Sustainable alternative livelihood for sand miners in Malang Regency, East Java, Indonesia: Application of the PROMETHEE method

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Abstract

Sand mining activities on agricultural land and rivers in Bambang Village, Wajak District, Malang Regency, have been ongoing for a long time. The sand mining activities on private agricultural lands, besides being illegal, also damage the land and the environment. In addition, these sand mining activities are also unsustainable. This study aimed to analyze and formulate sustainable alternative livelihoods of sand miners on agricultural lands in Bambang Village, Wajak District, Malang Regency, based on local resources. The study method was carried out using a combination of case studies and survey methods, accompanied by in-depth interviews and field observation. The in-depth interviews were conducted by interviewing 60 respondents for key informants from miners, farmers, many stakeholders, and experts that were selected purposively. The data obtained were analyzed using a multi-criteria analysis (MCA), namely PROMETHEE (Preference Ranking Organization Methods for Enrichment Evaluation) program to formulate sustainable alternative livelihoods. The results showed that the best alternative sustainable livelihood at this location is agriculture. The second best alternative sustainable livelihood is ecotourism, the third is animal husbandry, and the fourth is informal sectors based on local resources. The government should support the development of agriculture, ecotourism, animal husbandry, and the informal sectors in the village.

Keywords:
artisanal and small-scale mining environment livelihood sand mining sustainability

Introduction

Population growth and development in many countries in the world have led to an increase in the need for housing, infrastructure, and various facilities that require sand as a raw material. The global urban population is expected to grow to 5.2 billion in 2030, particularly in Global South cities (World Urbanization Report, 2018). The high demand for sand impacts the increase in sand mining activities. Sand mining can be carried out on common property or open access lands, as well as on private lands, both legal and illegal mining. Sand is the main ingredient in the concrete used for roads, houses, and high rises (Marschke et al., 2021); 80% of cement is made from sand (Koehken, 2018). According to Bendixen et al. (2019), sand and gravel are being extracted faster than they can be replaced. Approximately 32-50 billion tons
of sand and gravel are extracted globally each year (Koehnken, 2018; Bendixen et al., 2019), mainly for making concrete, glass, and electronics (Bendixen et al., 2019). Sand is also used for land reclamation or territorial expansion, dam building, and other products (Beiser, 2019; Bendixen et al., 2019; Marschke et al., 2021). Sand and gravel are the most extracted group of materials, even exceeding fossil fuels (Torres et al., 2017). Sand is the world’s third most utilized natural resource after air and water (Schandl et al., 2016). In Indonesia, the high demand for sand is caused by the development and rapid growth of housing, road infrastructure, and other facilities, especially on Java Island. It also has been driven by the government's massive infrastructure development policy since 1990 (Purnomo et al., 2021).

Sand mining has a negative impact on the environment, including land degradation as well as LUCC (land use and cover change), deforestation, problems with biodiversity and disturbing water systems (Sonak et al., 2006), land loss, loss of biological diversity (Farahani and Bayazidi, 2018; Worlanyo and Jiangfeng, 2021). Sand mining can affect local ecology, cause erosion, make this area more vulnerable to flood, and affect agricultural productivity (Sonak et al., 2006; Farahani and Bayazidi, 2018). It can impair the groundwater system, thus affecting the water flow and freshwater availability to the local population (Sonak et al., 2006). Extensive sand extraction also impairs water and food security because the extraction causes erosion, which can degrade the land and may disrupt crop productivity (Torres et al., 2017). Besides the negative impact, sand mining activities also have positive impacts, creating job opportunities, though it is temporary, and increasing income for sand miners.

Most of the sand mining in Indonesia is categorized as artisanal and small-scale mining (ASM). ASM is the mining by individuals, groups, families, or cooperatives with minimal or no mechanization (Hentschel et al., 2012), informal and unregulated systems (Utomo et al., 2014), with low technology, low capital, and labor-intensive resource extraction activity, also described as a poverty-driven activity with low barriers and minimum mechanization (Banchiragh and Hilson, 2010; Ofusil et al., 2020). The miners are struggling to make sufficient money to support their families, not to get big profits (Anderson, 2012; Suhartini and Abubakar, 2017). A lack of knowledge and supervision of sand mining activities makes exploitation unsustainable (Bendixen et al., 2019).

