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Awareness, Perceptions, and Acceptability of Bioremediation of a Mined-Out Area in Claver, Surigao del Norte, Philippines

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ABSTRACT

Bioremediation is considered a safe, effective, and economical solution to contain, reduce, or remove hazardous substances from mined-out areas. However, community support and acceptability essential for the success to the success of bioremediation projects. Thus, a survey interview of 150 respondents using pre-tested questionnaires was conducted in Barangays Cagdianan, Hayanggabon, Taganito, and Urbiztondo in Claver, Surigao del Norte, Philippines to determine the community's awareness, perception, and acceptability of bioremediation of the mined-out area for nickel. Only 55% of the respondents were aware of the project and their knowledge was primarily gained through the stakeholders' forum during the survey period. The respondents had positive perceptions about bioremediation manifested by the widespread favorable responses on the value of trees; beliefs and expectations from the project; risks; environmental, community, and economic benefits; trust in the implementers; and participation albeit only 5% were involved in the project. Despite lack of awareness and non-involvement, the respondents were willing to accept (99%) the bioremediation initiative and to recommend (95%) this in other mined-out areas. This case demonstrates that awareness and participation is not of vital importance in the acceptability of a bioremediation project. Nonetheless, bioremediation and other environmental projects should be initiated with extensive information and education campaigns for well-informed and well-engaged communities to foster a sense of ownership and stewardship resulting to more successful and sustainable projects..

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INTRODUCTION

The mining industry has been a key contributor to economic and social development worldwide. In 2022, the top 40 global mining companies contributed US$ 943 B. The mining and quarrying production value in the Philippines amounted to PhP 258.7 B (US$ 4.67 B) and have provided 212,247 employment in 2023 (*MGB 2024*). Mining, however, causes drastic disturbance to the land. Some mined areas are also left barren that restoration is needed to prevent further damage and to re-establish their productive state.

Rehabilitation of mined-out areas is critical for the restoration of the affected ecosystems that provide numerous goods and services. Republic Act 7942 or the Philippine Mining Act of 1995 requires the "contractors and permittees to technically and biologically rehabilitate the excavated, mined-out tailings covered, and disturbed areas to the condition of environmental safety." The Administrative Order No. 2018-19 (DAO 2018-19) also provides new guidelines for environmental measures that will ensure sustainable environmental conditions covering all stages of mining operations and minimize disturbed areas due to mining activities.

Bioremediation is becoming a popular strategy for rehabilitating mined-out areas. It has already demonstrated successful applications for several chemical compounds in polluted environments (*Kocher et al. 2002*). Bioremediation is a natural process of treating contaminated areas with environmentally and ecologically sound technology that is relatively cost-effective. It is considered a safe, effective, and economical solution to reduce, remove, or contain toxins to restore the fertility of the soil and reestablish the landscape of contaminated sites (*Kuppan et al. 2024*). With this, it is widely advocated by the academic and research sectors. Though not so common in the Philippines, the technology has been used successfully in some parts of the country. Its unpopularity may be partly due to the lack of information about bioremediation, methods used, and

effectiveness in rehabilitating mined-out areas.

Conventional strategies, including physical and chemical techniques, are available for restoring polluted environments. However, many of these are costly, nonspecific, ineffective, with limited area coverage, harmful to the soil, and potentially generating toxic by-products causing the emergence of secondary pollutants (*Gupta and Diwan 2017, Rizvi et al. 2002*). These make bioremediation a more attractive and acceptable alternative. This simple method involves the use of microorganisms (microbial remediation or biostimulation), fungi (mycoremediation,) aand plants (phytoremediation) that can easily be cultivated. These are efficient, and does not produce waste and secondarypollution (*Wu et al. 2024*). It can also degrade, detoxify, and accumulate harmful organic and inorganic compounds (*Tarekegn et al. 2020*). Biofertilizers, also called microbial inoculants, microbial cultures, bacterial inoculants or bacterial fertilizer (*Ammar et al. 2023*), are used in bioremediation to enhance plant growth, improve soil fertility, and facilitate the metal uptake of plants (*Aloo et al. 2020, Ayangbenro and Babalola 2017, El-Ghamry et al. 2018, Haroun et al. 2023*).

Social acceptability of bioremediation projects are notably central to the success of its implementation. Challenges in the application of bioremediation technologies in degraded areas may be encountered if there is resistance or opposition from the stakeholders. Considering this, social acceptability assessments are pivotal in determining the success of bioremediation projects. *Kocher et al.* (*2002*), however, acknowledge that acceptance by the public could be difficult to predict. In their study of public attitudes toward the use of bioremediation in urban and natural sites, bioremediation was not the choice for the clean-up method.

Social acceptability, according to *Lundheim et al.* (*2022*), is "the quality of being satisfactory and able to be agreed to or approved of." Awareness and perception of the community or stakeholders on a technology or project may affect social acceptability. Informed communities are likely to perceive initiatives as legitimate and beneficial if the details about these are discussed with them and if they are duly consulted. However, community people may have positive perceptions about a project but this may be negatively influenced as they obtain more information (*Sütterlin and Siegrist 2017*), particularly if the project has undesirable features or effects. Communicating information comprehensively with the public, therefore, is key to increasing public awareness and acceptability. The value of such participatory and more inclusive approaches has been recognized in recent decades. Aside from the experts' knowledge and views regarding the appropriate technology, the views, perceptions, and local knowledge of stakeholders, particularly those who are or who will be directly impacted, are deemed important (*CRC CARE 2019*). As guidance for the formulation and implementation of remediation, evidence-based understanding of the community based on how they worry about the technology application in the local environment, how they perceive the risks and benefits, and their acceptance are worthy of consideration (*CRC CARE 2019*).

