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Mine reclamation practices and effects of stakeholder perception — a case study of Saoner mines, Maharashtra, India

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Abstract

The Saoner mine reclamation study conducted in Maharashtra, India, meticulously investigates the practicality and efficacy of ecological restoration initiatives post-mining operations. Employing multifaceted research approach, including field observations, interviews, and questionnaires, the study captures a diverse array of perspectives from stakeholders representing local communities, mining companies, regulatory bodies, and environmental organizations. Within this complexity, the research uncovers spectrum of viewpoints. Encouragingly, positive outcomes emerge from specific reclamation practices like revegetation and soil stabilization. However, substantial challenges linger in vital areas such as water management, soil quality restoration, and post-reclamation monitoring, demanding targeted interventions. Stakeholders' diverse concerns reflect varying priorities. Local communities express apprehension about the adequacy of reclamation efforts and potential health implications, underscoring immediate impact on their lives. Mining companies prioritize regulatory compliance and economic contributions, emphasizing their immediate obligations. Simultaneously, environmental organizations advocate for stringent monitoring and the adoption of more robust practices, reflecting long-term ecological perspective. The study suggests a holistic approach to mining, beyond regulatory compliance, involving integrated planning, ongoing monitoring, and stakeholder engagement. This approach can reduce the industry's environmental footprint, promote sustainable development, and foster harmony between mining activities and local communities, making it a crucial foundation for Saoner and other Indian mining regions.

Keywords: Mine reclamation, Stakeholder perception, Environmental impacts, Ecological restoration, Saoner mines

Introduction

Mining has a rich historical legacy, dating back to 4000 B.C., with coal mining in India officially documented since 1774 [79, 85, 86]. Coal stands as India's primary fossil fuel, crucial for its burgeoning population and growing economy [12]. While catering to the escalating energy demands, mining significantly contributes to economic growth, with coal predominantly consumed by the power sector, followed by iron, steel, and cement industries [94, 99, 108, 127, 130]. Despite its benefits, coal mining engenders detrimental

environmental impacts, affecting terrestrial and aquatic ecosystems and nearby communities [146, 136]. Chemical alterations influence groundwater and surface water, reshaping land morphology and topography [154, 156]. Microclimate changes disrupt wind patterns, flora, fauna, and soil productivity, exacerbating ecological degradation [164, 167]. Human activities, driven by population growth and development, further exacerbate environmental degradation through activities like deforestation, mining, and land clearing for agriculture and settlement [148, 152, 159, 153]. Environmental preservation efforts, including ecosystem rehabilitation, are imperative to mitigate these adverse effects, aiming to restore damaged ecosystems [118, 121, 131]. Such measures are projected to not only restore ecosystems but potentially enhance them beyond their original state.

Mine reclamation refers to the process of restoring a mined-out area to a state that is safe, environmentally sustainable, and suitable for future land use [117, 119]. It is an essential step in mitigating the negative impacts of mining activities on ecosystems and communities [161, 163]. Reclamation efforts involve a series of comprehensive measures aimed at minimizing erosion, restoring vegetation, rehabilitating water bodies, and addressing any potential contamination [158, 160].

Mine reclamation aims to restore land's physical characteristics and stability by reshaping land, regrading slopes, and stabilizing soil to prevent erosion and landslides [10, 18, 124]. This restoration facilitates various activities like agriculture, recreation, and supports diverse vegetation and wildlife habitats [98]. Replanting native species enhances ecosystem resilience, aesthetic value, and soil stability while considering local ecological factors [77, 82–84, 90, 92, 91, 97]. Additionally, reclamation efforts focus on rehabilitating water bodies impacted by mining, ensuring water quality and the health of aquatic ecosystems [81, 87, 88, 100, 101, 104]. Contaminated areas are addressed through remediation measures to clean up and restore soils, sediments, and groundwater, safeguarding human and ecological health [78, 80]. Community engagement throughout the reclamation process, including indigenous peoples' involvement, ensures long-term sustainability and compatibility with local needs and aspirations [57, 59, 60, 64–67, 70].

In conclusion, mine reclamation is a multifaceted process that aims to restore mined-out areas to a state of ecological and social well-being. Through careful planning, implementation of remediation techniques, and collaboration with communities, mine reclamation strives to mitigate the environmental impacts of mining and create sustainable landscapes for future generations [168].

Mine reclamation practices and stakeholder perception are closely intertwined and can have significant effects on each other [44, 61, 74, 76]. The perception of mine reclamation can have several effects, including social, economic, and environmental impacts [1, 3–5, 20, 21]. Here are some key points regarding the relationship between mine reclamation practices and the effects of stakeholder perception:

1. Stakeholder involvement: Stakeholder perception of mine reclamation practices hinges on their involvement in planning and decision-making processes [8]. Active engagement of stakeholders such as local communities, indigenous groups, environmental organizations, and government agencies, where their concerns are considered, leads to positive perceptions of reclamation efforts. Conversely, excluding

stakeholders or not addressing their concerns adequately can engender negative perceptions and potential conflicts [7, 11].

2. Trust and credibility: The perception of mine reclamation practices is closely linked to the trust and credibility of the mining industry and the companies involved [16]. If stakeholders perceive that mining companies are committed to responsible mining practices and prioritize effective reclamation, it can enhance trust and improve perceptions [3]. Conversely, if stakeholders perceive that the industry is not transparent, accountable, or committed to environmental stewardship, it can lead to skepticism and negative perceptions [2, 5, 6].
3. Communication and transparency: Effective communication and transparency about mine reclamation practices can significantly impact stakeholder perception [15]. Mining companies should proactively communicate their reclamation plans, progress, and outcomes to stakeholders, providing clear and accessible information. Transparent reporting on monitoring data, environmental impacts, and remediation efforts can help build trust and improve stakeholder perception [9, 13].
4. Demonstrated results: The actual outcomes of mine reclamation efforts play a crucial role in shaping stakeholder perception. When stakeholders observe successful reclamation projects that result in the restoration of ecosystems, improved water quality, and the creation of sustainable land uses, it can foster positive perceptions. Conversely, if stakeholders perceive that reclamation efforts are inadequate, ineffective, or result in long-term environmental harm, it can lead to negative perceptions and distrust [22].
5. Long-term monitoring and maintenance: Stakeholder perception can be influenced by the commitment of mining companies to long-term monitoring and maintenance of reclaimed mine sites [30, 34]. Demonstrating ongoing efforts to ensure the stability, safety, and ecological integrity of the reclaimed land can enhance stakeholder confidence in the reclamation practices. Neglecting long-term monitoring and maintenance can result in negative perceptions and concerns about the sustainability of the reclamation efforts [37].
6. Social and economic benefits: Stakeholder perception of mine reclamation practices can also be influenced by the social and economic benefits generated by reclaimed mine sites [4]. When reclamation efforts result in job creation, community development, and sustainable land uses, it can contribute to positive perceptions. Mining companies that actively engage with local communities and share the benefits of reclamation efforts can build stronger relationships and improve stakeholder perception [28, 33, 40].

It is essential for mining companies to prioritize stakeholder engagement, transparency, and the effective implementation of mine reclamation practices to ensure positive perceptions among stakeholders [32, 36]. By addressing concerns, demonstrating environmental responsibility, and delivering successful reclamation outcomes, companies can foster trust, gain social acceptance, and contribute to sustainable mining practices [165].

Mine reclamation in India is gaining increasing attention and importance due to the country's extensive mining activities and the need to address their environmental and

social impacts. The government and mining companies are actively involved in reclamation efforts to restore mined-out areas and mitigate the damage caused by mining operations [150, 151].

One of the primary goals of mine reclamation in India is the rehabilitation of abandoned mines, which pose significant environmental and safety hazards [155]. Efforts concentrate on stabilizing slopes, backfilling open pits, and implementing erosion control measures to prevent soil degradation and water pollution [147]. Identifying and prioritizing reclamation sites are crucial for restoring affected areas. Sustainable practices are increasingly emphasized, including ecological restoration with native plant species and soil remediation to address fertility issues and contamination [144]. These measures aim to restore biodiversity and promote long-term land health. Water management is another critical aspect, addressing impacts on local water sources through sedimentation ponds, water treatment systems, and conservation practices [122]. The goal is to restore and preserve water quality and availability in mining areas. Community engagement is integral, involving local communities in decision-making and activities to ensure plans respect their cultural practices and livelihoods [116]. Creating sustainable economic opportunities post-mining, such as agriculture or tourism, benefits local communities in the long term.

