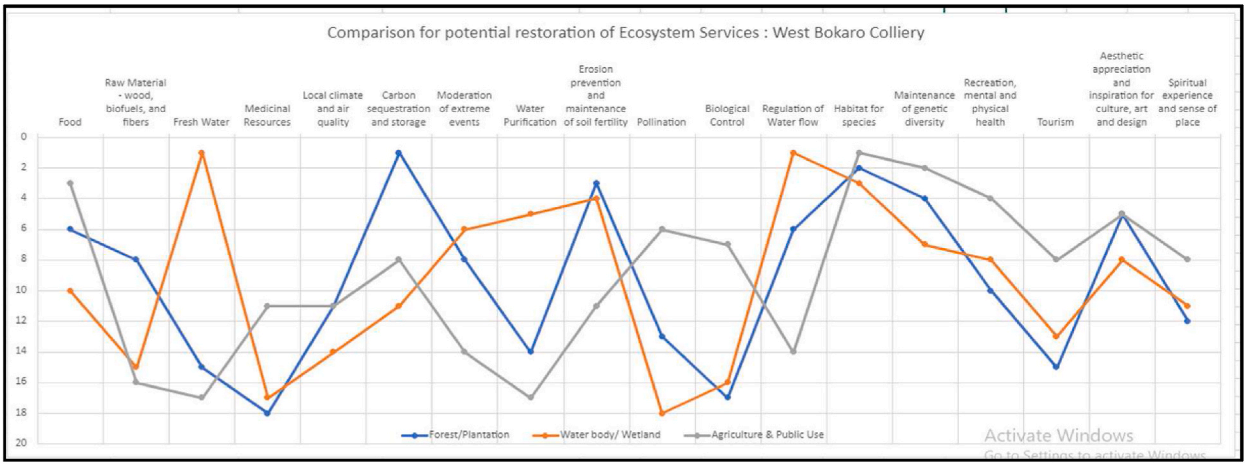

Fig. 4. Comparison of potential restoration of ecosystem services based on the type of area the degraded land has been restored for the West Bokaro Colliery.

Ore Mine area and the West Bokaro Colliery region. In terms of forest/plantation restoration, carbon sequestration and storage emerge as the top-ranked ecosystem service, emphasizing the contribution of reestablishing forests to climate change mitigation. The importance of providing habitats for species is also highlighted, emphasizing the need for diverse habitats to preserve local biodiversity. When it comes to water body/wetland restoration, water flow regulation takes the highest rank, suggesting that restoring water bodies and wetlands can help manage water resources and mitigate flooding or drought impacts. The significance of freshwater availability and water purification is also emphasized, underlining the importance of restoring water ecosystems for a sustainable supply of clean water. In the Agriculture and Public Use category, erosion prevention and maintenance of soil fertility rank highest, indicating the importance of converting degraded land into productive agricultural areas for sustainable agriculture practices. The potential benefits of restoration in terms of medicinal plant availability, local climate improvement, and air quality are also