The massive sand mining in many countries is a concern of many researchers worldwide. Based on a WWF report, 70 countries reportedly have illegal extraction of the river and coastal sand (Koehnken, 2018). The research on sand mining is mostly on common land resources like forests, mountains, and rivers; however, research on sand mining on private land is rare (Purnomo et al., 2021). Studies conducted at the same location of the Bambang Village showed that sand mining activities have decreased environmental quality (Fauzan et al., 2022; Handono et al., 2023). The sand mining activities significantly decreased soil quality, decreasing soil organic matter content, increasing soil bulk density, and decreasing soil porosity at 20-40 cm depth of soil; it has also changed soil properties such as topsoil removal and increasing soil erosion (Fauzan et al., 2022). The cost of land reclamation with revegetation by maize is about IDR 36,767,500/ha (Fauzan et al., 2022).

The main problem of sand mining activities on private lands is the negative impacts on the environment. Most of the private land in the sand mining is agricultural land, so it will damage the agricultural land. Most of the miners in Bambang Village were farmers and farm workers. The reason people do sand mining on private land is the land on the slope of Mount Semeru, which is rich in sand. They try to increase their income through sand mining activities. Sand is categorized as a non-renewable natural resource. Therefore, continuous sand mining causes the sand to run out over time; thus, the income from this sand mining will not be long-term. In other words, the sand mining livelihood is temporary or unsustainable. Like other artisanal and small-scale gold mining (ASGM) in Sekotong Lombok, the declining production and income of gold miners, as well as the unsustainability of artisanal and small-scale gold mining (ASGM), push the artisanal miners to look for alternative livelihoods such as agriculture and livestock (Suhartini et al., 2020). Sand miners have no guarantee that they will be able to maintain their livelihoods for a long time, so they have to find new livelihoods (Marschke et al., 2021). The sand mining activities are unsafe. Their adaptation strategy to vulnerability is dominated by short-term reactive strategies rather than long-term anticipations to stabilize livelihoods (Purnomo et al., 2021). The alternative sustainable livelihoods for sand miners at Bambang Village, Wajak District, Malang Regency, based on local potenacy, are urgent to study and formulate.

The objective of this study was to analyze or formulate sustainable alternative livelihoods of sand miners on private lands.

**Materials and Methods**

**Conditions of the study area**

The research location at Bambang Village, Wajak District, Malang Regency, East Java (Figure 1), was determined purposively. Bambang Village is located on the slope of Mount Semeru, which has many sand mining activities. The area of this village is around 1,761 hectares, the second largest area in Wajak District, and its location is directly adjacent to the Bromo Tengger Semeru National Park (TNBTS) area. Bambang Village area is used for residential land
(89 ha), agricultural land (212 ha), forest (1,396 ha), and smallholder's plantation land (53 ha). Some agricultural products that can be produced in Bambang Village include food crops such as maize (850 t/year), sweet potatoes (7 t/year), cassava (105 t/year), and taro (8 t/year). Moreover, bananas are the most produced horticultural crop (112 t/year), avocados are the second highest horticultural crop production (85 t/year), and papayas produce up to 60 t/year.

Smallholder plantation crops, including sugarcane, produce 4,335 t/year, and cloves crops produce 8 t/year. Turmeric is one of the products of biopharmaceutical crops with a farming area of around 0.25 ha, and it produces 0.5 t/year. In addition to agricultural products, the community in Bambang Village has animal husbandry products, specifically poultries, sheep, goats, and cows.

**Research methods**

This study applied a quantitative and qualitative approach to formulating sustainable alternative livelihoods from environmental, economic, and socio-cultural aspects for sand miners on agricultural land. This research was conducted from September to November 2022. The data used in this study were primary and secondary data. The research method used for this study was a case study with a survey method. Primary data collection used several methods, namely field observation and surveys, by conducting in-depth interviews with 60 respondents who were randomly selected by simple random sampling. The respondents consisted of miners, farmers, several stakeholders (local government officers), and experts who are competent in their fields and understand this research problem using an instrument in the form of a questionnaire. The questionnaire consisted of respondent characteristics (age, education, gender, occupation), family income, activities in sand mining, agriculture, animal husbandry, ecotourism, informal sectors, and the preference scale for several indicators on three aspects: environment, economics, and socio-culture that can be seen at Table 1. Secondary data were obtained from scientific publications by several agencies, such as the Central Bureau of Statistics, which supported the data in this study.