Mine reclamation and geotourism are two interconnected concepts that can work hand in hand to promote sustainable development and environmental conservation in mining regions. Visiting scenic natural areas is a long-standing tradition. However, the concept of geotourism has only recently emerged. Geotourism is a novel addition to the rapidly expanding niche or special interest tourism [74] that uses landscapes with significant geological and geographical significance as the focal point of tourism appeal. Unlike ecotourism, which emphasizes biotic aspects (flora and fauna), geotourism emphasizes abiotic elements of nature and focuses on the interpretation and preservation of these earthly features by boosting their touristic value [47, 114]. Thomas Hose coined the phrase in 1995, defining it as "geology-based tourism," which allows tourists to get in-depth understanding of a location's geology and geomorphology through interpretive and service facilities.

In the context of India, mine reclamation practices and stakeholder perception have significant implications for the mining industry and the environment. Here are some key points specific to India:

1. Regulatory framework: India has established a regulatory framework for mine reclamation, including guidelines and regulations for environmental impact assessments, mine closure plans, and reclamation activities. Stakeholders, including government agencies, local communities, and environmental organizations, closely monitor and evaluate mining companies' compliance with these regulations. The perception of how well these regulations are enforced and implemented can influence stakeholder perception of mine reclamation practices [19].
2. Community engagement: In India, mining operations often directly impact local communities, especially in tribal and rural areas. Effective engagement with these communities is crucial for successful mine reclamation practices and positive stakeholder perception. Engaging stakeholders through consultations, information shar-

ing, and incorporating their traditional knowledge and concerns into the reclamation plans can build trust and foster positive perceptions [23].

3. Environmental impacts: Mining activities in India can have significant environmental impacts, including land degradation, deforestation, soil erosion, and water pollution. Stakeholder perception of mine reclamation practices is influenced by the extent to which these environmental impacts are addressed and mitigated. Effective reclamation practices, such as revegetation, soil stabilization, and water treatment measures, can improve stakeholder perception by demonstrating a commitment to minimizing environmental harm [25, 27].
4. Social and economic benefits: Stakeholder perception is also shaped by the social and economic benefits generated through mine reclamation. In India, reclaimed mine sites can be repurposed for agriculture, forestry, renewable energy, or other sustainable land uses, providing opportunities for employment, income generation, and community development. Ensuring that local communities benefit from these opportunities and sharing the economic benefits can contribute to positive stakeholder perception [31, 35].
5. Transparency and accountability: Transparent reporting on mine reclamation progress, monitoring data, and environmental outcomes is essential for building trust and improving stakeholder perception. Mining companies should provide accessible information to stakeholders, including local communities, environmental organizations, and government agencies, to demonstrate their commitment to responsible mining practices and the effectiveness of reclamation efforts [38].
6. Traditional knowledge and cultural heritage: In India, mining activities often impact areas with rich cultural heritage and traditional knowledge systems. Incorporating traditional knowledge into mine reclamation practices and respecting cultural sensitivities can positively influence stakeholder perception. Engaging with indigenous communities and incorporating their perspectives and practices into reclamation plans can help preserve cultural heritage and foster positive relationships with stakeholders [39, 41, 42].

In summary, mine reclamation practices and stakeholder perception in India are influenced by regulatory frameworks, community engagement, environmental impacts, social and economic benefits, transparency, and the preservation of traditional knowledge. Mining companies that prioritize sustainable and responsible reclamation practices, engage with stakeholders, address environmental concerns, and share the benefits of reclamation efforts can improve stakeholder perception and contribute to the sustainable development of the mining industry in India [143].

Studying mine reclamation measures in India is essential for several reasons. Firstly, it enables us to mitigate the environmental impacts caused by mining activities, such as land degradation and water pollution. By understanding effective reclamation techniques, we can restore ecosystems and promote sustainable land use. Secondly, studying mine reclamation measures helps ensure compliance with regulations and guidelines set by the government, ensuring responsible mining practices [138, 140]. It also enables the development of best practices and innovative approaches to improve the efficiency and effectiveness of reclamation efforts [137, 139, 141]. Finally, studying mine reclamation

in India fosters stakeholder engagement, including mining companies, government bodies, and local communities, to address their concerns and aspirations [135]. Overall, this knowledge contributes to sustainable development, environmental protection, and responsible land management in the mining sector.

Literature review on mine reclamation

Mine reclamation stands as a pivotal process aiming to restore both ecological integrity and socio-economic value to land affected by mining activities. This review delves into pertinent studies, encapsulating best practices, challenges, and environmental considerations surrounding mine reclamation [129].

Numerous studies underscore the significance of early planning, site-specific approaches, and ecosystem-based restoration in mine reclamation. Strategies such as recontouring land to match original topography; stabilizing soil through amendments, erosion control; and utilizing native plant species foster successful vegetation establishment and biodiversity recovery. Water management techniques like constructed wetlands and sedimentation ponds play crucial roles in preserving water quality and aquatic habitats [123, 134, 162].

Evaluations of ecological impacts post-reclamation reveal the potential for restoring soil fertility, establishing diverse plant communities, and reinstating native fauna [107]. However, the timeframe for ecosystem recovery varies based on mining operations, soil characteristics, and climate conditions [115]. Considering socio-economic factors, community engagement and integration of traditional knowledge are found to enhance the success and sustainability of reclamation efforts. Positive outcomes include employment creation, infrastructure development, and local economy revitalization [106]. Yet, balancing short-term economic gains with long-term environmental sustainability remains a challenge [102]. Robust environmental regulations and policy frameworks guide responsible mine reclamation practices. Incorporating impact assessments, reclamation plans, and monitoring protocols within regulatory frameworks enhances outcomes. However, ongoing monitoring, enforcement, and adaptive management are crucial for compliance and addressing emerging challenges [89, 93].

Recent studies explore emerging technologies like remote sensing, GIS-based modeling, and biotechnology for soil remediation to enhance reclamation efficiency, resource optimization, and minimize environmental impacts [55]. In conclusion, leveraging existing knowledge and addressing research gaps are pivotal for enhancing mine reclamation effectiveness and promoting sustainable mining practices.

Literature review on perception modeling and its connection to mine reclamation

Perception is a crucial cognitive process that involves the brain's intricate mechanisms for interpreting sensory input and understanding the world. It begins with sensation, where sensory receptors detect stimuli from the environment [89, 93]. These stimuli are then transmitted to the brain, where they undergo organization and interpretation. The brain categorizes, integrates, and synthesizes incoming data into coherent patterns, creating a structured representation of the sensory input. Selective attention is crucial, as individuals prioritize stimuli based on their relevance or significance [55]. The brain then assigns meaning to the perceived stimuli, relying heavily on prior knowledge,

experiences, and expectations. Contextual cues, emotional states, and individual beliefs also influence the interpretation process, leading to subjective perceptions. Factors such as sensory thresholds, individual differences, cultural norms, and societal influences further shape perception [115]. Cultural relativism highlights the role of culture in shaping perceptual experiences and behaviors. Perceptual illusions and biases also influence the brain's interpretation of sensory information. Illusions, such as the Müller-Lyer illusion, distort individuals' perceptions of line lengths, while cognitive biases, like confirmation bias or stereotyping, favor information that confirms preexisting beliefs or stereotypes [123]. Understanding the intricacies of perception and its underlying mechanisms is essential for comprehending human behavior, designing effective communication strategies, and improving decision-making processes across diverse fields.

Perception modeling, essential for understanding how individuals interpret information, is widely used across psychology, marketing, and decision-making fields [24]. By employing theoretical frameworks and statistical techniques, researchers analyze data to simulate and predict human perception [75]. This modeling aids in understanding consumer behavior in marketing, assessing public opinion in public policy, and designing user interfaces in human–computer interaction [50]. The complexity of perception requires interdisciplinary approaches, integrating insights from psychology, neuroscience, and sociology [53]. Understanding how individuals perceive the world enables decision-makers to develop effective strategies and interventions across various domains [103].

In the context of mine reclamation, perception modeling is crucial for understanding stakeholder perceptions [105, 120, 134]. Identifying relevant stakeholders, collecting comprehensive data on their perceptions, and understanding factors influencing perception are essential [111, 128, 142, 157].

Factors influencing stakeholder perception include environmental impacts, economic benefits, and trust in the mining industry [166]. Employing appropriate techniques like statistical analysis or machine learning ensures an accurate representation of stakeholder perception [17].

Overall, perception modeling in mine reclamation requires a multidimensional understanding of stakeholder perspectives, robust data collection, identification of influential factors, and appropriate modeling techniques. This approach provides valuable insights to inform decision-making and promote sustainable mine reclamation practices. However, a standardized framework to determine applicable reclamation strategies based on stakeholder perceptions is currently lacking.