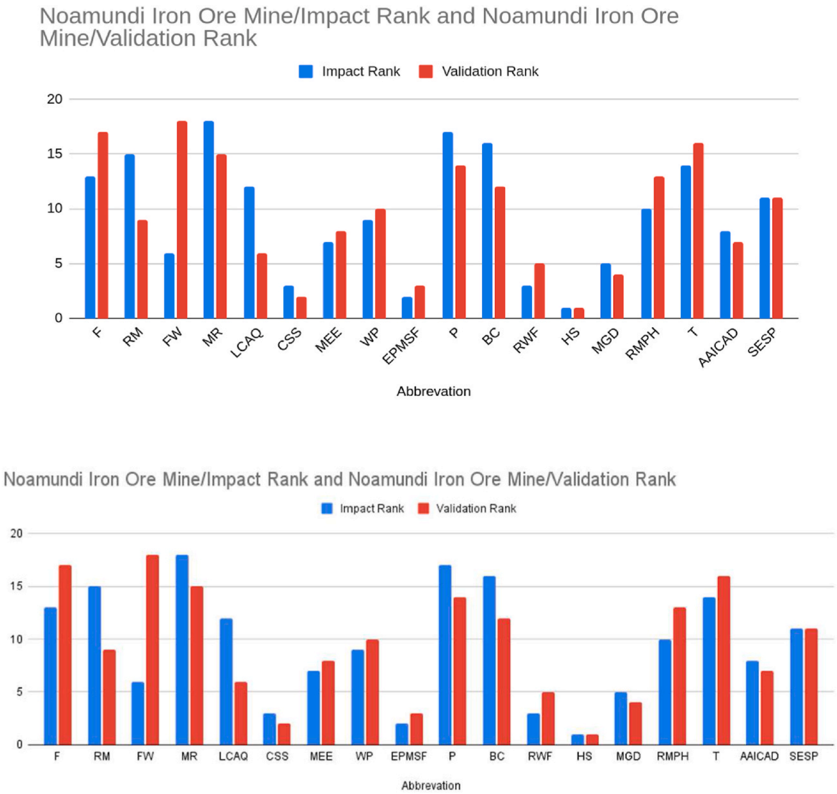

Fig. 5. Comparison of the impact and validation ranks for the Noamundi iron ore mine.

highlighted. However, it is interesting to note that certain ecosystem services, such as raw materials, recreation, and mental and physical health, consistently rank across all three restoration categories. While raw material availability ranks relatively low, recreation and its associated health benefits maintain a moderate rank, showcasing the potential of restoring natural areas for recreational opportunities and community well-being.

The comparison presented in Fig. 4 further highlights the variation in ecosystem service rankings across different land use scenarios. Forest/Plantation restoration shows the highest potential for enhancing food production, while Water body/Wetland restoration has limited potential in this regard. However, Water body/Wetland restoration ranks highest in providing fresh water, underscoring the importance of wetlands for water purification and storage. Forest/Plantation stands out as the top performer in carbon sequestration and storage, emphasizing the role of forests in combating climate change. The rankings also emphasize the significance of different land uses in supporting biodiversity and habitat conservation. Agricultural lands are shown to have the potential to provide suitable habitats, while forests and wetlands closely follow in their ability to support diverse species.

The Noamundi Iron Ore Mine comparison highlights "Habitat for species" (HS) and "Maintenance of genetic diversity" (MGD) as the top-ranking impact categories, holding the first and fifth positions, respectively. This underscores the mine's crucial role in biodiversity conservation and safeguarding genetic resources. Meanwhile, "Carbon sequestration and storage" (CSS) and "Regulation of Water flow" (RWF) both hold third positions in impact ranks, highlighting their substantial roles in mitigating climate change and ensuring sustainable water management (Fig. 5).

In validation, "Erosion prevention and soil fertility maintenance" (EPMSF) and "Regulation of water flow" (RWF) secure the second and third positions. This affirms their crucial contributions to sustaining the ecological equilibrium of the site. These ranks also underscore the mine's commitment to sustainable land use and water resource management. The lower validation ranks of some services, such as "Pollination" (P) and "Tourism" (T), suggest potential areas for improvement in these aspects. Overall, this analysis provides a useful tool for assessing ecosystem services' ecological impact and validation, helping the Noamundi Iron Ore Mine and similar operations prioritize and improve their environmental practices.

West Bokaro Colliery's most impactful ecosystem service appears to be "Habitat for species" (HS), which holds the top position in impact and validation ranks. This highlights the colliery's crucial role in preserving biodiversity and providing a home for various species. Additionally, "Carbon sequestration and storage" (CSS) holds the third position in both impact and validation ranks, emphasizing its vital contribution to mitigating climate change through carbon storage (Fig. 6).