**Data analysis methods**

The data analysis method used PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) with the software Visual PROMETHEE Academic 1.4. for Windows. PROMETHEE is one of the powerful tools for Multi-Criteria Analysis (MCA), which was first developed in 1982 by Jean-Pierre Brans and Bertrand Marsechal (Batubara et al., 2016). Multi-Criteria Analysis considered an evaluation structure to solve environmental, economic, and socio-cultural aspects based on the outranking method (Preference Index) and the alternatives assessed (Kumar et al., 2017).
There were two types of PROMETHEE methods used in this research, i.e., PROMETHEE I and PROMETHEE II. PROMETHEE I establishes a partial preorder among the alternatives. PROMETHEE II establishes a complete preorder among the alternatives and consists of building a valid outranking relation (Balali et al., 2014; Batubara et al., 2016). The steps of data analysis using the PROMETHEE method were determining the purpose of the analysis, which was to find the sustainable alternative livelihoods for sand miners, making alternative livelihoods, making criteria used to evaluate various alternative livelihoods, and choosing the preference. Furthermore, the procedure for implementing the PROMETHEE is begun by determining the deviations based on pairwise comparisons of the alternatives, followed by using a relevant preference function for each criterion, calculating the global preference index, calculating the negative and positive outranking flows for each alternative (Batubara et al., 2016).

The outranking method is a well-established outranking multi-attribute decision analysis approach; it is also the most attractive outranking method because of its mathematical simplicity and transparency (Sotiropoulou and Vavatsikos, 2021). Outranking methods such as PROMETHEE are one of the popular measures that facilitate pairwise comparisons of alternatives to assign rankings or partial rankings and are most often used because of their ease and simplicity in conception and application by decision-makers (Sapkota et al. 2018). According to Behzadian et al. (2010) and Brans and De Smet (2016), PROMETHEE has several advantages compared to other Multi-Criteria Decision Making (MCDM) methods because it is efficient and user-friendly.

In addition, PROMETHEE is often paired with GAIA (Geometrical Analysis for Interactive Aid), providing a representative graphical visualization (Agustin et al., 2022). The GAIA offers a visual analysis that makes it possible to reach several conclusions: actions located near (far) have similar (different) performance. The quality of the GAIA representation is given by the delta parameter (δ), which indicates the quantity of information reflected in the GAIA field. As a rule of thumb, a value greater than 70% can be considered to provide a good and reliable representation of the decision problem (Batubara et al., 2016; Lopes et al., 2018; Moreira et al., 2021). The process in the PROMETHEE analysis can be seen in Figure 2. In this study, alternative sustainable livelihoods were determined based on local resources and the local community. Actions that determined the alternative sustainable livelihoods are agriculture, animal husbandry, ecotourism, and the informal sectors.

This research used the criteria on three aspects, i.e., environment, economics, and socio-culture. Then, each aspect had four indicators or scenarios. The next step was choosing a preference for all of the respondents with indicators that are measured as very bad (1), bad (2), average (3), good (4), and very good (5) (Table 1).

**Building an evaluation matrix:**
- Determine actions (Alternatives Livelihood)
- Determine criteria (Environment, Economic, Socio Culture)
- Determine scenarios (Indicators)
- Determine preference (Preference Scale)
- Organizing criteria into groups and clusters
- Give weight to criteria

![Figure 2. PROMETHEE analysis process flow.](image)

Determination of the PROMETHEE ranking was based on a pairwise comparison of actions, determining how much action “a” is preferred over action “b” based on certain criteria to measure the deviation of the evaluation value of two actions for each criterion. The difference in the evaluation values of the two actions is adjusted into the degree of preference between 0-1. The PROMETHEE procedure consists of an overall preference index and outranking flows (Brans and De Smet, 2016; Zuraiddah, 2019):

