Policy development of sustainable model on small scale gold mining in Riau province

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Abstract. Generally, gold mining activities are small scale (community mining) and many times illegal. Illegal gold mining has the potential to have a large and negative impact on the environment. The purpose of this paper was the in-depth study of the small-scale gold mining activities in Riau Province, Indonesia, with a comprehensive and integrated approach to the economic, social and environmental aspects. The analysis method is based on the specific objectives of the study, including: descriptive analysis, MDS-Raps analysis and prospective analysis. The results of research showed that, overall, the management of small-scale gold mining in Kuantan Singingi District is less sustainable, with index values ranging from 30.93 to 41.16%. There are 5 main leverage attributes of gold mining: a) environmentally friendly gold mine planning; b) interactions between institutions; c) land improvement and restoration; d) water pollution; e) coordination of the parties. The formulation of strategies to improve the sustainability of small-scale gold mining management in Kuantan Singingi District are: a) environmentally friendly mining management through environment-based mine planning and environmental pollution control; b) increasing coordination between institutions and increasing the role of stakeholders.

Key Words: environment, impact, MDS, pollution, strategy.

Introduction. Riau Province has potential mineral resources, such as petroleum, coal and gold, in several districts. Petroleum is found in Bengkalis, Siak, Kampar, Rokan Hulu, Rokan Hilir and Indragiri Hulu Regencies (BPS Riau 2019). Coal is found in Indragiri Hulu, Indragiri Hilir, Kampar and Rokan Hulu Regencies. Gold mines are found in Kuantan Singingi Regency (Budidarsono et al 2013). Generally, the gold mining activities are small scale (community mining) and, generally, illegal. Illegal gold mining has the potential to have a large and negative impact on the environment (Armindo et al 2019).

Small-scale gold mining activities generally consist of extracting mining materials, destruction or refinement, amalgamation, and incandescence. At the time of excavation, simple tools are used, such as shovels or hoes, but some activities use hydraulic power, where mining material is sprayed with high pressure water (Domínguez et al 2019). Spraying breaks mining materials in pieces or large particles. The material is then sucked up and passed by a slicer to collect minerals containing gold. When miners use a shovel or hoe, they transport the mining material by putting it in a sack and smoothing it (Winn et al 2018). Mining materials are dissolved with water and Hg in a rotating drum. During excavation activities, physical damage is caused to the environment by standing water, changes in river flow or disturbed forest ecosystems. Illegal mining occurs for several reasons, like economic factors (increasingly difficult life needs), and convoluted regulatory factors. Illegal mining not only harms the country/region financially, but often causes other problems, such as environmental degradation and social conflict (Teschner 2012). Illegal mining does not have standard operation procedures (SOP) and does not understand the rules of good mining practices, because it mines any part of the river without a clear boundary, and it is difficult to design waste treatment (Kahhat et al 2019).

Based on the report of the Environmental Agency related to the results of environmental quality monitoring in 2012-2018 in Kuantan Singingi Regency (BLHD Kuantan Singingi 2019), it is known that the mercury levels in the Kuantan River have exceeded the maximum allowable limit based on the Government Regulation No. 82 of 2001 concerning Water Quality Management and Water Contamination Control (KLH 2001). The pollution condition of the Kuantan rivers with mercury was also confirmed by the results of Tomiyasu et al (2017), who determined that the Hg concentration in waters is 0.00 to 49.5 $\mu g\ L^{-1}$ and in sediments is 50-252 $\mu g\ kg^{-1}$. Thus, the quality of the rivers from Kuantan has been degraded by pollution and the water is unfit for use. In addition to the impact on water quality, gold mining activities, especially mining without permits, also degrade lands (Fazlagić & Skikiewicz 2019). This condition is exacerbated by the low awareness of the community towards the impact caused by uncontrolled gold mining activities (Spiegel et al 2018).

Gold mining activities carried out by the community have not shown significant results on improving the welfare of communities (Spiegel et al 2018). There are also some obstacles in small-scale mining, including simple technology, lack of knowledge about the potential and prospects for development, and limited availability of data and information. In this context, adding efforts to manage natural resources, spatial aspects are important to facilitate the process of utilization and preservation of environmental functions (Niane et al 2019). In addition, the development of data collection and information systems about natural resources is an absolute requirement for various efforts to manage natural resources (Souza & Alves 2018). Good and correct mining management needs to be reviewed and developed. Through the application of good mining procedures, mineral resource waste can be avoided, and resource optimization, protection of environmental functions, and better worker safety and health can be achieved (Charatsari & Lioutas 2019).

The impact of illegal mining activities is not only in the form of physical impacts, but also causes chemical, biological, socio-economic and cultural impacts on the community and environment. Thus, systematic and integrated handling needs to be conducted. The impact on the environment can be prevented or minimized (Karst & Nepal 2019). For this reason, the aim of this research is to formulate the development of a sustainable small scale gold mining model in Kuantan Singingi Regency. The development of a small scale gold mining model is expected to be an alternative and solution for gold mining activities, especially for small scale and illegal gold mining activities.

Material and Method. The data used in this study include primary and secondary data. Primary data includes land degradation data obtained from soil sampling, and aquatic biota data (plankton and benthos) obtained from water sampling, and data from stakeholder interviews. The research was conducted in Kuantan Singingi District, from September to November 2019.

The research samples were determined by purposive sampling, with the consideration that only the locations that suffered the most damage were used as sampling points. Sampling was carried out at 5 sampling points: Station 1, located in Lubuk Ambacang Village; Station 2, located in the opposite village of Teluk Kuantan; Station 3, located in Teluk Pauh Village, Pangean District; Station 4, located in Muara Bunta Village, Benai District; Station 5, located in Kuantan Hilir Village Seberang, Baserah Subdistrict.