On the validation side, "Maintenance of genetic diversity" (MGD) secures the second position in validation ranks, highlighting the importance of preserving genetic resources at the colliery. In the fourth position, the strong validation rank of "Erosion prevention and maintenance of soil fertility" (EPMSF) underscores the commitment to sustainable land use and soil management. However, some services, such as "Food" (F) and "Recreation, mental and physical health" (RMPH), have lower validation ranks, indicating potential areas for improvement in these aspects. In summary, this analysis provides a comprehensive understanding of the ecological impact and validation of ecosystem services at the West Bokaro Colliery, aiding in assessing and enhancing its environmental practices. These findings align with Sustainable Development Goal 15, emphasizing the need to safeguard and restore terrestrial ecosystems, manage forests sustainably, combat desertification, reverse land degradation, and halt biodiversity loss. Ecosystem services like watershed protection, carbon sequestration, and climate regulation are vital. Forested areas, acting as natural carbon sinks, play a crucial role in mitigating climate change by absorbing greenhouse gases from the atmosphere.

While India has made significant progress in forest conservation and sustainable management, it is important to note that there are ongoing challenges, such as illegal logging, encroachment, and habitat fragmentation. However, the government, civil society organizations, and local communities continue to work together to address these challenges and promote the sustainable development of forests in alignment with SDG 15. This study aligns with SDG-15. Notably, certain ecosystem services, such as erosion prevention, soil fertility maintenance, recreation, mental and physical health benefits and aesthetic appreciation and inspiration, consistently maintain high rankings across different land use types. This resilience suggests their effectiveness in restoration, regardless of specific land use choices. The data emphasizes the significance of considering diverse ecosystem services for potential restoration in land management strategies. It offers crucial insights for decision-makers in planning sustainable land use practices and concurrently advancing ecosystem conservation in the Noamundi Iron Ore Mine area and the West Bokaro Colliery region.

5. Conclusion and suggestion

In the realm of sustainable management and the potential ecosystem restoration of mining sites, this research comprehensively explores the potential for restoring ecosystem services through the meticulous implementation of biodiversity management plans at TATA Steel's Noamundi Iron Ore Mine and the West Bokaro Colliery. The insights garnered from this study transcend geographical boundaries, providing valuable lessons for international audiences grappling with similar challenges in the delicate balance between industrial activities and environmental conservation [34]. The profound implications of this research underscore the transformative impact of preventive measures and multifaceted restoration strategies, offering a nuanced perspective on the intricate interplay between human activities and ecological resilience. The research findings cast a spotlight on the remarkable outcomes achieved through the restoration endeavors at these mining sites, where degraded land has been rejuvenated into thriving forests, complemented by strategically created water bodies, wetlands, and designated areas for public use and agriculture. This multifaceted approach not only underscores the potential for enhancing ecosystem services but also highlights the pivotal role of ecological resilience in sustaining these services over the long term. The restoration strategies adopted at Noamundi Iron Ore Mine and West Bokaro Colliery exemplify a holistic commitment to mitigating environmental impacts, promoting biodiversity, and bolstering overall ecological resilience.

An in-depth analysis of impact scores and ranks assigned to various ecosystem services reveals a fascinating narrative of ecological