**Overall preference index (Brans and De Smet, 2016)**

The equation about the overall preference index can be described as follows:

Let \( a, b \in A \), and let:

\[
\pi(a, b) = \sum_{j=1}^{k} w_j P_j(a, b)
\]

where:

- \( \pi(a, b) \) = degree \( a \) is preferred to \( b \) over all the criteria
- \( w_j \) = weight of criterion \( j \)
- \( P_j(a, b) \) = preference function \( a \) to \( b \) for criterion \( j \)
- \( \pi(a, b) \sim 0 \) = weak global preference of \( a \) over \( b \)
- \( \pi(a, b) \sim 1 \) = strong global preference of \( a \) over \( b \)
Table 1. Indicators for each alternative livelihood.

<table>
<thead>
<tr>
<th>Alternatives Livelihood (Action)</th>
<th>Aspects (Criteria)</th>
<th>Indicators (Scenario)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>a. Business permits</td>
<td>(1) No permit, (2) In the process of getting a permit, (3) Get a permit from local society, (4) Get a permit from local government, (5) Getting permit from district institution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Application of conservation practices</td>
<td>(1) Not apply, (2) A small number of lands apply conservation practices, (3) Half of the land apply conservation practices, (4) Most of the land apply conservation practices, (5) Whole of the land applies conservation practices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c. Environmental damage</td>
<td>(1) Very Damage, (2) Damage, (3) Slightly Destructive, (4) Not Destructive, (5) Highly Non-Destructive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d. Waste Recycle</td>
<td>(1) No waste recycled, (2) 1%-24% of waste was recycled, (3) 25%-49% waste was recycled, (4) 50%-74% waste was recycled, (5) &gt;75% was recycled</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Increasing job opportunities for society</td>
<td>(1) No, (2) Slightly, (3) Moderate, (4) Enough, (5) High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c. Business costs</td>
<td>(1) Very high cost, (2) High cost, (3) Moderate cost, (4) Low cost, (5) Very low cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d. Long-term business prospects</td>
<td>(1) Very Bad, (2) Bad, (3) Fairly Good, (4) Good, (5) Very Good</td>
<td></td>
</tr>
<tr>
<td>Socio-Culture</td>
<td>a. Society acceptance</td>
<td>(1) The whole society refuses, (2) Most people refuse, (3) A small number of people refused, (4) Most people accept, (5) The whole community accepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Participation in organization</td>
<td>(1) No participation, (2) 1%-24% of community participate, (3) 25%-49% of community participate, (4) 50%-74% of community participate, (5) &gt;75% of community participate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c. Government supports</td>
<td>(1) None, (2) Have support from sub-village, (3) Have support from the village, (4) Have support from sub-district, (5) Have support from local government and district</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d. Training related to the business</td>
<td>(1) Never exist, (2) 1 time per year, (3) 2 times per year, (4) 3 times per year, (5) More than 3 times per year</td>
<td></td>
</tr>
</tbody>
</table>

Outranking flows (Brans and De Smet, 2016)

Each alternative \( a \) is facing \( (n - 1) \) other alternatives in \( A \). There are two outranking flows, those are:

(a) The positive outranking flow (\( \phi^+ \))

The positive outranking flow expresses how an alternative \( a \) is outranking all the others. It is its power, its outranking character. The positive value of flow is obtained based on the equation as follows.

\[
\phi^+(a) = \frac{1}{n - 1} \sum_{b \in A} \pi(a, b)
\]

where:
- \( \pi(a, b) \) = preference value \( a \) is better than value \( b \)
- \( n \) = the number of alternatives

(b) The negative outranking flow (\( \phi^- \))

The negative outranking flow expresses how an alternative \( a \) is outranked by all the others. It is its weakness, its outranked character. The negative flow value was obtained based on the equation as follows.

\[
\phi^-(a) = \frac{1}{n - 1} \sum_{a \in A} \pi(b, a)
\]
where:
\[
\pi(b, a) = \text{preference value } a \text{ is better than value } b
\]
\[
n = \text{the number of alternatives}
\]