The Ministry of Energy and Natural Resources of Quebec also recognizes the influence of social acceptability in the success of development projects (*MERN 2017*). Extensive workshop on social acceptability was conducted and guidelines on this subject was also published by the Ministry. The framework, as adopted from *Yelle* (*2013*) and *Stankey and Shindler* (*2006*), considered eight factors that may influence social acceptability: participation in decision-making; trust in the promoters and institutions; social, economic, territorial and geographic contexts; local knowledge; values, beliefs, and expectations; real or perceived risks and uncertainties; impact on the living environment and the environment; and benefits and repercussions for local communities. With this as guide, the study was conducted to describe the awareness, perceptions, and acceptability of the residents in barangays Cagdianan, Hayanggabon, Taganito, and Urbiztondo in Claver, Surigao del Norte, Philippines regarding the bioremediation project in an area in the municipality mined out for nickel.

MATERIALS AND METHODS

Study Area

Claver (**Figure 1**) is the largest municipality in the province of Surigao del Norte in the Philippines with 33,692.13 ha of land area. Bounded by Becebos Bay (north), Municipality of Gigaquit (west), and Municipality of Carrascal in Surigao del Sur (south), it is approximately 60 km southeast of Surigao City, the provincial capital. Previously at the lowest rank (6th class) based on the country's classification of municipalities, it was upgraded to 2nd class due to improved economic status and income classification which can be attributed to the mining sector. A large portion of the municipality is classified as a mining reservation (17,387.52 ha) due to its extensive mineral deposits where chromite ore and nickel/iron ore are found, particularly in barangays Cagdianan, Hayanggabon, Taganito, and Urbiztondo.

The municipality's thrust is to be globally competitive in mining (and sustainable agri-fishery) (*Claver CLUP 2014*) envisioning Claver as a progressive city and a mineral processing center in the country. The area was proclaimed as a Special Economic Zone for Mining under the Philippine Economic Zone Authority (PEZA).

A mining company, the Taganito Mining Corporation (TMC), operates in the municipality for nickel. Revegetation efforts in the mining sites were not so promising until the intervention of National Institute of Molecular Biology and Biotechnology of the University of the Philippines Los Baños (BIOTECH-UPLB) with its fungi- and bacteria-based technologies following their scientifically proven bioremediation protocol. The BIOTECH-UPLB was testing the effectiveness of the Marinduque Bioremediation Protocol (used for the copper mined-out and mine tailing area in Barangay Capayang, Mogpog, Marinduque, Philippines) in rehabilitating the area mined out for nickel by the TMC. Three native tree species: Narra (*Pterocarpus indicus*); Lahi-lahi (*Syzygium acuminatissimum*); and Mangkono (*Xanthostemon verdugonianus*) were used in five field trials at the TMC's site. The project has been implemented by the UPLB-BIOTECH since 2020.

Four barangays (Cagdianan; Hayanggabon; Taganito; and Urbiztondo) directly impacted by the mining activities and the bioremediation project were considered in the study of the communities' awareness, perceptions, and acceptability of the bioremediation (**Figure 1**).

Research Design

A quantitative descriptive research method was used to study the awareness, perceptions and acceptability of the bioremediation in a nickel mined-out area in Claver. Data were collected from barangays Cagdianan, Hayanggabon, Taganito, and Urbiztondo through survey interviews.

The pre-tested survey instrument was a modified questionnaire of *Alaira et al.* (*2021*) customized to the study area. It was organized into five major sections with questions on: demographic information; awareness of the bioremediation technology implemented in the study area; perceptions and knowledge on the bioremediation technology as applied in the greening project; past and present description of the study area in terms of environmental, health and sanitation, safety, family, social relations, leisure, institutional/political, public services, community provisions, community resources and

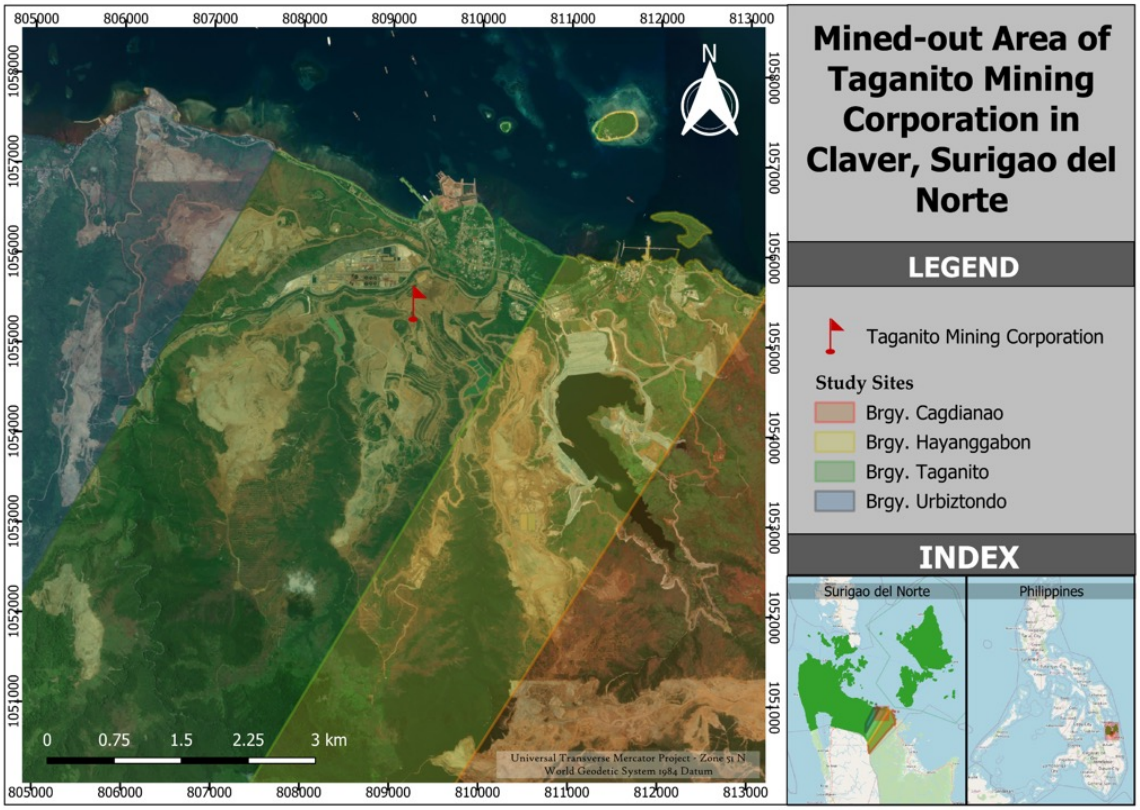

Figure 1. Location of the impact barangays for the study on the awareness, perception, and acceptability of the bioremediation in a nickel mined-out area in Claver, Surigao Del Norte, Philippines, 2023.

structural and processes; and social acceptability of the bioremediation project.