Literature review on Saoner mines

Extensive research and accumulated knowledge on mine reclamation practices provide valuable insights into restoring mined lands and mitigating environmental impacts [52, 54, 56]. These practices aim to rehabilitate disturbed areas, promote ecological restoration, and ensure the sustainable use of reclaimed lands. Studies have emphasized the significance of early planning, site-specific reclamation plans, and the integration of ecological, social, and economic factors in the reclamation process.

One key aspect of mine reclamation is land recontouring, which involves reshaping the land to its original topography or creating landforms that mimic natural landscapes.

This helps to prevent erosion, enhance soil stability, and facilitate the establishment of vegetation [49, 51]. Soil stabilization techniques, such as the use of soil amendments and erosion control measures, contribute to the successful establishment of healthy soil conditions for plant growth. Vegetation establishment is another critical component of mine reclamation [48]. Native plant species are preferred for their ability to adapt to local conditions, support biodiversity, and restore ecological functions. Studies have highlighted the importance of selecting appropriate plant species and using techniques like seeding, planting, and ecological succession to ensure successful vegetation establishment. Water management is another essential aspect of mine reclamation [46]. Proper control and treatment of water flows, including runoff and discharge from reclaimed areas, play a crucial role in maintaining water quality and preventing pollution of surrounding water bodies. Techniques such as constructed wetlands and sedimentation ponds can be employed to manage water effectively and promote habitat creation [43, 45].

Relevant environmental regulations

India has implemented stringent environmental regulations to govern mine reclamation activities and ensure sustainable mining practices. The Mines and Minerals (Development and Regulation) Act, 1957, serves as a primary legislation governing mining operations in the country. It outlines provisions for environmental protection, safety measures, and the sustainable development of mineral resources.

The Environmental Impact Assessment (EIA) Notification, 2006, mandates the assessment of potential environmental impacts of mining projects, including mine reclamation activities. This regulation requires mining companies to undergo an EIA process before obtaining environmental clearances. The EIA process involves evaluating the project's environmental impacts, proposing mitigation measures, and incorporating public consultation and stakeholder engagement.

Reclamation plans are a key requirement under the EIA process. These plans outline the measures and strategies to be undertaken for restoring the mined areas after the cessation of mining operations. They specify the intended land use, reclamation methods, and monitoring protocols to ensure the successful implementation of reclamation measures.

Previous studies on Saoner mine and similar reclamation projects

Previous studies have been conducted to evaluate the effectiveness of reclamation measures and assess the environmental and socio-economic impacts of the Saoner mine and similar reclamation projects. These studies provide valuable insights into the challenges faced and successes achieved in the reclamation efforts [109, 110, 112]. Environmental impact assessments have examined changes in soil quality, water quality, vegetation cover, and biodiversity before and after reclamation [63]. They have assessed the extent to which reclamation measures have restored or improved the environmental conditions in the Saoner mine area.

Studies have also investigated the socio-economic impacts of mine reclamation on local communities. These include evaluating changes in employment opportunities, income levels, infrastructure development, and community well-being. The socio-economic analysis helps to understand the benefits and challenges associated with mine

reclamation projects and enables the formulation of sustainable development plans for affected communities [113, 126].

In conclusion, the existing knowledge on mine reclamation practices, relevant environmental regulations, and previous studies related to the Saoner mine and similar reclamation projects provide essential insights into effective reclamation strategies, regulatory compliance, and the evaluation of environmental and socio-economic impacts. By building upon this knowledge, policymakers, researchers, and stakeholders can continue to improve mine reclamation practices, ensure environmental sustainability, and promote the well-being of affected communities.

Methods

The following structure was followed to study mine reclamation of Saoner mines in India. First, defining of the objective of the case study, such as evaluating the effectiveness of reclamation measures or analyzing the environmental and socio-economic impacts of the Saoner mine reclamation project, was done. Relevant data through various methods were gathered. This included site visits to Saoner mine to observe the reclamation activities first hand, interviews with key stakeholders involved in the reclamation process (such as mining company representatives, government officials, and local community members), and collection of documents and reports related to the reclamation project.

- Analyzing the collected data using appropriate analytical methods. This involved qualitative analysis of interview transcripts and document content, as well as quantitative analysis of environmental parameters, socio-economic indicators, or other relevant data.
- Identifying patterns, trends, and key insights from the data analysis
- Providing a comprehensive description of the Saoner mine reclamation project
- Including details about the mining history, reclamation objectives, strategies employed, timeline of activities, challenges encountered during the reclamation process, and present information on the environmental conditions pre- and post-reclamation
- Evaluating the effectiveness of the reclamation measures implemented at Saoner mine
- Assessing the degree of ecological restoration, land stability, and habitat rehabilitation achieved
- Considering the success of the reclamation project in meeting its intended objectives and any gaps or areas for improvement
- Examining the environmental, socio-economic, and community impacts of the Saoner mine reclamation
- Assessing changes in water quality, soil fertility, vegetation cover, and biodiversity
- Analyzing the socio-economic effects on local communities, such as employment opportunities, infrastructure development, and changes in livelihood patterns
- Discussing the findings of the case study in relation to the research objective and broader context

- Comparing the Saoner mine reclamation project with other similar projects or industry best practices
- Addressing any limitations or challenges encountered during the case study
- Concluding the case study by summarizing the key findings and their implications for mine reclamation practices and future research (refer to Fig. 1).

In assessing the effectiveness and sustainability of mine reclamation efforts, various criteria play pivotal roles, each highlighting important dimensions of the relationship between mining activities, reclamation strategies, and the surrounding environment. The dependence between mine surroundings and non-mine-related activities underscores the interconnectedness of mining operations with broader socio-economic systems, emphasizing the need for integrated planning. Resident satisfaction with living near mines reflects the quality-of-life impact, necessitating reclamation efforts that enhance community well-being. The influence of reclamation on residents' daily lives underscores the importance of ensuring that reclaimed areas support functional and safe environments. Additionally, the level of involvement in reclaimed mine activities and resident support for mine closure signify community engagement and acceptance, vital for successful reclamation outcomes. The connection of resident participation to mine activities emphasizes the need for inclusive decision-making processes that consider local perspectives. Economic generation influenced by reclamation highlights the potential for reclaimed sites to contribute to sustainable economic development. Satisfaction with reclamation's economic outcomes underscores the importance of balancing economic benefits with environmental and social considerations. The dependence between reclamation strategies and mine type highlights the need for tailored approaches that address site-specific challenges and opportunities. Reuse sufficiency and the requirement of closed mines emphasize the importance of maximizing the utilization of reclaimed land while minimizing environmental impacts. Environmental factors such as water and air quality, soil fertility, and climate conditions underscore the ecological considerations crucial for successful reclamation. Socio-economic factors, including agricultural productivity, livelihood availability, and community resilience, highlight the broader societal implications of reclamation efforts. Stakeholder involvement, expenditure dependence,

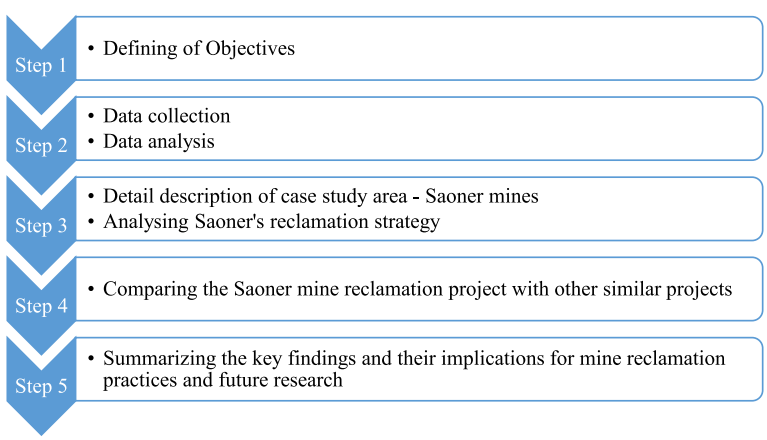

Fig. 1 Research methodology adopted for the study

and the provision of non-mining activities reflect the multi-stakeholder nature of reclamation planning and implementation. Ultimately, these criteria collectively inform the formulation of comprehensive and sustainable mine reclamation strategies that balance environmental protection, social equity, and economic development, ensuring the long-term well-being of both human and ecological communities (see Table 5 in Appendix).

Research objectives

To assess the effectiveness of the Saoner mine reclamation project by analyzing its environmental and socio-economic impacts through the establishment of clear criteria, including parameters such as vegetation establishment, water quality improvement, habitat restoration, community engagement, economic benefits, and social well-being.

Data collection — settings and methodology

Collecting data manually for a survey conducted among mine residents and workers is a common practice in many research studies. Manual data collection involves directly interacting with participants and recording their responses using paper-based or other non-digital methods. While manual data collection has its advantages, such as cost-effectiveness and ease of implementation, it also poses some challenges and limitations.