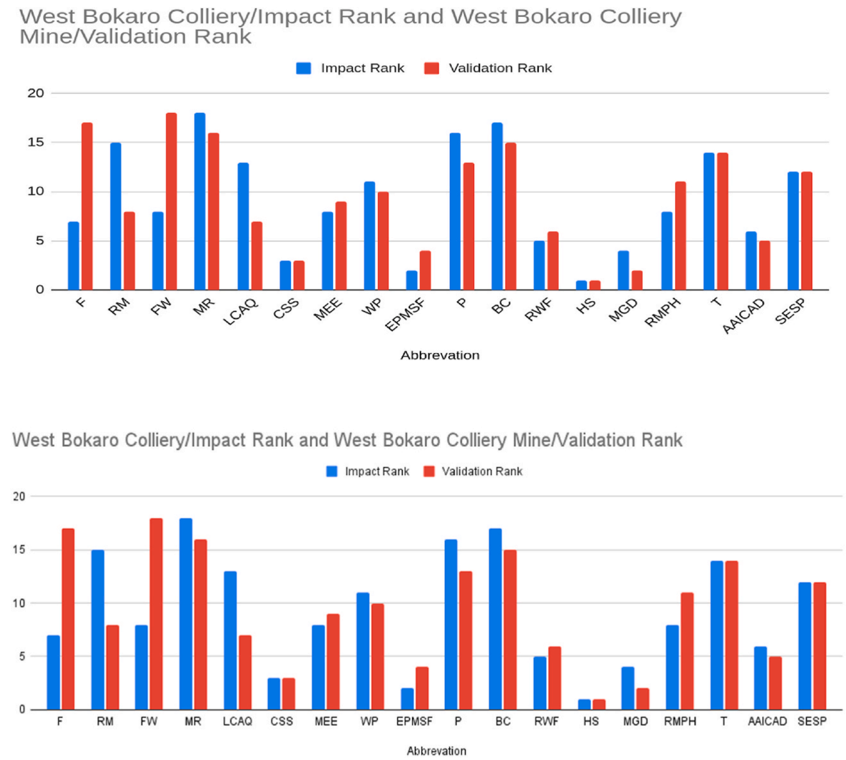

Fig. 6. Comparison of the impact and validation ranks for the west Bokaro colliery.

recovery. Essential services such as carbon sequestration, erosion prevention, soil fertility maintenance, habitat creation, and genetic diversity conservation emerge as key contributors to the restoration's success, each carrying a substantial impact score. These findings underscore the intricate web of ecological functions that collectively contribute to maintaining a healthy and resilient ecosystem [34]. The rankings of ecosystem services across different land types further enrich our understanding, offering nuanced insights into the differential impacts of restoration efforts. Furthermore, the success of these restoration initiatives, particularly in enhancing critical ecological functions like carbon sequestration, soil fertility, and habitat creation, serves as a testament to the efficacy of preventive measures in mitigating the environmental footprint of mining activities. This success story augments our understanding of the restorative potential of proactive measures and serves as a beacon for industries worldwide seeking sustainable practices [35].

Inextricably linked with the global sustainability agenda, the research aligns closely with the tenets of Sustainable Development Goal 15 (SDG-15), which advocates for ecosystem conservation and restoration. The emphasis on preventive measures, coupled with the facilitation of ecosystem services through biodiversity management plans, contributes to sustainable natural resource management and aligns with the broader narrative of responsible tourism, fostering a more resilient and sustainable future [36]. As detailed in this research, the restoration of ecosystem services stands as a crucial pillar in achieving the aspirations of SDG-15, delivering tangible benefits to both the environment and society at large. In addition, identifying priority services, such as "Habitat for species," "Carbon sequestration and storage," "Maintenance of genetic diversity," and "Erosion prevention and soil fertility maintenance," presents a strategic roadmap for future restoration projects. When prioritized, these key services preserve and enhance biodiversity and contribute significantly to global challenges. For instance, restoration projects focusing on carbon sequestration actively participate in mitigating climate change, playing a pivotal role in reducing the overall carbon footprint. This, in turn, supports broader climate action objectives and underlines the interconnectedness of ecological health and global challenges [34]. However, maintaining genetic diversity, another priority service holds significant implications for the sustainable use of terrestrial ecosystems. Beyond the immediate ecological benefits, preserving genetic diversity within these mining operations contributes to a broader pool of genetic resources with potential applications in agriculture, medicine, and conservation. This strategic approach aligns not only with the objectives of SDG-15 but also with the broader narrative of responsible and sustainable resource use [36]. ligned with Sustainable Development Goal 15 (SDG-15) - which emphasizes ecosystem conservation and restoration - the research emphasizes the importance of preventive measures and biodiversity management plans in promoting sustainable natural resource management. It directly contributes to SDG-15 targets, notably Target 15.1 (conservation and restoration of terrestrial and inland freshwater ecosystems) and Target 15.9 (integration of ecosystem and biodiversity values into planning processes).