Sampling and Survey Techniques

The respondents were selected in proportion to the 2023 population of the four barangays (**Table 1**). Population data were based from the records of the office of the barangay government of the study areas. Sample size was computed using the Cochran Formula (*Israel 1992*) with 7% margin of error. Considered in the study were 150 respondents. Most of them were from Barangay Taganito (38%), followed by those from Barangay Cagdianan (26%), Barangay Urbiztondo (18.67%), then Barangay Hayanggabon (17.34%).

Using a purposive sampling method, respondents were selected based on prior judgment of their relevance to the study (*Uyimadu 2005*). This sampling method with predetermined criteria enabled the selection of respondents that were residing near the mined-out area and were knowledgeable of the mining activities. This allowed for the consideration of various perspectives which increased the generation of more information crucial to the projects' findings.

Courtesy calls to the local leaders were conducted prior to the survey. As they were not aware of the ongoing bioremediation, the project was introduced to them. The objectives of the study were presented and the permission to conduct interviews in their locality were requested. With the permission granted by the local leaders and with coordination with the concerned barangay officials, face-to-face interviews were conducted with the identified respondents.

The respondents were first informed about the project and the objectives of the survey interview, how they were selected as interviewees, why they have been selected, and how the results of the survey will be used. They were presented with Informed Consent Form for which they were requested to read and sign to signify their willingness and voluntary participation in the interview. Explanations and clarifications were provided whenever necessary.

Table 1. Population and distribution of respondents in the study areas in Claver, Surigao del Norte, Philippines.

Barangay	Population (Year 2023)	Sample Size (n)	Percent
Taganito	1,671	57	38
Urbiztondo	814	28	19
Cagdianao	1,152	39	26
Hayanggabon	774	26	17
Total	4,411	150	100

Guided by MERN's Framework (2013) as adopted from *Yelle* (*2013*) and *Stankey and Shindler* (*2016*), this study in Claver, Philippines considered several factors in understanding the perceptions of respondents that influenced social acceptability. Related themes were combined and some aspects that were beyond the scope of the study were excluded. The following were considered: values, beliefs and expectations; risks; environmental benefits and impacts; benefits for the local community; economic benefit; trust in the project implementers; and participation in the project.

The data gathered from the interview survey were analyzed using descriptive analysis. Cross tabulation and calculation of the frequency distributions and percentages were processed using Google Sheet.

RESULTS AND DISCUSSIONS

The bioremediation technology of the University of the Philippines Los Baños - National Institute of Molecular Biology and Biotechnology (UPLB-BIOTECH) is being applied in the nickel mined-out area in Claver, Surigao del Norte, Philippines since 2020. This is a GMAP-Surigao project implemented under the Greening Mined-out Areas in the Philippines (GMAP) Program with a bioremediation protocol using biofertilizers. After 43 months of field planting, the survival rate of 88% for Narra (*Pterocarpus indicus*) seedlings inoculated with new mycorrhiza (NMYC) from Marinduque, Philippines was achieved. Survival rate of 89% was also observed for Lahi-lahi (*Syzygium acuminatissimum*) and 74% for Mangkono (*Xanthostemon verdugonianus*) seedlings inoculated with new nitrogen-fixing bacteria (NNFB). Height and stem size increments of these seedlings were also notable with the use of the developed bioremediation protocol.

Community Overview: Demographic Information

Majority of the respondents were females (64%) as they were the ones available during the time of interview while the males or husbands were out for work. Most of them were also married (63%). Their ages ranged from 21 to 83 years with an average of 41 years, which is within the range of prime working age. The mean household size was five members. The respondents had been residing in the area for an average of 23 years. Most of them were high school graduates (39%), while only a few graduated from college (8%). Their main source

of income was employment with 27% as Barangay Health Workers and 25% employed with the mining company operating in the study area. Few barangay officials (7%) were also interviewed. More than half of the respondents had a monthly household income below PhP 5,001.00 (58%) while some earned monthly between PhP 5,001 and PhP 10,000 (27%) (**Table 2**). The poverty incidence is relatively high with at least 96% of the families considered as poor based on the indicative range of monthly family incomes for a family of 5 with the poverty threshold of PhP 12,319 per month in Region XIII (*PSA 2023*).

Awareness and Perceptions on the Bioremediation Project

The increasing need for the remediation of diverse classes of waste and waste sites has created a demand for improved remediation techniques applicable to a wider variety of cases. Bioremediation is poised for rapid development believed to have considerable benefits to the environment and human health (*Bonaventura and Johnson 1997*). However, information about the technology is at times not widely disseminated especially among the communities where the technology is directly introduced or implemented. Thus, determining the awareness and perceptions about the project, including the benefits and risks, is integral to this study as they are also deemed influential in the acceptability of the bioremediation project.

Table 2. Profile of respondents in the assessment of the awareness, perception, and acceptability of the bioremediation in a mined-out area in Claver, Surigao Del Norte, Philippines, 2023.