(c) Net flow \((\phi)\)

The net flow value is obtained from the value of positive outranking flow minus the value of negative outranking flow, with the equation as follows.
\[
\phi(a) = \phi^+(a) - \phi^-(a)
\]

where:
\[
\phi^+(a) = \text{Positive Outranking Flow (PROMETHEE I)}
\]
\[
\phi^-(a) = \text{Negative Outranking Flow (PROMETHEE I)}
\]
\[
\phi(a) = \text{Net Flow (PROMETHEE II)}
\]

Results and Discussion

Characteristics of respondents and people livelihood in Bambang Village

Sand mining activities carried out by the people of Bambang Village can be divided into two: land owners who excavate their sand and miners who collect sand from several locations. Geographically, almost all land areas on the slopes of Mount Semeru of Bambang village contain high-quality sand. Therefore, some of the local communities have perceptions that sand mining activities are more prospective than farming. Even in their farming activities, they only use their private land and do not rent land elsewhere. As reported by Handono et al. (2023), the people of Bambang Village think that renting land will increase farming costs. The average size of agricultural land in the village is small, so the farm income is not high. The majority of people in the village prefer to sell the sand on their land rather than use the land for agriculture. They would rather think about short-term than long-term strategies. It is proven from the results presented in Table 2 that the number of people who own sand mines (24 respondents) is more than sand mining workers (23 respondents). In addition, when viewed from their education, the majority of respondents have elementary education, and some sand miners are still young, aged 24 years. Limited knowledge causes them to be unable to utilize and manage the available natural potential to improve welfare. Sand mining activities in Bambang Village have been operating for a long time. One of the key informants in this study stated that sand mining activities in Bambang Village started in 1969. They do sand mining with traditional technology and traditional equipment, such as hoes, shovels, and sieves (Figure 3). One group of sand mining workers consists of 3 persons who get sand from about 3 trucks per day, with the wage of each truck being IDR 50,000/worker/truck. Other livelihoods in Bambang Village are agriculture, animal husbandry, and the informal sector. The kinds of livestock are goats, cattle, and chickens. The average number of goats owned is 2-4 goats. They recycle livestock waste into organic fertilizer and then apply the organic fertilizer to agricultural land. The informal sectors are small groceries, construction workers, tailors, carpenters, and bricklayers.

Table 3 shows that agriculture has the highest score on environmental and economic aspects, followed by ecotourism, animal husbandry, and the informal sector. Ecotourism has the highest score on the socio-cultural aspect. In this aspect, agriculture has the second highest score, followed by animal husbandry and the informal sector. Furthermore, sand mining has the lowest score on the environmental, economic, and socio-cultural aspects. The agricultural sector is the main livelihood of the people of Bambang Village, both as landowners and just as farm laborers. The land condition is dominated by dry land. Most farmers plant sugar cane, maize, and cassava with intercropping patterns (Figure 4). Besides that, there are coffee plantations on the land owned by the government, namely “PERHUTANI”, which involves local society to manage it. The coffee plantations support ecotourism in Bambang Village, with "Kopi Rejo Hill Tourism". The other ecotourism object in Bambang Village is “Julung Agroedutourism” which was established by The Ministry of Environment and Forestry Republic Indonesia in 2019. The village also has a local ecotourism organization, namely “POKDAWIS” or Tourism Awareness Group. This ecotourism object is very prospective because it is in the Bromo Tengger Semeru National Park area.

Table 2. Characteristics of the respondent in Bambang Village.

<table>
<thead>
<tr>
<th>No</th>
<th>Occupation</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Education</th>
<th>Total (person)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male</td>
<td>Minimum</td>
<td>Maximum</td>
<td>Average</td>
</tr>
<tr>
<td>1</td>
<td>Sand miners (Land owners)</td>
<td>23</td>
<td>26</td>
<td>67</td>
<td>54.91</td>
</tr>
<tr>
<td>2</td>
<td>Sand miners (Workers)</td>
<td>23</td>
<td>24</td>
<td>78</td>
<td>45.34</td>
</tr>
<tr>
<td>3</td>
<td>Government officer</td>
<td>3</td>
<td>25</td>
<td>55</td>
<td>39.75</td>
</tr>
<tr>
<td>4</td>
<td>Expert</td>
<td>5</td>
<td>22</td>
<td>55</td>
<td>27.77</td>
</tr>
<tr>
<td></td>
<td>Number of respondents</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Distribution of research respondents based on scores for all livelihood indicators.