Moreover, the research underscores the commitment to sustainable land use practices, with a specific focus on erosion prevention and maintenance of soil fertility. Beyond preventing land degradation, this commitment also bolsters agricultural productivity, presenting a symbiotic relationship between restoration efforts, local communities, and the broader environment. It echoes the sentiment that sustainable land use is not only an environmental imperative but also a pathway to improving the quality of life for local communities [34,37–40]. The practical applications of the research findings extend across a spectrum of stakeholders. Mining and colliery companies can leverage the insights to develop robust restoration plans, meet regulatory requirements, gain social acceptance, and enhance their reputations as responsible corporate entities. Government bodies and environmental agencies can draw upon the research's findings to formulate policies and guidelines for land restoration, thereby promoting sustainable land management practices on a broader scale [41–47]. The local communities, urban planners, and community organizations can tap into the restoration potential detailed in the research to initiate projects aimed at restoring degraded land, creating green spaces, and ultimately improving the quality of life. Conservation organizations and Non-Governmental Organizations (NGOs) have a unique opportunity to align their projects with the research's recommendations, maximizing their conservation impact and contributing to the broader global sustainability narrative. The research framework holds promise for influencing policy by advocating for biodiversity management plans in mining operations, thereby supporting the conservation and restoration of ecosystems. Additionally, prioritizing key ecosystem services can inform land-use planning, resource allocation, and environmental regulations, aligning with SDG-15's aim of integrating ecological considerations into policy formulation.

In essence, the research paints a vivid picture of the potential for restoring ecosystem services and provides a comprehensive and practical framework for stakeholders worldwide. The intricate interplay between preventive measures, restoration strategies, and the multifaceted benefits for the environment and society is a guiding beacon for sustainable land use practices. With its nuanced insights and practical applications, this research contributes significantly to the ongoing global discourse on advancing ecosystem conservation and promoting sustainable land management.

Funding

No funding is applied.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Hishmi Jamil Husain: Writing – original draft, Validation, Software, Resources, Investigation, Data curation, Conceptualization. **Xiuqing Wang:** Software, Resources. **Saied Pirasteh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Davood Mafi-Gholami:** Validation, Software, Resources, Methodology, Formal analysis. **Bhavesh Chouhan:** Software, Resources, Methodology, Formal analysis, Data curation. **Mohammed Latif Khan:** Software, Resources, Methodology, Formal analysis. **Mehdi Gheisari:** Software, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work was international joint research for building a foundation with the Institute of Artificial Intelligence, Shaoxing University, to support cross-disciplinary study, Geospatial Artificial Intelligence (GeoAI) and climate change for SDGs 2030. This work has not received any funds.

Appendix

Name of the Ecosystem Service	Abbreviation
Food	F
Raw Material - wood, biofuels, and fibers	RM
Fresh Water	FW
Medicinal Resources	MR
Local climate and air quality	LCAQ
Carbon sequestration and storage	CSS
Moderation of extreme events	MEE
Water Purification	WP
Erosion prevention and maintenance of soil fertility	EPMSF
Pollination	P
Biological Control	BC

(*continued on next page*)

(*continued*)

Name of the Ecosystem Service	Abbreviation
Regulation of Water flow	RWF
Habitat for species	HS
Maintenance of genetic diversity	MGD
Recreation, mental and physical health	RMPH
Tourism	T
Aesthetic appreciation and inspiration for culture, art and design	AAICAD
Spiritual experience and sense of place	SESP