Demographic Characteristics	Frequency (n=150)	Percentage (%)
Sex		
Male	54	36
Female	96	64
Civil Status		
Single	40	27
Married	95	63
Widowed/Divorced/Separated	9	6
Common Law/ Live-in	6	4
Educational Attainment		
Elementary Level	14	9
Elementary Graduate	15	10
High School Level	27	18
High School Graduate	58	39
College Level	20	14
College Graduate	12	8
Vocational Course Level	2	1
Vocational Course Graduate	2	1
Main Source of Income		
Driving	23	15
Employment	77	52
Laborer	5	3
Vending	8	5
Fishing	8	5
Barangay Official	11	7
None (Housewife)	18	12
Monthly Income (PhP) (1 US$ = PhP 56.78)		
≤ 1,000	17	12
1,001-5,000	69	46
5,001-10,000	41	27
10,001-20,000	17	11
20,001-30,000	2	1
>30,000	4	3

The Stakeholders' Forum held as an informational session last September 2023 was a worthwhile avenue where the science behind the bioremediation project was explained and the community's concerns, issues, and misunderstandings or misconceptions were discussed. The presence and involvement of the experts and local leaders during the forum also helped in facilitating and manifesting support and commitment to the project. This also helped in establishing trust between and among the community members and the project implementers

Awareness. The respondents had limited technical understanding about bioremediation. Noting their educational background, most of them were high school graduates and may not have learned about bioremediation before. Regarding the bioremediation in their area, only 55% of the respondents were aware about the project despite the promising status in greening the mined-out area in its third year (2023) (**Table 3**). The community's minimal information about the bioremediation project was obtained through the two-day Stakeholders' Forum conducted in the community during the project survey, from the Taganito Mining Company; and from several barangay officials. Attendance to similar activities, such as bioremediation lectures, increases knowledge but can also influence positive attitudes toward the project and its acceptability based on a survey of 259 household members in Marinduque, Philippines by *Nelson et al.* (*2020*).

Despite the limited information, the respondents in Claver had knowledge about the institution that was implementing the project (97%). Although they were not familiar with BIOTECH, most of them knew about the University where it is based which is a national university in the country with academic, research, and extension mandates. It was after the Stakeholders' Forum that some of them learned all about the bioremediation project in their community and the technology used. They

learned that bioremediation is a project that can bring benefits in numerous ways and most (63%) believed that the community people are the ones primarily benefiting from it (**Table 4**). They also remarked that the bioremediation would be useful in carrying out the obligations of the mining company in rehabilitating the mined-out area (93%) (**Table 3**). They were aware that mining companies have the responsibility to take care of the environment, thus, they identified that the mining company could also benefit from the project (21%). Some respondents, particularly those who were not able to attend the Forum could not identify the beneficiaries due to lack of information about the project.

The respondents also believed that the project would be advantageous to the agriculture and tourism sectors in their community (**Table 4**). Based on the municipalities' Comprehensive Land Use Plan (CLUP) 2014, agricultural lands are becoming limited due to urban development, nonetheless, they believed that crop production (53%) may improve when the mined-out area will be rehabilitated. If the area is declared safe for food production, additional land may become available for growing crops and raising livestock.

Table 3. Awareness of the respondents in barangays Hayanggabon, Urbiztondo, Taganito and Cagdianao of the bioremediation in Claver, Surigao del Norte, Philippines, 2023.

Awareness	Frequency (n=150)	Percentage
Aware of the bioremediation project in the area	83	55
Aware of the implementing institutions of the bioremediation project	145	97
Aware of the benefits and beneficiaries of the bioremediation project	95	63

Table 4. Beneficiaries of the bioremediation project in Claver, Surigao del Norte, Philippines as perceived by respondents from barangays Hayanggabon, Urbiztondo, Taganito and Cagdianao, 2023.

Group	Frequency (n=150)	Percentage
People's Organization	4	3
Community People	94	63
Mining Company	32	21
No answer	20	13
Activities/Sectors*		
Crop Production	79	53
Livestock	39	26
Tourism	43	29

*multiple answers

Perceptions. Bioremediation technologies have been extensively studied and proven (e.g., *Kulshreshtha et al. 2014; Pande et al. 2022*) to be effective in cleaning up mined-out areas. Bioremediation is a method that uses natural organisms, such as bacteria, fungi, or plants to degrade or remove pollutants from the environment. This method is considered safe, non-toxic, and environmentally friendly. It offers a promising solution to address problems caused by toxins that can affect the soil, water, air, and human health. However, perceptions about bioremediation technologies vary. While some believe that these are environmentally beneficial, cost effective, and with positive long-term impact on the environment, others believe otherwise. As stakeholders' views have an effect on their decision to accept and adopt or reject the technology, determining their perceptions is therefore important to identify and understand their reasons for rejection, misconceptions, or acceptance. These serve as bases for evaluating bioremediation projects to realize their full potential so as to attain widespread acceptance and adoption, and ensure the sustainability of the projects. For this study, the perceptions of the respondents on the bioremediation project in Claver was evaluated on the following factors:values, beliefs and expectations; risks; environmental benefits and impacts; benefits for the local community; economic benefits; trust in the project implementers; and participation in the project.

Values, Beliefs, and Expectations. Individual values, beliefs, attitudes, expectations, and personal experiences, can influence the decision to accept actions, products, or technologies (*Podnar and Mustafai 2024*). Values shape what individuals see as important, beliefs affect how they view the world, and expectations guide what they think should happen. Positive or negative experiences and attitudes also impact decisions. Together, these factors shape how people respond to changes or innovations.

The greening project in Claver uses trees in its bioremediation protocol. Seedlings were inoculated with mycorrhizal and nitrogen-fixing bacteria, which enhance their growth and survival, increase biomass production and counts of mycorrhizal spore and nitrogen-fixing bacteria, and enhance metal containment in roots (*Magsayo et al. 2024*). The capacity of trees to absorb heavy metal pollutants through their roots contribute to the decontamination of soil. In addition to the these features, rapid growth, big root systems, high transpiration rates, and genetic variability are also exhibited by many tree species contributing to their capacity to accumulate

certain metals, thereby making them suitable in cleaning up polluted mine fields (*Favas et al. 2024, Gomez et al. 2019*). With their potential to develop and spread on low-nutrient substrates, revegetation could also be expedited (*Favas et al. 2024*). Trees also improve air quality by directly removing air pollutants, such as capturing particulate matter on their surfaces and absorbing gaseous pollutants (*Nowak et al. 2014*). They also aid in soil and water conservation, which are crucial in degraded mined areas, particularly in steep or sloping fields.