Advantages of manual data collection

- Personal interaction: Manual data collection allows for face-to-face interaction with participants, which can help build rapport and encourage open and honest responses.
- Flexibility: Researchers can adapt the survey process and ask follow-up questions based on participants' responses, enabling deeper exploration of specific topics.
- Cost-effectiveness: Manual data collection eliminates the need for expensive digital tools or software, making it a more affordable option, especially in resource-constrained settings.
- Accessibility: Participants who may not have access to digital devices or are unfamiliar with technology can comfortably participate in the survey.

Challenges and limitations of manual data collection

- Human error: Manual data collection is prone to errors during data entry and transcription, potentially leading to inaccuracies in the recorded data.
- Time-consuming: Manual data collection can be time-consuming, especially when dealing with large sample sizes or complex questionnaires. It requires adequate resources and manpower to efficiently collect, record, and manage the data.
- Data security: Manual data collection may raise concerns about data security and privacy, as physical documents can be lost, damaged, or accessed by unauthorized individuals.

- Limited data analysis capabilities: Manual data collection often requires additional effort for data entry and cleaning before analysis, which can prolong the research process and delay the dissemination of findings.

Mitigating challenges

- To address the limitations of manual data collection, researchers can implement strategies to minimize human errors, such as double-checking data entries and conducting data quality checks. Additionally, ensuring the security and confidentiality of collected data through proper storage and restricted access is essential. Exploring data digitization options at a later stage can facilitate data analysis and interpretation.

While manual data collection for a survey conducted among mine residents and workers may have certain limitations, it remains a viable and commonly used method in research studies. Researchers must carefully consider the advantages, challenges, and limitations associated with manual data collection and implement strategies to mitigate potential issues. By acknowledging these considerations, researchers can effectively utilize the collected data to generate meaningful insights and contribute to the field of mine reclamation.

For the current study, a 33-point questionnaire was prepared for the survey. As per SEM sample size formula and 33 Likert scale questions, sample size should be 330, but the formula yields 382. Hence, 428 participants have been surveyed manually after removal of any incomplete questionnaires and double checking of data.

Case study area description

Saoner is a town located in the Nagpur district of Maharashtra, India. Situated in the central part of the country, Saoner lies approximately 33 km south of Nagpur, the largest city in the region. The town is characterized by its serene rural surroundings, with vast stretches of agricultural land and the Nag River flowing nearby (refer to Fig. 2).

As for its population, Saoner is estimated to have around 63,462 residents (refer to Fig. 3 and Table 1). The town has experienced gradual population growth over the years, with a mix of diverse communities residing within its boundaries. The predominant language spoken in Saoner is Marathi, which serves as the official language of Maharashtra. Saoner's geography is marked by its average elevation of around 272 m (892 feet) above sea level. It is nestled amidst the fertile plains of the region, which contribute to the town's strong agricultural base. Farmers cultivate a variety of crops such as cotton, soybeans, wheat, and vegetables, contributing to the local economy (Fig. 4).

The city has 70% population employed, 25% unemployed, and 5% population are children. Among the 70% employed population, 60% are mine workers, and 40% are other workers.

In terms of connectivity, Saoner is well-connected to neighboring areas. The town has a railway station on the Nagpur-Mumbai main line, enabling convenient travel to and from major cities. Additionally, the Nagpur airport, located in close proximity, provides air connectivity to domestic and international destinations. Saoner also caters to the educational and healthcare needs of its residents. The town boasts

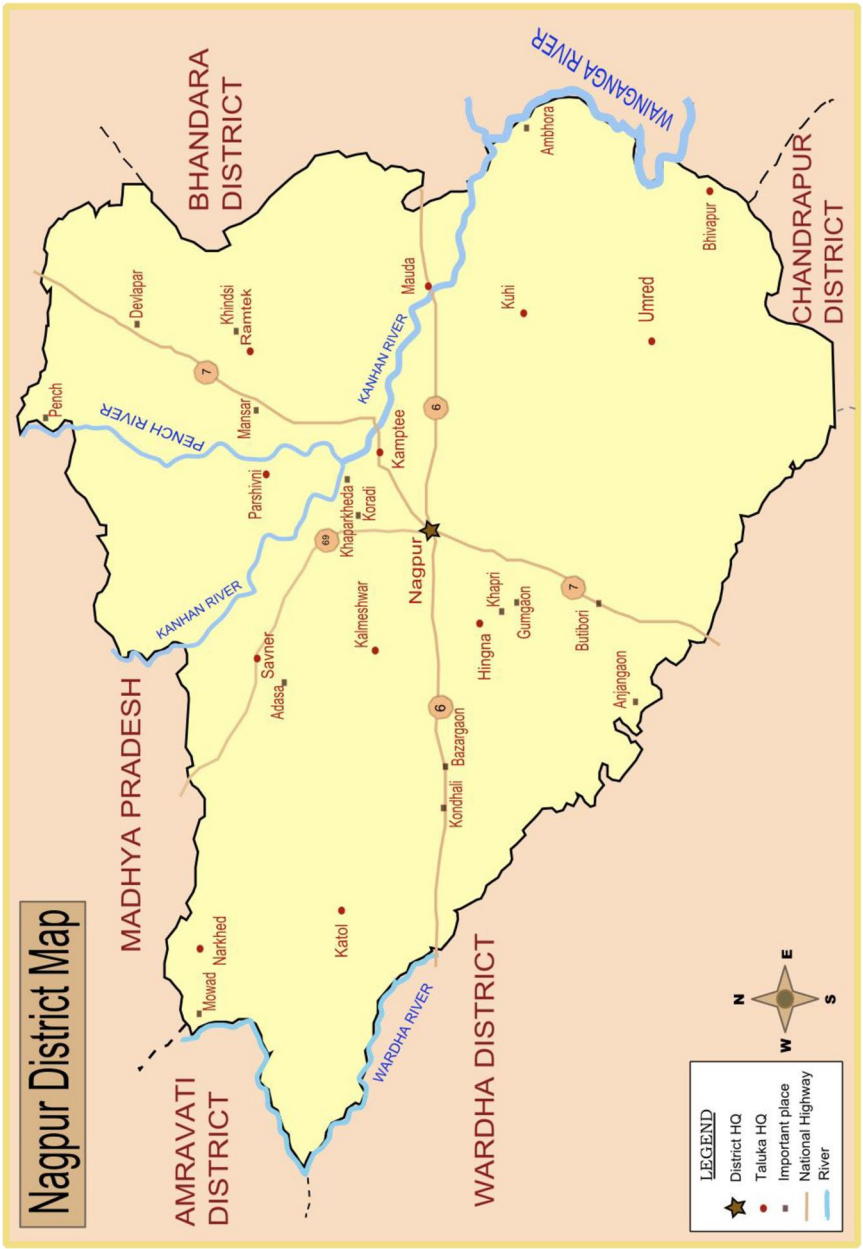

Fig. 2 Nagpur district map (source: https://www.gem.wiki/Saoner_coal_mine)

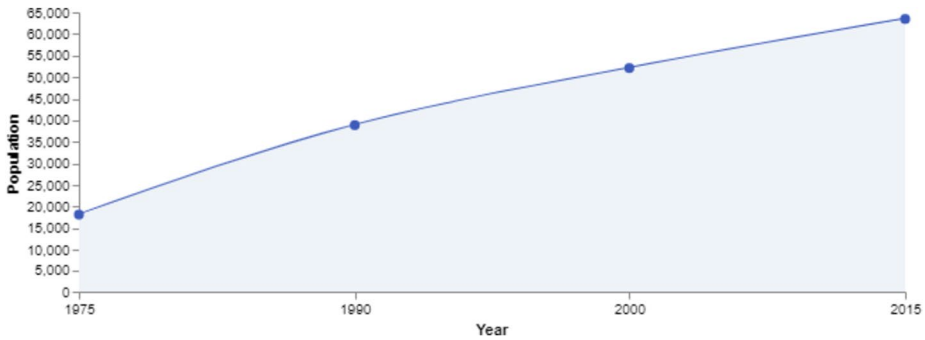

Fig. 3 Saoner population 1975–2015

Table 1 Saoner population 1975–2015

Data	1975	1990	2000	2015
Population	18,172	38,886	52,099	63,462
Population density	1886/km^2	4037/km^2	5409/km^2	6589/km^2

Fig. 4 Saoner eco-park

several schools and educational institutions that impart knowledge and facilitate the growth of its young population. Healthcare facilities, including hospitals and clinics, are available to provide medical services and ensure the well-being of the community.

These demographic and geographic details provide a glimpse into the characteristics of Saoner, showcasing its rural charm, agricultural significance, and connectivity to the wider region.