References

[1] B. Fisher, R.K. Turner, P. Morling, Defining and classifying ecosystem services for decision making, Ecol. Econ. 68 (3) (2009) 643–653.
[2] R.T. Cenfetelli, I. Benbasat, S. Al-Natour, Addressing the what and how of online services: Positioning supporting-services functionality and service quality for business-to-consumer success, Inf. Syst. Res. 19 (2) (2008) 161–181.
[3] M.A. Palmer, D.C. Richardson, Provisioning services: a focus on fresh water, in: The Princeton Guide to Ecology, Princeton University Press, Princeton, NJ, 2009, pp. 625–633.
[4] K.M. Chan, J. Goldstein, T. Satterfield, N. Hannahs, K. Kikiloi, R. Naidoo, N. Vadeboncoeur, U. Woodside, Cultural services and non-use values. Natural Capital: Theory and Practice of Mapping Ecosystem Services, 2011, pp. 206–228.
[5] V. Hatzopoulos, Regulating Services in the European Union, Oxford University Press, Oxford, 2012, p. 346.
[6] R. Haines-Young, M. Potschin, The links between biodiversity, ecosystem services and human well-being, Ecosystem Ecology 1 (2010) 110–139.
[7] K. Peng, W. Jiang, Z. Ling, P. Hou, Y. Deng, Evaluating the potential impacts of land use changes on ecosystem service value under multiple scenarios in support of SDG reporting: a case study of the Wuhan urban agglomeration, J. Clean. Prod. 307 (2021) 127321, https://doi.org/10.1016/j.jclepro.2021.127321.
[8] Y.I. Zhang, S. Singh, B.R. Bakshi, Accounting for ecosystem services in life cycle assessment, Part I: a critical review, Environ. Sci. Technol. 44 (7) (2010) 2232–2242.
[9] S. Timsina, N.G. Hardy, D.J. Woodbury, M.S. Ashton, S.C. Cook-Patton, R. Pasternack, M.P. Martin, Tropical surface gold mining: a review of ecological impacts and restoration strategies, Land Degrad. Dev. 33 (18) (2022) 3661–3674.
[10] S. Zhang, Y. Zhou, R. Yu, X. Xu, M. Xu, G. Li, W. Wang, Y. Yang, China's biodiversity conservation in the process of implementing the sustainable development goals (SDGs), J. Clean. Prod. 338 (2022) 130595, https://doi.org/10.1016/j.jclepro.2022.130595.
[11] I. Pérez-Ramírez, J.M. Requena-Mullor, A.J. Castro, M. García-Llorente, Land transformation changes people's values of ecosystem services in Las Vegas agrarian landscapes of Madrid Spain, Land Use Pol. 134 (2023) 106921, https://doi.org/10.1016/j.landusepol.2023.106921.
[12] K. Prach, A. Tolvanen, How can we restore biodiversity and ecosystem services in mining and industrial sites? Environ. Sci. Pollut. Control Ser. 23 (2016) 13587–13590.
[13] J. Zhu, Y. Zhai, S. Feng, Y. Tan, W. Wei, Trade-offs and synergies among air-pollution-related SDGs as well as interactions between air-pollution-related SDGs and other SDGs, J. Clean. Prod. 331 (2022) 129890, https://doi.org/10.1016/j.jclepro.2021.129890.
[14] R. Boldy, T. Santini, M. Annandale, P.D. Erskine, L.J. Sonter, Understanding the impacts of mining on ecosystem services through a systematic review, Extr. Ind. Soc. 8 (1) (2021) 457–466, https://doi.org/10.1016/j.exis.2020.12.005.
[15] D. Brown, L. Baker, The Lord Howe Island biodiversity management plan: an integrated approach to recovery planning, Ecol. Manag. Restor. 10 (2009) S70–S78, https://doi.org/10.1111/j.1442-8903.2009.00449.x.
[16] T. Husodo, S.S. Shanida, E.N. Megantara, Biodiversity management plan in the non-conservation area, Cisokan hydropower plan area, Cianjur, West Java, Indonesia. Biodiversitas *Journal of Biological Diversity* 20 (6) (2019).