The respondents valued trees in several ways. Almost all of them agreed that trees are vital in the sustenance of ecosystems (98%), important for future generations (99%), and for recreation and hobbies (99%) (**Table 5**). This is consistent with *Kulczyk et al.* (*2014*) that recreation is an important contributor to human well-being. Nature is valued as a place for rest, relaxation, refreshment, and recreation (*Kulczyk et al. 2014*) which are becoming widespread in forests and natural areas (*Elands and van Marwijk 2012*). The respondents also valued trees for their contribution to the beauty and character of the local setting/landscape. Although most of them had not seen the area, based on the reports and presentations of the implementing institution during the forum and the survey, they believed that the landscape had improved (98%) and the environment became greener (95%) because of the trees that had been planted in the area.

Local belief in bioremediation's effectiveness varies and depends largely on communication and stakeholder involvement. For example, trust in site management, understanding of the technology, and active public participation have been shown to significantly boost acceptance near U.S. Department of Energy sites (*Focht et al. 2009b*).

The belief of the respondents in Claver regarding the bioremediation project was based on their learnings from the Stakeholders' Forum about the potential ability of the technology in removing toxins or treating the sources (99%) that can affect human health. They trust that it has been tested as an effective method to remove any heavy metals that may be present in the mining site (96%). (*Verma and Kuila 2019; Bhatt et al. 2021; Chaudhary et al. 2023*) accounted that different microbial enzymes have been reported to be helpful in the removal of pollutants in the environment, particularly heavy metals. As such, it could provide a significant pathway towards restoring the fertility and vitality of the mined-out land enabling land use sustainability and providing opportunities for long-term environmentally responsible economic development (98%).

Beliefs on the impacts and benefits of bioremediation and the expectations from the project regarding opportunities for livelihood particularly by lower income families were observed by *Alaira et al.* (*2021*) in a study of the acceptability of bioremediation in Marinduque, Philippines. Expectations on the potential of the project as a means to recover from the adverse impacts of mining were also noted. The project was acceptable by almost all of the respondents and they also favored its implementation in other areas.

Perceived Risks. Perceptions on risks can be used to predict the acceptance of a technology or method. *Focht et al.* (*2009a*) surveyed the judgments and beliefs of 79 people living near the reservations and facilities of the Department of Energy in Tennessee and Washington

Table 5. Value orientation, beliefs, and expectations of respondents affecting social acceptability of the bioremediation project in Claver, Surigao del Norte, Philippines, 2023.

Statement	Frequency (n=150)	Percentage
Value of Trees		
Trees are vital in the sustenance of ecosystems.	147	98
Trees are important for recreation and hobbies.	149	99
Trees are important for future generations.	148	99
Trees are valuable for scenic quality:		
The landscape of the area has improved after it has been planted with trees.	147	98
The environment became greener.	143	95
Beliefs and Expectations		
Bioremediation protects human health and the environment by treating or removing the source of contaminants from a former mine site.	148	99
The developed bioremediation technology has been tested as a possible solution to environmental challenges in the mining industry.	144	96
The benefits of the developed bioremediation technology is potential for the economic recovery of the rehabilitated mined-out area.	147	98

about the bioremediation of subsurface contamination. They reported that those who support bioremediation are those who believe that risk is lower [and those who trust the site managers]. Similarly, an online survey of 418 residents in Tianjin City by *Fang et al.* (*2022*) on the use of a risk control method for contaminated sites revealed that when perceived risks are lesser than the perceived benefits, people tend to accept the technology or method.

The respondents of the study in Claver perceived that no risks were associated with the biotechnology because it uses beneficial microorganisms (94%) (**Table 6**). The mycorrhizal fungi and nitrogen-fixing bacteria used in the protocol were perceived to be safe both for the people and the environment (95%). With this, the bioremediation project was viewed as a safe, fast, and effective solution to reduce or even eliminate toxicity from mined land (91%).

The respondents also believed that the bioremediation project used tree species (**Figure 2**) that were appropriate in the mined-out area (97%). The project planted 6-month old native seedlings of Narra (*Pterocarpus indicus*), Mangkono (*Xanthostemon verdugonianus*), and Lahi-lahi (*Syzygium acuminatissimum*), which are all native to the Philippines. While non-native plants may provide benefits for the native flora and fauna in some ways, indigenous species are more appropriate for reforestation to prevent possible risks or harm to native habitats and biodiversity. Non-native or exotic plants can reproduce rapidly, be highly invasive and pose damages to the local environment.

Kuppan et al. 2024; Kang 2014, De-Bashan et al. 2012, Garbisu and Alkorta 2003; Perelo 2010, Kulik et al. 2006; and *Xu and Lu 2010* are among those who describe bioremediation as a safe, less invasive, and effective method of removing a variety of contaminants; likewise, it does not generate waste products (*Kocher et al. 2002*) that may also pose significant risks to the environment and human health. It should be noted from *Milić et al.* (*2024*), however, that bioremediation necessitates further research for a more effective strategy to address issues on incomplete biodegradation and secondary contamination by other chemicals. *Liu et al.* (*2024*) underscore the understanding and mitigation of such risks to guarantee the potential of bioremediation initiatives without worsening the conditions of the environment.

Environmental Benefits and Impacts of the Bioremediation Project. The advantages and

Table 6. Perceptions of respondents on the risks of bioremediation in Claver, Surigao del Norte, Philippines, 2023.