Saoner in Maharashtra, India, is known for the Saoner coal mines. The Saoner coal mine is part of the Western Coalfields Limited (WCL), a subsidiary of Coal India Limited (CIL). It is situated in the Nagpur Coalfield region, which is one of the major coal-producing areas in the country. The Saoner coal mine contributes to the production of coal, which is an important natural resource used for various purposes, including

electricity generation, industrial processes, and domestic fuel. The mine plays a significant role in meeting the energy demands of the region and supporting economic activities associated with coal mining. The mining operations in Saoner involve the extraction of coal from underground mines. These mines employ various techniques and equipment to extract the coal, ensuring safety standards and environmental regulations are followed. The extracted coal is transported for processing and distribution to meet the requirements of different industries and consumers. It is important to note that specific details regarding the Saoner coal mine, such as production capacity, mining methods employed, or environmental management practices, may be subject to change and may require more up-to-date information from the authorities responsible for overseeing mining operations in the area.

The Saoner coal mine, located in Maharashtra, India, is an important site for mine reclamation efforts. The mine has been the focus of initiatives aimed at restoring the land and mitigating the environmental impacts caused by coal mining activities. The reclamation efforts at the Saoner mine include various measures to restore the land's physical characteristics and stability. This involves reshaping the land, regrading slopes, and implementing erosion control measures to prevent soil degradation and landslides. These actions are crucial for creating a safe and stable environment that can support future land use and minimize the risks associated with mining operations.

Additionally, reclamation efforts at the Saoner mine aim to rehabilitate the vegetation in the area. Native plant species are being reintroduced to restore biodiversity and promote the development of a self-sustaining ecosystem. This helps in preventing soil erosion, improving air quality, and providing habitat for wildlife. The reestablishment of vegetation also enhances the aesthetic value of the reclaimed land. Water management is another critical aspect of mine reclamation at the Saoner mine. Measures are being taken to address water pollution and ensure the restoration of water bodies affected by mining activities. This includes implementing water treatment systems, constructing sedimentation ponds, and managing water runoff to preserve water quality and support the health of aquatic ecosystems. Community engagement is an integral part of the Saoner mine reclamation efforts. Local communities and stakeholders are involved in the decision-making process, providing valuable insights into the social and economic aspects of the land. Their involvement ensures that the reclamation plans align with their needs and aspirations, fostering sustainable development and benefiting the local community [133].

The reclamation of the Saoner mine showcases the commitment of the government, mining companies, and local stakeholders to mitigate the environmental impacts of mining activities and restore the land to a state that is safe, ecologically balanced, and suitable for future use. Through these efforts, the Saoner mine is being transformed into a reclaimed area that contributes to the sustainable development and preservation of the region's natural resources.

Saoner survey

Collecting data from 428 participants within a 5-km radius of the Saoner mines provided valuable insights into stakeholder perceptions and attitudes towards mine reclamation practices in that specific area. This manual survey involved designing a questionnaire

or interview guide to gather information from participants. The survey covered various aspects related to mine reclamation, such as environmental impacts, community engagement, economic benefits, transparency, cultural heritage, and overall satisfaction with the reclamation efforts. Questions were structured to assess participants' knowledge, beliefs, concerns, and opinions regarding these aspects. To ensure the survey's reliability and validity, it was important to employ appropriate sampling techniques to ensure a representative sample from the target population. Additionally, ensuring the confidentiality and anonymity of participants' responses promoted honest and unbiased feedback.

Once the survey data was collected, it was analyzed using statistical methods (SEM in this particular case) to identify patterns, trends, and correlations within the data set. This analysis provided insights into the overall perception of mine reclamation practices in the area and helped identify key factors that influence stakeholders' opinions.

Among the surveyed participants, a random mix of mine area residents and other neighboring stakeholders were taken (refer to Fig. 5 for the participant mix as per residency and nativity).

Survey analysis

Analyzing survey data involves several steps to derive meaningful insights and draw conclusions (refer to Table 2).

It is important to select appropriate statistical methods and consult with experts or resources familiar with survey data analysis to ensure accurate interpretation of the findings. For this particular study, data cleaning was conducting where nonresponses were removed from the dataset to be analyzed. Then a descriptive analysis was conducted where the questions as ranked by the participants were checked for measure of central tendency of the indicated rankings to get an overview of participants' characteristics and initial insights into their perceptions (refer to Table 5 in Appendix for criteria label and Table 3 for criteria average).

Since the survey included multiple variables, inferential analysis was conducted to examine relationships and associations between variables. Statistical techniques such as

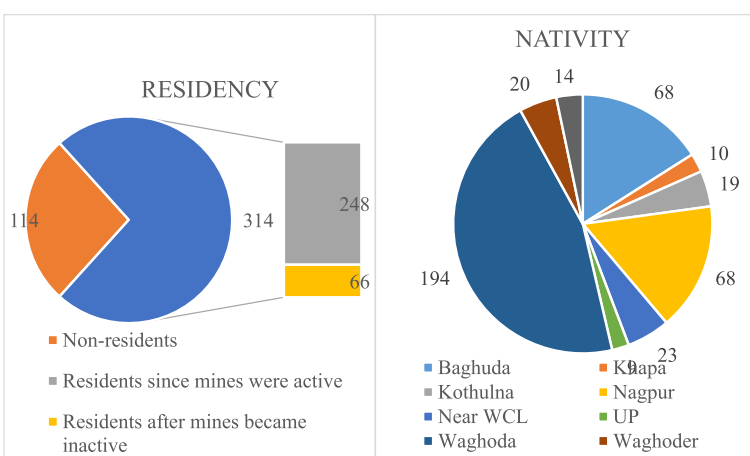

Fig. 5 Saoner survey participant mix as per residency and nativity

Table 2 Steps of survey data analysis

Data cleaning	Before starting the analysis, it is important to clean and prepare the survey data. This involves checking for missing or incomplete responses, ensuring data accuracy, and organizing the data in a structured format for analysis
Descriptive analysis	Conduct descriptive analysis to summarize and describe the survey data. This includes calculating frequencies, percentages, and measures of central tendency (e.g., mean, median) for each survey question. Descriptive analysis helps provide an overview of participants' characteristics and initial insights into their perceptions
Data visualization	Use charts, graphs, and other visualizations to present survey findings effectively. Bar charts, pie charts, and histograms can be used to visually represent the distribution of responses. This visual representation helps to highlight patterns, trends, and differences in perceptions across different survey questions or participant groups
Inferential analysis	If the survey includes multiple variables, inferential analysis can be conducted to examine relationships and associations between variables. Statistical techniques such as chi-square tests, *t*-tests, correlation analysis, or regression analysis can be applied to identify significant relationships or differences between variables
Segmentation analysis	If relevant to the research objectives, segment the survey data based on participant characteristics or responses. This allows for a more detailed analysis of different subgroups or clusters within the sample, which can provide deeper insights into variations in perceptions
Qualitative analysis	If the survey includes open-ended questions or qualitative data, qualitative analysis techniques such as thematic analysis or content analysis can be used to identify recurring themes, patterns, or key topics from participants' responses. This qualitative analysis complements the quantitative analysis and provides richer insights into participants' perceptions
Interpretation and conclusion	After analyzing the survey data, interpret the findings in the context of the research objectives and draw conclusions. Identify key insights, patterns, and trends that emerge from the analysis. Discuss the implications of the findings and how they align with existing literature or theoretical frameworks
Reporting	Summarize the survey analysis results in a clear and concise manner. Present the findings in a report or presentation format, including tables, charts, and interpretations. It is essential to accurately report the analysis methods used, limitations, and recommendations for future research or actions based on the findings

Table 3 Survey criteria ranking average as per stakeholder and expert rankings on Likert scale of 1–5

Criteria	A1	A2	A3	A4	A5	A6	A7	A8
AVG	3.308411215	3.502336449	3.663551402	2.964953271	3.142523364	3.08411215	3.341121495	3.044392523
Criteria	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**
AVG	3.046728972	3.563084112	3.553738318	3.780373832	3.390186916	3.35046729	3.567757009	3.728971963
Criteria	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**
AVG	3.726635514	3.801401869	3.478971963	3.147196262	3.614485981	3.654205607	3.448598131	3.455607477
Criteria	**A25**	**A26**	**A27**	**A28**	**A29**	**A30**	**A31**	**A32**
AVG	3.58411215	3.193925234	3.38317757	3.981308411	3.161214953	3.186915888	3.436915888	2.918224299
Criteria	**A33**	**A34**	**A35**	**A36**	**A37**	**A38**	**A39**	**A40**
AVG	3.296728972	3.644859813	3.369158879	3.028037383	3.462616822	3.406542056	3.574766355	3.628504673
Criteria	**A41**	**A42**	**A43**					
AVG	3.549065421	3.182242991	3.408878505					

ANOVA, correlation analysis, and covariance analysis were applied to identify significant relationships or differences between variables.