[17] M. Ćosović, M.N. Bugalho, D. Thom, J.G. Borges, Stand structural characteristics are the most practical biodiversity indicators for forest management planning in Europe, Forests 11 (3) (2020) 343, https://doi.org/10.3390/f11030343.
[18] D. Govindarajulu, R. Pritchard, A. Chhatre, T. Foster, J.A. Oldekop, Rights based approaches to forest landscape restoration; learning from the Indian forest policy experience, For. Pol. Econ. 157 (2023) 103073, https://doi.org/10.1016/j.forpol.2023.103073.
[19] K. Prins, M. Köhl, S. Linser, Is the concept of sustainable forest management still fit for purpose? For. Pol. Econ. 157 (2023) 103072 https://doi.org/10.1016/j.forpol.2023.103072.
[20] M.H. Ayazi, S. Pirasteh, B. Pradhan, A. Mahmoodzadeh, Disasters and risk reduction in groundwater: Zagros mountain, southwest Iran using geoinformatics techniques, Disaster Advances 3 (1) (2010) 51–57.
[21] S. Pirasteh, M. Varshosaz, Sustainable Development Goals Connectivity Dilemma Land and Geospatial Information for Urban and Rural Resilience, CRC Press, Taylor & Francis Group, 2019, pp. 93–108. ISBN:13:978-0-367-25935-8.
[22] P. Amanehalsadat, F.H. Lotfi, S. Pirasteh, Vulnerability assessment and modeling of urban growth using data envelopment, Journal of the Indian Society of Remote Sensing 49 (2) (2020) 259–273, https://doi.org/10.1007/s12524-020-01206-4.
[23] S. Pirasteh, J. Husain Hishmi, R. Tammineni, COVID-19 Pandemic Challenges and Impacts on the SDGs 2030: Indian Perspective, CRC Press, Taylor & Francis Group, 2020, pp. 455–468. ISBN 9780367775315, 544 Pages 148.
[24] D. Mafi-Gholami, S. Pirasteh, J.C. Ellison, A. Jaafarid, Fuzzy-based vulnerability assessment of coupled social-ecological systems to multiple environmental hazards, J. Environ. Manag. 299 (2021) (2021) 113573, https://doi.org/10.1016/j.jenvman.2021.113573.
[25] W. Li, J. Zhu, S. Pirasteh, Q. Zhu, L. Fu, J. Wu, Investigations of disaster information representation from geospatial perspective: progress, challenges, and recommendations, Trans. GIS (2022), https://doi.org/10.1111/tgis.12922,00:1–23.
[26] E.M. Bennett, G.D. Peterson, L.J. Gordon, Understanding relationships among multiple ecosystem services, Ecol. Lett. 12 (12) (2009) 1394–1404, https://doi.org/10.1111/j.1461-0248.2009.01387.x.
[27] G.C. Daily, P.A. Matson, Ecosystem services: from theory to implementation, Proc. Natl. Acad. Sci. USA 105 (28) (2008) 9455–9456, https://doi.org/10.1073/pnas.0804960105.
[28] S.R. Carpenter, E.M. Bennett, G.D. Peterson, Scenarios for ecosystem services: an overview, Ecol. Soc. 11 (1) (2006), https://doi.org/10.5751/ES-01610-110129.
[29] S. Panda, K. Banerjee, M.K. Jain, Identification of iron ore mines of Noamundi, Jharkhand by using satellite based hyperspectral and geospatial technology, Int. J. Sci. Res. 3 (6) (2014) 149–152.
[30] Indian Bureau of Mines, Noamundi Iron Mine, M/s TATA Steel LTD, IBM, 2014. Retrieved from, https://ibm.gov.in/writereaddata/files/08202014164430Nuvamundi%20Iron%20Ore%20Mnes-.pdf.
[31] International Union for Conservation of Nature (IUCN) & TATA Steel, Biodiversity management plan: west Bokaro colliery, in: In TATA Steel, IUCN, 2016.
[32] Millennium Ecosystem Assessment (MEA), Ecosystems and Human Well-Being: Synthesis, 2006. www.millenniumassessment.org/documents/document.356.aspx.pdf.
[33] M.A. Zahid, H. De Swart, The borda majority count, Inf. Sci. 295 (2015) 429–440.