Awareness	Frequency (n=150)	Percentage
There are no risks associated with the use of the technology in implementing the project.	141	94
The mycorrhizal fungi and nitrogen-fixing bacteria used in the rehabilitation project are safe for the people and the environment.	142	95
The project is a fast and effective solution to reduce or eliminate toxicity from mine tailings.	136	91
The plant species planted in the mined-out area are appropriate.	146	97

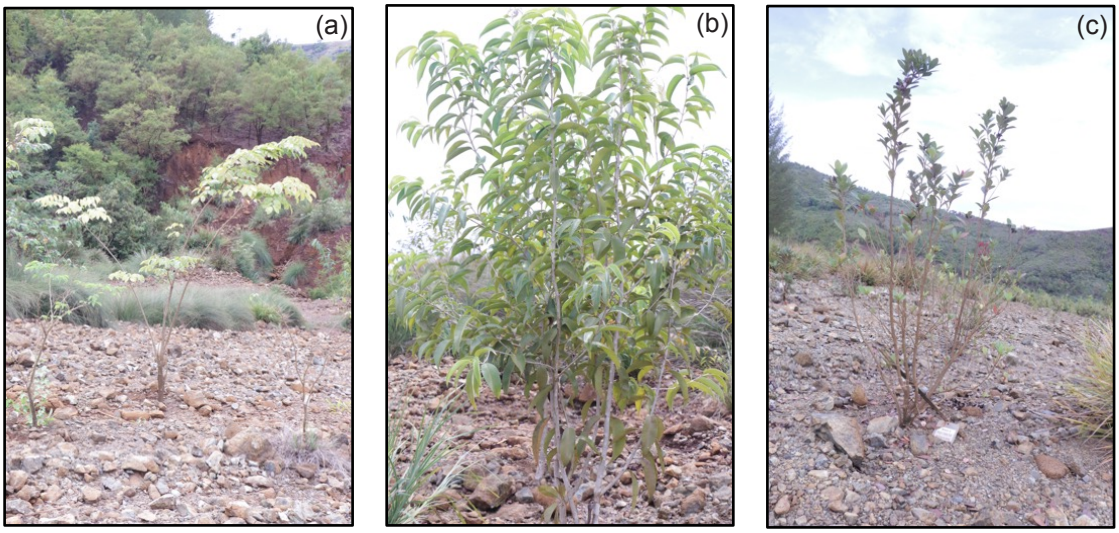

Figure 2. (a) Narra (*Pterocarpus indicus*), (b) Lahi-lahi (*Syzygium acuminatissimum*), and (c) Mangkono (*Xanthostemon verdugonianus*) after 29 months of planting in the nickel mined-out area in Claver, Surigao del Norte, Philippines, 2023.

consequences of the bioremediation project can be more meaningfully understood when viewed from the perspective of the community directly affected by the initiative. Thus, perception toward the benefits and impacts on the different aspects of the environment were identified. These covered the value and effects of the bioremediation project particularly pertaining to water, soil or land, and air.

Water quality issues in mining areas are prevalent as the transport of sediment leads to the formation of suspended solids in water bodies (*Jacobsen and Efthymiou 2022*). These deteriorate the quality of water making it unsuitable for biodiversity habitat. Some areas in the study area experienced problems with water quality. Some respondents recounted that reddish water and limited supply especially during the dry months were encountered. With the bioremediation in the area, almost all respondents perceived that it was a reassurance for improved supply of quality and sufficient water (97%) which were also crucial for the habitat (89%) and conservation (94%) of many aquatic organisms. They related this to the important role of trees as natural filters and water regulators as they were aware of the ability of trees to absorb pollutants, slow down run-off, and increase groundwater storage.

Similarly, the majority of the respondents perceived that the bioremediation can prevent soil erosion and degradation (89%) aiding the mined-out area to regain productivity. With this, it was perceived that terrestrial biodiversity resources will increase as the habitat for both plants and animals will be restored (85%), and consequently terrestrial plants and animals will be conserved (90%). Trees grown in the mined-out area werealso perceived to filter air pollution (82%) and enhance oxygen supply (93%) in the community (**Table 7**).

Benefits for the Communities. The perceived benefits of bioremediation on health and sanitation, safety, family, cultural values, and community relations were also factors that shaped how the respondents viewed bioremediation. They believed that benefits will be widely distributed among the community people and other stakeholders because the outcome of the project will be advantageous for everyone, directly or indirectly.

Health and Sanitation: The respondents did not consider the bioremediation project to have caused loss of lives and diseases. Although some perceived that the bioremediation project decreased the mortality (48%) and morbidity rate (36%) in the community. Others also perceived that there were no changes or improvements to public health that are attributed to the on-going bioremediation. They believed that health care services had increased (63%), but this was through the initiatives of the mining company in the area who provided healthcare facilities. A similar study by *Nelson et al.* (*2020*) reported that focus group participants believe that bioremediation translates to good health and a clean environment. The bioremediation was acceptable as a solution to remove toxic wastes for domestic use.

Safety: The bioremediation technology implemented in the mined-out area of Claver was regarded as less invasive in contrast to some remediation methods, such as excavation-based procedures which have been identified as disruptive (*Jorgensen 2011; Bala et al. 2022; Singh et al. 2016*). Nonetheless, due to limited awareness and understanding of bioremediation among respondents, anticipated responses, such as the contribution of planted trees to reducing ambient temperature and mitigating flood risks, were not reflected in the survey results. This could be due to their

Table 7. Environmental benefits and impacts of the bioremediation project in Claver, Surigao del Norte, Philippines as perceived by the respondents in barangays Taganito, Cagdianan, Urbiztondo, and Hayanggabon, 2023.