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Agriculture</th>
<th>Ecotourism</th>
<th>Animal Husbandry</th>
<th>Informal Sector</th>
<th>Sand Mining</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-2 (%)</td>
<td>3 (%)</td>
<td>4-5 (%)</td>
<td>1-2 (%)</td>
<td>3 (%)</td>
</tr>
<tr>
<td>Env</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b</td>
<td>23</td>
<td>12</td>
<td>65</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>d</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>Eco</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>0</td>
<td>5</td>
<td>95</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>b</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>c</td>
<td>5</td>
<td>90</td>
<td>5</td>
<td>32</td>
<td>68</td>
</tr>
<tr>
<td>d</td>
<td>22</td>
<td>10</td>
<td>68</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Soc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>d</td>
<td>2</td>
<td>20</td>
<td>78</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Remarks: Env = Environment, Env a, b, c, d = Indicators of Environment, Eco = Economics, Eco a, b, c, d = Indicators of Economics, Soc = Socio-Culture, Soc a, b, c, d = Indicators of Socio-Culture, 1, 2, 3, 4, 5 = Score (See Table 1)
Analysis of sustainable alternative livelihood with PROMETHEE method

PROMETHEE analysis results described in Figure 5 show that agriculture is preferred as the top livelihood alternative, followed by ecotourism, animal husbandry, and the informal sector. PROMETHEE II concluded that agriculture is the best rank and has a Phi score with a positive value of 0.8750, followed by ecotourism, which has a Phi score with a positive value of 0.6250, with a green color. Animal husbandry has a Phi score of 0.0000 on the middle limit scale. Furthermore, informal sectors have a Phi score with a negative value of -0.5000, followed by sand miners who have a Phi score with a negative value of -1.0000 at the lowest rank indicated by a red color (negative). It is also can be seen in Table 3.

Figure 5. The output of PROMETHEE I Partial Ranking and II Complete Ranking.
The output of PROMETHEE in Table 4 shows that agriculture is in the first rank with a Phi value of 0.8750. This value shows that this sector contributes positively to the net flow score, and the implication is to provide real benefits to alternative livelihoods. Then, the sand miners are in the lowest rank, with a Phi value of -1.0000, indicating that this sector contributes negatively to the net flow score, and the implication is to give a real weakness to alternative livelihoods. The PROMETHEE diamond output presented in Figure 6 shows that agriculture is the best alternative livelihood, followed by ecotourism, animal husbandry, and informal sectors. This is consistent with the output in Figure 5.

Table 4. Result output PROMETHEE table.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Alternative Livelihood</th>
<th>Phi</th>
<th>Phi+</th>
<th>Phi-</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture</td>
<td>0.8750</td>
<td>0.9375</td>
<td>0.0625</td>
</tr>
<tr>
<td>2</td>
<td>Ecotourism</td>
<td>0.0625</td>
<td>0.8125</td>
<td>0.1875</td>
</tr>
<tr>
<td>3</td>
<td>Animal Husbandry</td>
<td>0.0000</td>
<td>0.5000</td>
<td>0.5000</td>
</tr>
<tr>
<td>4</td>
<td>Informal Sector</td>
<td>-0.5000</td>
<td>0.2500</td>
<td>0.7500</td>
</tr>
<tr>
<td>5</td>
<td>Sand Mining</td>
<td>-1.0000</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Figure 6. The output of PROMETHEE diamond.