ANOVA is a statistical technique used to compare means between three or more criteria, typically with a categorical independent variable and a continuous dependent variable. It determines significant differences in means among criteria by calculating the

F-value and associated *p*-value. If the *p*-value is below the chosen significance level, it indicates a significant difference in at least one criterion mean. ANOVA is a valuable tool for understanding criteria differences and is often followed by post hoc tests to identify specific criteria differences.

The single-factor ANOVA analysis revealed a *p*-value of 5.9E-149 and F crit of 1.384589 (refer to Table 4).

Correlation analysis is a statistical method used to measure the relationship between two or more variables, assessing their degree and direction of association. It uses correlation coefficients like Pearson's or Spearman's rank to quantify the strength and direction of the relationship. Correlation analysis is useful in fields like psychology, economics, and social sciences to understand interdependence and patterns between variables. However, it is important to note that correlation does not imply causation, and other factors may also contribute to the observed relationship. A correlation analysis was carried out for the 428 participant responses to understand the level of relation between each criteria.

Covariance analysis, also known as ANCOVA, is a statistical technique that combines elements of ANOVA and regression analysis to examine criteria differences while controlling for the effects of continuous covariates. It involves regressing the dependent variable on both the categorical independent variable and the continuous covariate(s). The goal is to determine significant criteria differences in the dependent variable while accounting for the influence of the covariate(s). This helps reduce confounding effects and increase the precision of criteria comparisons. Key statistics like *F*-values, *p*-values, and adjusted means provide insights into the significance of criteria differences after accounting for the covariate(s).

Covariance analysis is commonly used in research fields where there is a need to examine criteria differences while controlling for relevant covariates. It is especially useful when there are potential confounding factors that may influence the relationship between the independent variable and the dependent variable. A covariance analysis was carried out for the 428 participant responses to understand the direction of relation between each criteria.

Structural equation modeling (SEM) is a statistical technique used to analyze complex relationships between observed and latent variables. It combines elements of factor analysis, path analysis, and regression analysis to provide a comprehensive understanding of the relationships among variables within a theoretical framework. Researchers specify a hypothesized model that represents the relationships between variables, which can include both observed variables and unobserved constructs inferred from multiple indicators. Path diagrams visually represent the directional links between variables. SEM

Table 4 ANOVA analysis of Saoner for *p*-value and F crit

ANOVA						
Source of variation	SS	df	MS	F	*p*-value	F crit
Between criteria	1111.033	42	26.45317	20.43315	5.9E-149	1.384589
Within criteria	23,770.52	18,361	1.29462			
Total	24,881.55	18,403				

estimates the relationships between variables using maximum likelihood estimation or other suitable methods, providing estimates of the strength, direction, and significance of these relationships. It also assesses model fit through various fit indices, such as chi-square, comparative fit index (CFI), root-mean-square error of approximation (RMSEA), and standardized root-mean-square residual (SRMR). SEM has wide-ranging applications in social sciences, psychology, and economics, enabling researchers to test complex theories, examine causal relationships, and explore mediating or moderating effects among variables. It provides a powerful tool for investigating complex models and contributes to theory development and hypothesis testing in various disciplines. For this particular study, after constructing the conceptual SEM in SmartPls4, the survey data was fed into the model to understand the variable relationship strength, significance, and skewness (refer to Fig. 6).

In conclusion, the survey conducted with 428 stakeholders to analyze their satisfaction and other related criteria regarding Saoner mine reclamation provides valuable insights into the perceptions and opinions of the key individuals and groups involved in the reclamation process. The findings of the survey indicate that overall stakeholder satisfaction with the Saoner mine reclamation efforts is varied. While some stakeholders expressed satisfaction with the progress and outcomes of the reclamation activities, others raised concerns and expressed dissatisfaction with certain aspects of the process. Overall, the conceptual SEM proposed showcases the level of current relationship significance and how the stakeholders perceive the reclamation opportunity in relation to other factors.

The survey revealed several key factors that influence stakeholder satisfaction. Effective communication and engagement emerged as a crucial element, with stakeholders expressing a desire for more transparent and timely information about the reclamation progress, objectives, and potential environmental and social impacts. Regular updates and opportunities for meaningful participation were also highlighted as important factors for stakeholder satisfaction. Furthermore, the survey shed light on the importance of environmental and social outcomes in determining stakeholder satisfaction. Stakeholders emphasized the need for effective restoration of ecosystems, including biodiversity conservation, soil quality improvement, and water resource management.

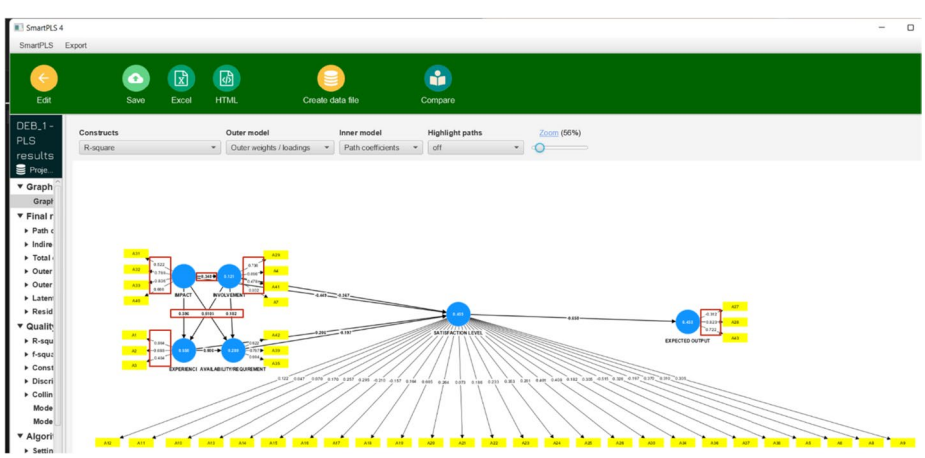

Fig. 6 Conceptual SEM model for Saoner survey analysis

Additionally, the impact on local communities, such as job creation, livelihood opportunities, and social infrastructure development, played a significant role in determining stakeholder satisfaction. The survey also highlighted areas where improvements are needed to enhance stakeholder satisfaction. These include addressing concerns related to the effectiveness of reclamation measures, ensuring compliance with environmental regulations, and providing clear guidelines and accountability mechanisms for mining companies involved in reclamation activities. Stakeholders also expressed the need for long-term monitoring and maintenance of reclaimed sites to ensure the sustainability of the reclamation efforts.

Overall, the survey findings emphasize the importance of actively involving stakeholders in the decision-making process, addressing their concerns and expectations, and ensuring transparency and accountability throughout the reclamation process. By incorporating stakeholder feedback, implementing sustainable practices, and demonstrating a commitment to environmental and social well-being, the Saoner mine reclamation efforts can work towards achieving higher stakeholder satisfaction and greater overall success in restoring the site's ecological and socio-economic value.

Results

The Saoner mine reclamation survey data from 428 stakeholders revealed mixed responses, with some expressing satisfaction and others expressing concerns. Effective communication and engagement were identified as critical factors influencing satisfaction, emphasizing the importance of transparent information sharing and opportunities for stakeholder participation. Environmental and social outcomes significantly impacted satisfaction, emphasizing ecosystem restoration and community benefits. Improvements include addressing concerns about reclamation effectiveness, ensuring regulatory compliance, and establishing long-term monitoring mechanisms. The findings emphasize the importance of stakeholder involvement, sustainable practices, and accountability in enhancing satisfaction and achieving success in mine reclamation efforts. A single-factor ANOVA analysis showed a significant correlation between selected criteria, indicating a relationship between stakeholder satisfaction and various aspects of the reclamation process. The survey findings underscore the complexity of stakeholder satisfaction in mine reclamation projects and the need for comprehensive analysis incorporating multiple criteria.

Constructing a conceptual SEM allowed for a deeper exploration of complex relationships between observed and latent variables. SEM provided a comprehensive understanding, assessing relationships' strength, direction, and significance, aiding in evaluating the fit of the theoretical model to observed data. The survey uncovered pivotal factors influencing stakeholder satisfaction:

1. Effective communication and engagement

Effective communication and engagement are crucial for stakeholder satisfaction in reclamation efforts. Transparent and timely information about progress, objectives, and environmental and social impacts is essential. Stakeholders desire open channels for information and meaningful participation in decision-making processes. Inclusivity

fosters ownership and integration of concerns into strategies. A culture of transparency and engagement can build trust and credibility, leading to greater satisfaction and support for reclamation efforts [14, 132].