Statement	Frequency (n=150)	Percentage
Water		
Bioremediation is important in improving the quality and quantity of water in the area.	146	97
Habitats of many living organisms are restored.	133	89
Conservation of water plants and animals are promoted.	141	94
Land/Soil		
Risks of soil erosion and degradation are prevented/minimized.	134	89
Floods are prevented/minimized.	131	87
Biodiversity in the area and its surrounding environment is increased.	127	85
Conservation of terrestrial plants and animals are promoted.	135	90
Air		
Pollution gases, odors, and particulate matters are filtered.	123	82
Supply of oxygen is enhanced.	139	93

experience that warm weather and flooding still occur in the community. On the one hand, the respondents perceived that rockfalls and erosions (47%), vibrations (46%), and generation and spread of dust (42%) will be reduced. They regarded the trees and other vegetation as a means to reduce soil erosion and lessen dust spread.

Family: The respondents associated the bioremediation project to trees and forests that provide leisure, such as enjoying the beauty of nature, breathing fresh air, and spending time with family and friends. They also perceived that several opportunities for economic activities will be available (72%). They had the appreciation that the project can provide income sources for families, e.g., qualified family members may be hired as part-time or full-time workers during plantation and maintenance activities. Drivers, laborers, vendors, and fisherfolk were among the respondents who may avail of this opportunity to earn additional income.

Cultural Values: The cultural values of trees, woods, and forests are becoming an increasingly important aspect of sustainable forest management according to *O'Brien* (*2003*). The cultural benefits could be improved health and well-being; social contacts; personal pride; education; inspiration; spiritual well-being, and economic benefits (recreation and tourism, local economy activity).

If the mined-out area will be transformed into forest, the respondents believe that the community will have a scenery to enjoy, there will be opportunities for entertainment (64%), cultural activities (70%), and religious services (73%). Around 65% of the respondents also believed that a rehabilitated mined-out area will be a valuable legacy for the future generations in the community for them to enjoy such benefits.

Seedlings of narra, mangkono, and lahilahi which are all indigenous species of trees are planted in the bioremediation site. These trees are also of cultural importance to the community. Propagating or planting narra, a highly valued tree which is already classified as Endangered in the International Union for Conservation of Nature's Red List, brings pride to the residents. Mangkono, known for its exceptional hardness and durability, hence called Philippine ironwood, is one of the hardest in the world and is also embedded in the culture of the Surigaonon people as a "symbol of strength, resilience, and resourcefulness". Similarly, lahi-lahi, also known for its hard and heavy wood, is another valuablematerial of commercial importance.

Community Relations toward the Environment: With the implementation of the bioremediation in the area, the residents reckoned the project to have advanced cooperation and participation between and among them and the concerned agencies relative to efforts on conserving natural areas (96%). With these efforts, they also considered the project to have made the community more aware of the importance of a balanced and healthful environment (97%) motivating them to be more supportive of local environmental initiatives.

Economic Benefits. The respondents positively perceived the cost-value of the bioremediation. Bioremediation is believed to be more affordable and cost-effective (95%) in bringing mined-out areas back to life and renewing their productivity. Compared to conventional remediation methods such as the use of chemical treatment and excavation that employ physical and chemical engineering procedures, further contamination and damage to the environment could occur (*Kang 2014*). With bioremediation, which could be implemented on-site, the extensive, energy-consuming, and complicated civil engineering works could be avoided thereby minimizing expenses (*Troquet and Troquet 2002*). The respondents also believed that the developed technology is a fast and effective long-term environmentally friendly solution to reduce or eliminate toxicity from mine tailings (91%) therefore, could offer cost savings. Particularly, phytoremediation, a type of bioremediation that uses plants, is a cost-efficient technology due to low establishment and maintenance costs, energy requirement is primarily from sunlight, and potentially a rapid process *Glick* (*2003*); and with minimal disturbance and site maintenance compared with other technologies *De-Bashan et al.* (*2012*).

Mining companies are expected to be financially responsible for the remediation of areas that they had mined out. With such an available bioremediation technology, the respondents expected that the performance of the mining company in restoring the mining site in the study area will be expedited.

Trust in the Implementing Institutions and Partners. Mutual trust among communities, implementers, and institutions, as explained, is a crucial component for any decision-making (*Ellis and Ferrero 2016*). An environmental study in Korea with 200 participants revealed that public trust in government was among the most significant predictors of the decision to accept and recommend climate technologies (*Song et al. 2024*). Similarly, trust directly influences the attitude and intention to use a technology on urban air mobility based on a survey by *Yao et al.* (*2024*).

Scientific or research institutions are usually the key holders of bioremediation technology while the mining companies were seen as the co-implementer of the technology and the community will adopt and safeguard the plantation in the mined-out area. Distrust between the cooperating agencies and research institutions due to uncertainties particularly on the technology and the services needed to implement bioremediation projects effectively may generate unsupportive community residents. People who are generally more trusting of others, including scientific institutions and government are more supportive of the application of remediation technologies (*Prior and Rai 2017, Prior 2018*). People also have the tendency to accept technologies supported by the government even when they are aware of the risks associated with these (*Song et al. 2024*). It is, therefore, imperative that the agencies and institutions are implementing the most appropriate and proven environmental intervention for the mined-out area.

The answers of the respondents were positive in terms of the trustworthiness of the cooperating agencies, funding agency, and implementers of the bioremediation project (97%) (**Table 8**). The researcher and project implementer is the University of the Philippines Los Baños National Institute of Molecular Biology and Biotechnology (UPLB-BIOTECH) and the Department of Science and Technology's National Research Council of the Philippines (DOST-NRCP) is the funding agency. UPLB, one of the eight Constituent Universities of the University of the Philippines System, is a coeducational publicly funded institution with a tripartite thrust on academic, research, and extension. UPLB-BIOTECH has already successfully implemented five bioremediation projects in 10 mined-out sites in the country. The NRCP is an attached agency to the DOST mandated to promote and support matters related to research, researchers, scientists, scientific and technological culture, and information sharing through linkages with local and international scientific organizations. As these are reputable government institutions, the respondents expressed trust in their competence and expertise and this greatly influenced their decision to accept and support the project.