The cones were drawn from the active position on the plane for each livelihood alternative. When the cones overlap with all other cones according to preference and are preferred over all other cones in partial rating PROMETHEE I. Conversely, when two cones intersect each other, there is incommensurability in partial rating PROMETHEE II. The PROMETHEE rainbow output in Figure 7 shows that agriculture does not describe a negative bar because all criteria contribute positively to the net flow score. In addition, agriculture also has the largest bar area, indicating that agriculture is the best sustainable livelihood with all the criteria: environment, economy, and socio-cultural. The second-best alternative livelihood is ecotourism, which has a positive net flow score. The animal husbandry sector has a zero Phi score. This indicates that it has equal negative and positive indicators. The informal sector has a negative net flow score, indicating that this sector is unsustainable. Sand mining has the lowest negative bar, so it has a negative score on the net flow, indicating that sand mining is the most unsustainable livelihood. Figure 8 is GAIA visual analysis that describes the descriptive component of PROMETHEE ranking (Ariyani et al., 2016). The output of GAIA Visual Analysis in Figure 6 shows that the quality of information reached 100 percent, which verified that the GAIA analysis is reliable. The GAIA analysis will be reliable if the percentage value of information quality is above 70 percent (Batubara et al., 2016; Lopes et al., 2018; Moreira et al., 2021). GAIA visual analysis uses Principal Components Analysis (PCA) to reduce the number of criteria by minimizing loss of information. GAIA has three dimensions: “U” is the first principal component, contains the maximum possible quantity of information; ”V” is the second principal component, providing the maximum additional information orthogonal to U; W is the third principal component, providing the maximum additional information orthogonal to both U and V. The GAIA presents three criteria (environment, economics, and socio-cultural) represented by lines and five livelihoods represented by squares. As seen in Figure 6, agriculture and ecotourism are close, while the informal sector and sand mining are far from the axis. This means that agriculture is the most sustainable alternative livelihood, followed by ecotourism in that location. Agriculture is the main livelihood at the location, considering the inputs used in agriculture are renewable resources, such as land and water, seed, and organic fertilizer, so agriculture is the most sustainable livelihood based on local resources.

Ecotourism also has potential future livelihood due to the location of Bambang Village is at the slope of Semeru mountain near Bromo Tengger Semeru National Park (TNBTS). In accordance with the general conditions in developing countries, agriculture is a common traditional livelihood activity of rural communities across the developing world (Sanitka et al., 2019). Rural communities are highly dependent on traditional livelihoods such as agriculture, both on-farm and off-farm (Bires and Raj, 2020). Generally, this is also related to the rural communities' education. Heads of households in rural areas with high formal education are more likely to engage in non-farm-based
alternative livelihoods (Kennedy et al., 2020). Data presented in Table 3 show that the majority of respondents were elementary school graduates, so they were more likely to engage in farm-based alternative livelihoods. Tourism community-based is a vital approach for rural areas; it has a significant effect on the economic well-being of rural households (Bires and Raj, 2020). Moreover, ecotourism, nature-based and community-based, offers a sustainable future for rural society (Lasso and Dahles, 2021).

Figure 7. Output of PROMETHEE rainbow.

Figure 8. Output of PROMETHEE rainbow.
According to Genanewe et al. (2019), ecotourism activities are a gainful alternative livelihood, creating different employment opportunities for rural society. Some tourist activities significantly contribute to the socio-economy of rural/local communities. Some tourism is related to other activities, such as transportation, tour guiding, cooking, food and beverage services, etc., that contribute to the livelihoods of the local community. Local community involvement in ecotourism impacts the preservation of natural, environmental conservation, and cultural heritage (Lasslo and Dahles, 2021).

Conclusion

The high demand for sand caused by the development and rapid growth of housing and infrastructure due to population growth has been driving massive sand mining activities. Sand mining in Indonesia is extracted from common land resources and private lands, both legal and illegal. It has a negative impact on the environment, both positive impacts that create job opportunities and income. The lack of knowledge and supervision also because sand is categorized as a non-renewable natural resource; therefore, the sand mining livelihood is temporary or unsustainable. Their adaptation strategy is dominated by short-term strategy. Therefore, they need sustainable alternative livelihoods based on local resources. The research result showed that the best alternative sustainable livelihood at this location is agriculture, the second best is ecotourism, the third is animal husbandry, and the fourth is the informal sector. The government should support those sectors at Bambang Village. The post-sand mining land must be reclaimed to be used for agricultural cultivation.

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