2. Environmental and social outcomes

The study emphasizes the importance of environmental and social outcomes in determining stakeholder satisfaction. Environmental aspects include ecosystem restoration, biodiversity conservation, soil quality improvement, and sustainable water resource management. Social impacts include job creation, livelihood support, and social infrastructure development. Stakeholders evaluate reclamation efforts based on their positive impact on local communities. Addressing these concerns directly contributes to stakeholder satisfaction, ensuring reclamation aligns with community well-being. Therefore, comprehensive efforts are crucial for reclaiming land and rejuvenating ecological balance [29, 69, 73].

3. Concerns and improvements

Stakeholders expressed concerns about the effectiveness of reclamation measures, highlighting the need for clear guidelines and accountability mechanisms to ensure mining companies adhere to environmental regulations and industry standards. Long-term monitoring and maintenance of reclaimed sites are also crucial. Addressing these concerns directly through robust monitoring systems and strict adherence to regulations would alleviate doubts and boost stakeholders' confidence in the reclamation process [62, 96].

The main findings of the Saoner mine reclamation study emphasize the need of stakeholder participation, environmental stewardship, and proactive actions to resolve concerns. The reclamation operations can not only satisfy legislative requirements but also acquire the support and satisfaction of the communities affected by actively involving stakeholders, establishing transparent communication, and maintaining high environmental and social standards. The study offers practical findings that will guide future efforts to have a positive and long-term influence on both the environment and the lives of the local people.

Discussion

The Saoner mines in Maharashtra, India, have a long history of mining activities that have caused significant environmental and socio-economic damage. The extraction of minerals like coal and limestone has led to extensive land disturbances and ecological degradation. To restore the site's ecological balance and socio-economic well-being, reclamation efforts have been undertaken. The primary objectives of the reclamation process are to promote biodiversity conservation [149], provide social and economic benefits to local communities, and restore the mined areas to a state of environmental sustainability.

Strategies employed in the reclamation process include site characterization, stakeholder engagement, vegetation establishment, soil reclamation techniques, and water

management measures. The timeline of activities in the reclamation process typically follows a structured approach, starting with pre-reclamation assessments, followed by planning and permitting stages, land grading, infrastructure removal, soil stabilization, vegetation establishment, and water management [26].

However, the reclamation process in Saoner mines faces several challenges. Securing sufficient financial resources; addressing stakeholder perceptions; fostering effective engagement among local communities, environmental organizations, and mining companies; and ensuring regulatory compliance with environmental regulations are all significant challenges. Addressing these challenges is crucial for the success of the reclamation efforts in Saoner mines. By overcoming financial constraints, promoting stakeholder collaboration, leveraging technical expertise, and ensuring regulatory compliance, sustainable and effective mine reclamation can be achieved, restoring the site's ecological integrity and providing long-term benefits to local communities [145].

1. Importance of stakeholder engagement

The study underscores the pivotal role of stakeholder engagement in reclamation projects. Transparent communication and active involvement empower stakeholders, enabling them to become advocates for the reclamation efforts. By integrating their insights and addressing concerns promptly, mining companies can foster a sense of shared responsibility. This engagement not only ensures the success of the reclamation process but also establishes a foundation for sustainable relationships between mining operations and the community [95, 149].

2. Environmental and social sustainability

The study's focus on environmental and social outcomes highlights a shifting paradigm in reclamation efforts. It is no longer sufficient to merely reclaim land; the quality of the reclamation, particularly its ecological impact and socio-economic contributions, is under scrutiny. Environmental restoration, encompassing biodiversity conservation, soil quality improvement, and water resource management, must align with community needs and expectations. Moreover, the creation of job opportunities, supporting local livelihoods, and enhancing social infrastructure are integral components of successful reclamation initiatives. Companies must recognize that their responsibility extends beyond ecological remediation; it encompasses enriching the lives of the communities in which they operate [58, 71].

3. Addressing concerns and ensuring accountability

The study reveals specific concerns among stakeholders regarding the effectiveness of reclamation measures. Addressing these concerns requires a proactive approach. Implementing rigorous monitoring systems, adhering to environmental regulations, and demonstrating accountability are essential. Establishing clear guidelines and robust accountability mechanisms can instill confidence among stakeholders. Long-term monitoring and maintenance, often underestimated, are critical components that ensure the sustained success of reclamation projects. Regular assessments and adjustments based

on monitoring data are essential for adaptive management and continuous improvement [26, 125].

4. Integrating findings into policy and practice

The insights from this study offer valuable input for policymakers, mining companies, and environmental agencies involved in reclamation projects. Policymakers can utilize these findings to create frameworks that emphasize stakeholder engagement, stringent environmental standards, and long-term sustainability. Mining companies can incorporate these insights into their corporate social responsibility initiatives, ensuring that their reclamation efforts are not only compliant but also beneficial to the communities they serve. Environmental agencies can use these findings to shape regulations that encourage comprehensive and impactful reclamation strategies [68, 72, 145].

Finally, the Saoner mine rehabilitation study offers a road plan for effective and long-term mine rehabilitation. Reclamation operations may go beyond basic compliance to significant, community-driven programs by prioritizing stakeholder participation, emphasizing environmental and social results, resolving concerns, and guaranteeing accountability. The study's findings highlight the need of a holistic strategy in which ecological and socioeconomic variables are inextricably connected, ensuring that reclamation efforts benefit both the environment and the populations they serve. As the mining sector progresses, these insights will serve as a guidepost, directing efforts towards a future in which ethical mining and reclamation practises are associated with environmental preservation and community well-being.

Conclusions

The environmental conditions in Saoner mines underwent significant changes both pre- and post-reclamation efforts. Prior to reclamation, the mining activities had caused severe environmental degradation and disturbances to the natural ecosystem. Pre-reclamation, the mined areas suffered from land degradation, soil erosion, and loss of vegetation cover. The removal of topsoil during mining operations led to barren land surfaces and exposed subsoils, rendering them susceptible to erosion and compromising soil quality. The disruption of natural drainage patterns and the creation of open pits and mine waste dumps further disrupted the hydrological system, potentially causing water pollution and affecting local water resources. The loss of vegetation cover also resulted in a decline in biodiversity, impacting the ecological balance of the area. Post-reclamation, the environmental conditions in Saoner mines showed significant improvements. The reclamation efforts aimed to restore the ecological integrity of the mined areas and promote sustainable land use practices. Key changes observed include the following:

1. Vegetation restoration: Through reseeding, planting native species, and implementing soil stabilization techniques, vegetation cover was restored in the reclaimed areas. This contributed to enhanced biodiversity, improved soil quality, and reduced soil erosion.
2. Soil stabilization: Measures such as contouring, regrading, and the addition of organic matter helped stabilize the soils, preventing erosion and facilitating vegeta-

tion growth. This led to improved soil structure, increased water-holding capacity, and reduced nutrient loss.

3. Water management: Reclamation activities incorporated drainage systems, sediment control measures, and water treatment facilities to manage water resources and minimize potential pollution. Restoration of natural watercourses and the creation of retention ponds helped restore the hydrological balance.
4. Habitat creation: Reclamation efforts aimed to recreate suitable habitats for wildlife and promote biodiversity conservation. The restoration of native vegetation and the establishment of diverse ecosystems provided nesting sites, food sources, and shelter for various species.
5. Landform reconstruction: The reshaping of the landscape to approximate pre-mining topography and the rehabilitation of infrastructure, such as roads and waste disposal areas, contributed to the aesthetic and functional improvements of the reclaimed areas.

Overall, the post-reclamation environmental conditions in Saoner mines showed significant positive changes. The restoration of vegetation, stabilization of soils, improved water management, and habitat creation contributed to the recovery of the ecosystem and the overall ecological balance. However, long-term monitoring and maintenance efforts will be necessary to ensure the sustained success of the reclamation efforts and the preservation of the restored environmental conditions.

The reclamation measures implemented at Saoner mine have shown promising effectiveness in restoring the ecological balance and providing socio-economic benefits. Through the establishment of native vegetation, soil stabilization techniques, and water management strategies, significant progress has been made in ecological restoration. The reclaimed areas have witnessed increased vegetation cover, improved soil quality, and enhanced water resources. Stakeholder engagement efforts have contributed to socio-economic benefits, including job creation and community infrastructure development. However, long-term monitoring and adaptive management are necessary to ensure the sustained effectiveness and ecological sustainability of the reclamation measures at Saoner mine.