The stakeholders' forum served as an avenue where the issues and concerns of the community people regarding the project had been discussed. With this, the respondents believed that the project implementers were always considering the interests and opinions of the community people (94%) and that they had effectively communicated about the projects to them (96%). During the event, the residents and the participants from various sectors expressed their support for the implementation and sustenance of the bioremediation initiative. This was, therefore, regarded as an effective way to gain people's support and a major factor that contributed to the acceptability of the project. The importance of proper communication plans and strategies as among the critical factors to attain project success was also pointed out by *Albuali* (*2021*). That is, when the project's purpose is clearly stated, stakeholders are included in its promotion, and the associated benefits are properly explained.

The respondents also trust in the capacity of the project implementers in organizing partnerships for the environment by fostering participation and cooperation among the stakeholders (96%). They related this to the collaborations of the project implementer with the mining company, local and national governments or agencies or other sectors in the restoration project. Also to the initiative of being able to convene many of the community residents, barangay officials, government agencies, mining companies, and other stakeholders in the 2-day forum to discuss the efforts of restoring the natural resources from mining through the bioremediation project.

Participation in the Project. Local actors want to have

Table 8. Perceptions of the respondents in barangays Taganito, Cagdianan, Urbiztondo, and Hayanggabon on the implementing/partner agencies and other stakeholders of the bioremediation technology/project in Claver, Surigao del Norte, Philippines, 2023.

Statement	Frequency (n=150)	Percentage
The cooperating agencies, funders, and implementers of the bioremediation project are trustworthy institutions.	145	97
The project implementers are always considering the interests and opinions of the community people.	141	94
The project implementers have effectively communicated the projects and its objectives to the community.	144	96
The project implementers has fostered cooperation and participation between and among the residents and relevant agencies in relation to natural areas conservation.	144	96

an opportunity to be part of the decision-making process for projects that may affect their quality of life or living environment (*Yelle 2013*). People could potentially influence many different aspects when they participate in decision-making and in the project implementation processes, thus perceived that procedural fairness may mediate the effect of participation on project acceptability (*Liu et al. 2020*).

This was similar with this study's respondents when some of them remarked during the interviews that although they support the project, they could have appreciated more if they were informed and consulted beforehand and if they were engaged as soon as the project commenced. Nonetheless, the community people indicated their willingness to support the sustainability of the project because they believed in its goal of restoring the mined-out area to its original vitality.

With only 55% of the respondents aware of the project, only a few also were involved (5%) in the project activities. These were employees of the mining company operating in the area and they were involved in land preparation and planting of trees. No community residents were engaged or hired in bioremediation-related activities. With safety as a primary concern, the mined-out area was limited to carefully organized and coordinated community tours and site visits.

Social Acceptability of the Bioremediation Project

Overall, the survey revealed a widespread acceptability of the bioremediation in the nickel mined-out area. Almost all respondents (99%) were willing to accept the project using the established protocol and technology with the appreciation of the use of native forest trees in the rehabilitation. They were also willing to be involved in the activities of the bioremediation project (99%) if the mining company would allow them access to the area. They also expressed their willingness to recommend the technology to be adopted in other mined-out areas (96%). These were also emphasized during the stakeholders' forum last September 26 and 28, 2023 that was conducted near the project sites of the GMAP-Surigao Project, which is under the Greening Mined-out Areas in the Philippines (GMAP) Program. Various sectors and community members were in attendance in the forum and they conveyed their support for the bioremediation initiatives.

CONCLUSION AND RECOMMENDATIONS

In Claver, Surigao del Norte in the Philippines, bioremediation technology using tree species of Narra (*Pterocarpus indicus*), Mangkono (*Xanthostemon verdugonianus*), and Lahi-lahi (*Syzygium acuminatissimum*) was implemented in an area mined out for nickel. The trees planted were robustly growing, exhibiting vigorous height and stem diameter growth and survival rate of 74-89% after 43 months of planting. Despite these remarkable success indicators, the community members were not aware of the project until the Stakeholders Forum last September 2023.

In compliance with strict safety protocols and operational concerns, the mining company limits access to the area to carefully coordinated and controlled community tours and site visits. With this, the respondents, except those who were staff of the mining company, had not yet been to the mined-out area and had not yet seen the bioremediation site. This made their participation in the project unfeasible. People tend to believe more, trust more, and be more receptive if they see concrete proofs.

Despite the low awareness and non-involvement in the project, the community people had a favorable perception of the bioremediation in their area, and the project was still generally acceptable by them. Respondents believed and trusted the project implementers as to the promising performance and potential advantages and benefits of the environmental initiative. A widespread agreement for its implementation was notable and no strong objection was observed. This case demonstrates that awareness and participation may not be necessary in the social acceptability of a bioremediation project.

Acceptability of the project was based on the aspiration to restore the environment in support of the rehabilitation efforts of the mining company. Specific to the bioremediation, they attributed the potential benefits from the project in terms of socio-economic upliftment and environmental safeguards particularly on water, land/soil, and air. Many of them commented, however, that these may have yet to be realized in the long-term as the project was still in its early stage of implementation.

It is recommended that the stakeholders, including local residents, community officials, mining staff, and other industries or sectors, be well-informed and actively engaged in the project. This will establish their active role and support of the project and to empower them to assess, decide, and contribute to environmental interventions that may directly or indirectly affect their well-being and their communities. The community people will also feel a sense of ownership and stewardship thereby ensuring sustainability of the bioremediation

activities post-implementation of the project.

Community awareness can be promoted through broader information campaigns to apprise all stakeholders how the bioremediation technology works, the environmental and socio-economic advantages, the long term benefits that it could offer, and the potential risks, if any. The local communities can be part of the bioremediation project by providing them job opportunities relative to plantation maintenance, monitoring, and even research.

Part of the mining corporate social responsibility is to rehabilitate the mined-out area and among the primary actions are to plant trees and re-establish the productivity and environmental safety of the area. Adoption of bioremediation technology could augment success.

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