[34] W. Zhao, S. Wu, X. Chen, J. Shen, F. Wei, D. Li, L. Liu, S. Li, How would ecological restoration affect multiple ecosystem service supplies and tradeoffs? A study of mine tailings restoration in China, Ecol. Indicat. 153 (2023) 110451, https://doi.org/10.1016/j.ecolind.2023.110451, 110451.

[35] D.M. Evans, C.E. Zipper, J.A. Burger, B.D. Strahm, A.M. Villamagna, Reforestation practice for enhancement of ecosystem services on a compacted surface mine: path toward ecosystem recovery, Ecol. Eng. 51 (2013) 16–23, https://doi.org/10.1016/j.ecoleng.2012.12.065.

[36] J. Siqueira-Gay, Britaldo Soares-Filho, Enrique Sánchez Luís, A. Oviedo, L.J. Sonter, Proposed legislation to mine Brazil's indigenous lands will threaten amazon forests and their valuable ecosystem services, One Earth 3 (3) (2020) 356–362, https://doi.org/10.1016/j.oneear.2020.08.008.

[37] D. Pearce, Auditing the earth: the value of the world's ecosystem services and natural capital, Environment 40 (2) (1998) 23–28.

[38] Noamundi Iron Mine, M/s TATA STEEL LTD - IBM https://ibm.gov.in/writereaddata/files/08202014164430Nuvamundi%20Iron%20Ore%20Mnes-.pdf..

[39] M.J. Martínez-Harms, P. Balvanera, Methods for mapping ecosystem service supply: a review, International Journal of Biodiversity Science 8 (1–2) (2012) 17–25.

[40] G.M. Mace, K. Norris, A.H. Fitter, Biodiversity and ecosystem services: a multilayered relationship, Trends Ecol. Evol. 27 (1) (2012) 19–26, https://doi.org/10.1016/j.tree.2011.08.006.

[41] S. Kumi, P. Addo-Fordjour, B. Fei-Baffoe, Mining-induced changes in ecosystem services value and implications of their economic and relational cost in a mining landscape, Ghana, Heliyon 9 (10) (2023) e21156, https://doi.org/10.1016/j.heliyon.2023.e21156.

[42] D.B. Lindenmayer, G.E. Likens, A. Andersen, D. Bowman, C.M. Bull, E. Burns, C.R. Dickman, A.A. Hoffmann, D.A. Keith, M.J. Liddell, A.J. Lowe, Value of long-term ecological studies, Austral Ecol. 37 (7) (2012) 745–757.

[43] E. Kumar, T. Subramani, D. Karunanidhi, Integrated approach of ecosystem services for mine reclamation in a clustered mining semi-urban region of South India, Urban Clim. 45 (2022) 101246, https://doi.org/10.1016/j.uclim.2022.101246, 101246.

[44] M. Kaljonen, Bringing back the lost biotopes: the practice of regional biodiversity management planning in Finland, J. Environ. Pol. Plann. 10 (2) (2008) 113–132.

[45] T. Ashwani, S. Prasoon, M. Mukesh, Hydrogeochemical investigation and qualitative assessment of surface water resources in west Bokaro Coalfield, India, J. Geol. Soc. India 87 (2016) 85–96, https://doi.org/10.1007/s12594-016-0376-y.

[46] V. Assumma, M. Bottero, C. Caprioli, G. Datola, G. Mondini, Evaluation of ecosystem services in mining basins: an application in the piedmont region (Italy), Sustainability 14 (2) (2022) 872, https://doi.org/10.3390/su14020872.

[47] Tata Steel, Tata Steel's Noamundi and Joda East Iron Mines Accorded 5-star Rating for Sustainable Development for the Year 2021-22, Tata World, 2023, March 8. Retrieved from, https://www.tataworld.com/news/openinside/tata-steels-noamundi-and-joda-east-iron-mines.