Assessing the degree of ecological restoration, land stability, and habitat rehabilitation achieved at Saoner mines requires careful evaluation based on monitoring data and indicators. Positive progress has been observed in ecological restoration, with the establishment of native vegetation and an increase in vegetation cover. Measures aimed at land stability, such as contouring and soil stabilization techniques, have contributed to mitigating erosion and enhancing land stability. In terms of habitat rehabilitation, efforts to create suitable habitats for flora and fauna have shown promising results, as indicated by the return of wildlife populations and the presence of indicator species. Regular monitoring and adaptive management will be crucial to assess the overall effectiveness and ensure the long-term sustainability of the restoration efforts at Saoner mines.

While the reclamation efforts at Saoner mines have shown progress, there are still gaps and areas for improvement that can enhance the effectiveness and sustainability of the reclamation process. Some key areas for improvement include the following:

1. Long-term monitoring and maintenance: Establishing a robust and long-term monitoring program is crucial to assess the ongoing effectiveness of reclamation measures and identify any emerging issues. Regular monitoring of ecological indicators, soil erosion rates, water quality, and vegetation health will help detect potential challenges and allow for timely interventions.
2. Biodiversity enhancement: While efforts have been made to restore native vegetation, there may be room for further enhancing biodiversity by incorporating a wider range of plant species and creating diverse habitats. This can include the identification and incorporation of species that are important for supporting specific wildlife populations and enhancing ecosystem resilience.
3. Community engagement and collaboration: Strengthening community engagement and fostering collaboration among stakeholders are essential for successful reclamation. This includes involving local communities in decision-making processes, addressing their concerns, and incorporating traditional ecological knowledge. Effective communication and partnerships with relevant stakeholders, such as environmental organizations and government agencies, can contribute to better outcomes.
4. Adaptive management: Implementing adaptive management practices allows for flexibility and the ability to adjust strategies based on evolving conditions and new knowledge. Regular evaluations and the incorporation of lessons learned can help refine reclamation plans and improve their effectiveness over time.
5. Financial aid institutional support: Adequate financial resources and institutional support are crucial for implementing comprehensive reclamation measures. Ensuring sufficient funding and support for monitoring, maintenance, and adaptive management activities is vital for long-term success.
6. Integration of sustainable land-use practices: Going beyond mere restoration, integrating sustainable land use practices can further enhance the effectiveness of reclamation efforts. This can include exploring opportunities for sustainable agriculture, renewable energy projects, or other economic activities that align with the restored ecological conditions.

Addressing these gaps and focusing on continuous improvement will contribute to the long-term success of the reclamation efforts at Saoner mines, leading to a more sustainable and resilient post-mining landscape.

The Saoner mine reclamation has restored habitats, improved soil and water quality, and promoted ecological connectivity. It has also generated job opportunities, supported economic development through alternative land uses, and improved community infrastructure. The process involves stakeholder engagement, improved health and well-being through green spaces and better environmental conditions, and contributed to the preservation of cultural heritage. The reclamation process has resulted in positive changes in water quality, soil fertility, vegetation cover, and biodiversity. It has also created employment opportunities in land rehabilitation, vegetation management, and infrastructure development, contributing to local economic growth and income generation. The reclamation process has also led to changes in livelihood patterns for local communities, with potential shifts from mining-related work to alternative sectors like agriculture, renewable energy projects, or tourism. These socio-economic effects have

the potential to contribute to the well-being and economic development of the communities surrounding the mine site.

Future prospects and implications

The Saoner mine reclamation project presents promising opportunities for environmental restoration, sustainable development, and community revitalization. As mining activities end, the focus shifts to rehabilitation and reclamation, aiming to mitigate adverse impacts and restore ecological balance. The process involves land reclamation, water management, and ecosystem restoration and can be repurposed for agriculture, forestry, or renewable energy generation. The reclamation also holds the potential to uplift the local community. With proper planning, collaboration among stakeholders, and adherence to sustainable practices, the Saoner mine reclamation can serve as a shining example of environmental stewardship and holistic development. Collaborative efforts among stakeholders bring together diverse perspectives, expertise, and resources, leading to more effective and sustainable outcomes. This fosters trust, transparency, and accountability, minimizing conflicts and maximizing the chances of success. The engagement of local communities empowers them to participate actively in decision-making, enhancing social cohesion, and promoting sustainable development. Collaboration also facilitates knowledge exchange and innovation, enabling the implementation of best practices, cutting-edge technologies, and novel approaches in mine reclamation. This cross-pollination of ideas and experiences can lead to more efficient and cost-effective solutions, accelerating the pace of reclamation and delivering better environmental outcomes.

Furthermore, stakeholder collaboration in the Saoner mine reclamation can act as a catalyst for broader societal change. As the project demonstrates the benefits of collaborative and sustainable practices, it can inspire other mining regions, industries, and communities to adopt similar approaches. The knowledge and lessons learned from the Saoner mine reclamation can be shared as a blueprint for future endeavors, contributing to a more responsible and environmentally conscious mining sector. In conclusion, the future prospects and implications of stakeholder collaboration in the Saoner mine reclamation are transformative. By engaging diverse stakeholders, harnessing their expertise, and promoting inclusivity, the project can achieve comprehensive and sustainable outcomes. Moreover, this collaboration sets a precedent for future mining reclamation efforts, fostering a culture of shared responsibility, innovation, and environmental stewardship.

Appendix

Table 5 Delete

Criteria surveyed	Category	Indicated as
Dependence between mine surroundings and non-mine-related activities	Experience	A1
Satisfaction of experience with residence near mines	Experience	A2
Influence of reclamation on daily lives of residents	Experience	A3

Criteria surveyed	Category	Indicated as
Level of involvement in reclaimed mine activities	Involvement	A4
Support of residents for mine closure	Satisfaction level	A5
Connection of resident participation to mine activities	Satisfaction level	A6
Influence of reclamation over economic generation	Involvement	A7
Satisfaction with reclamation over economic generation	Satisfaction level	A8
Influence of mine development on resident satisfaction	Satisfaction level	A9
Dependence between reclamation strategies and mine type	Satisfaction level	A10
Reuse sufficiency	Satisfaction level	A11
Reuse requirement of closed mines	Satisfaction level	A12
Influence of environment surroundings over reclamation	Satisfaction level	A13
Influence of temperature over reclamation	Satisfaction level	A14
Influence of climate over reclamation	Satisfaction level	A15
Influence of water quality over reclamation	Satisfaction level	A16
Influence of water availability over reclamation	Satisfaction level	A17
Influence of air quality over reclamation	Satisfaction level	A18
Influence of soil quality over reclamation	Satisfaction level	A19
Influence of land fertility over reclamation	Satisfaction level	A20
Influence of land availability over reclamation	Satisfaction level	A21
Influence of rainfall quantity over reclamation	Satisfaction level	A22
Influence of rainfall quality over reclamation	Satisfaction level	A23
Influence of agricultural yield over reclamation	Satisfaction level	A24
Influence of agricultural quality over reclamation	Satisfaction level	A25
Influence of socio-economic change over reclamation	Satisfaction level	A26
Inducing of improvement upon reclamation	Outcome	A27
Inducing of stakeholder involvement upon reclamation	Outcome	A28
Inducing of non-mining activities upon reclamation	Involvement	A29
Influence of expenditure dependence over mining activities	Satisfaction level	A30
Impact of mine closure over residents' lives	Impact	A31
Impact of mine reclamation over economic output	Impact	A32
Impact of mine reclamation over health	Impact	A33
Impact of mine reclamation over facility availability in residing areas	Satisfaction level	A34
Influence of reclamation on living experiences of residents	Availability/requirement	A35
Impact of mine reclamation over livelihood availability in residing areas	Satisfaction level	A36
Impact of mine reclamation over livelihood sustainability in residing areas	Satisfaction level	A37
Dependence between reclamation benefits and residing population	Satisfaction level	A38
Requirement levels of reclamation	Availability/requirement	A39
Impact of mine reclamation over neighborhood	Impact	A40
Involvement between environment and reclamation strategy formulation	Involvement	A41
Requirement level of economic activity provision for reclaimed sites	Availability/requirement	A42
Use levels of reclaimed sites	Outcome	A43

Abbreviations

EIA Environmental Impact Assessment
WCL Western Coalfields Limited
CIL Coal India Limited
SEM Structural equation modeling
CFI Comparative fit index
RMSEA Root-mean-square error of approximation
SRMR Standardized root-mean-square residual

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Authors' contributions
DB — original writing, conceptualization, and data collection. SM — supervision and revision.

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Availability of data and materials
The survey data will be made available upon request, and the rest of the data utilized has been cited in the text itself.

Declarations

Ethics approval and consent to participate
Informed verbal consent was obtained from the participants (due to limited literacy rate) during the anonymous surveying for data collection and utilization of the survey data for research and publication. The survey was conducted as per the norms of the governing institute and company, Birla Institute of Technology Mesra and Central Coalfields Limited, India, respectively.

Competing interests
The authors declare that they have no competing interests.

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