Soil samples were visually identified as having contaminated appearance, such as discoloration and absence of vegetation. If the appearance of the soil in the sampling location was the same, the soil sample was collected randomly at 3 points using a ring sample measuring 4 cm high and 7.63 cm in diameter or a volume of 182.8 cm^3. The soil from a sampling location was mixed together, placed in plastic containers and transported to the laboratory for analysis.

The aquatic biota studied were plankton (phytoplankton and zooplankton) and benthos. Samples of aquatic biota were collected using a plankton net measuring 0.2 - 20 mm. Water was collected at a predetermined point using a 10 L recipient, then the water was filtered using a plankton net. The filtered water was then poured in the sample container mixed with 40% alcohol. It was then transported to the laboratory. Benthos samples were collected using the Grab Sampler (Eickman Grab), measuring a volume of 3.5 L. The benthos samples were stored in plastic containers for further analysis in the laboratory.

Public perception data is obtained from interviews with respondents who are the people around the mine. The number of respondents was 66 people including: 60 public respondents and 6 expert respondents. The technique of determining public respondents was purposive sampling, namely the people who interact with the mine site. The determination of expert respondents was based on Yusuf et al (2016). Expert respondents are those who meet one of 3 criteria: level of education, his position as a decision maker, and experience.

The analysis method is based on the specific objectives of the study, including analysis of damage/criticality level, diversity analysis of aquatic biota, sustainability analysis and small scale gold mine management model scenarios.

Soil samples were analyzed in the Global Analytical Quality Laboratory (Bogor) to determine the parameters of pH, cation-exchange capacity (CEC), C-organic, Na, Ca, Mg, Pb, AL, H and soil texture, as indicators for determining the criticality level of land that occurred. Other parameters were determined *in situ*: soil effective depth, erosion rate, land cover, surface rocks, slopes. The assessment results of these parameters were then weighted (%) with reference to Arsyad (1989) (Table 1).

Table 1

The land criticality class and the cumulative score

Critical land class	*Score*
Very critical	100-175
Critical	176-250
Rather critical	251-325
Not critical	326-400

The analysis of aquatic biota includes analysis of abundance, diversity and dominance. The identification results show some environmental characteristics. The diversity analysis employed the Shannon Index (Krebs 1978):

$$H' = \sum_{i=1}^{n} pi \, ln \, pi$$

Where: H' - diversity index; pi = ni/N; ni - the number of individuals of species-i; N - the total number of individuals. A H' value lower than 2.3026 shows a small diversity and low community stability; if 2.3026<H'<6.9078 there is a moderate diversity and moderate community stability; and if H'>6.9078, there is a high diversity and high community stability.

The dominance index is calculated using the Simpson formula (Odum 1993):

$$D = \sum n/Ni^{2}$$

Where: D - Simpson Dominance Index; ni - the number of individuals of species-i; N - the total number of individuals. The dominance index ranges from 0 to 1, where values close to 0 indicate there is no dominant species, and values close to 1 indicate the dominance of a particular species (Odum 1993).

The status of the sustainability of small-scale gold mining was determined by a Multi-Dimensional Scaling (MDS) approach. The analysis of the sustainability status had several stages, as follows:

1. Determining the factors/attributes of sustainability. The determination of sustainable factors consists of ecological, social, economic and institutional aspects. The attributes chosen in one dimension must reflect the continuity of that dimension and can be modified with other attributes.

2. Attribute rating in ordinal scale. For each attribute in the aspect, a score is given that reflects the sustainability condition of the aspects studied. The score ranges are determined based on criteria that can be found from the results of field observations and secondary data. The score ranges from 0 to 3, depending on the state of each attribute, which can be interpreted from bad to good. Bad scores reflect the most unfavorable conditions for the sustainable management of Small Scale Gold Mining. Conversely, good values reflect the most favorable conditions. The score value of each attribute is analyzed in a multidimensional manner to determine the position of the sustainability of the small-scale gold mining management being studied relative to 2 reference points, namely the "good" and "bad" points. To produce a visualization of this position, an ordination analysis was used. The ordination process uses the Rapfish Software (Kavanagh & Pitcher 2004).

3. Preparation/determination of index and status of sustainability. Measurements in MDS are done by mapping 2 points (or the same object in one point) that are close to each other. Conversely, objects or points that are not the same are described as points that are far apart. The technique of ordination or distance determination in MDS is based on the Euclidean distance which in n dimension space can be written as follows:

$$\mathrm{d} = \sqrt{(x_1 - x_2| + |y_1 - y_2| + |z_1 - z_2| + \cdots)}$$

Where: d - distance between Euclidean points; x_1-x_2 - the difference in value between attributes (x); y_1-y_2 - difference in attribute values (y); z_1-z_2 - difference in attribute values (z).

The configuration of the object or point in the MDS is then estimated by regressing the Euclidian distance (j) from point i to point j, with the origin (σij) as follows:

$$\mathrm{d}_{ij} = \alpha + \beta\sigma_{ij} + \epsilon$$

Where: dij - the Euclidean distance from point i to j; α - constant; β - regression coefficient; σ_{ij} - Euclidean value; ϵ - standard error.

The technique used to regress the above equation is the ALSCAL algorithm (Alder et al 2000). The ALSCAL method optimizes the square distance (square distance=d_{ijk}) to the quadratic data (origin=o_{ijk}), which in three dimensions (i, j, k) is written in a formula called S-stress as follows:

$$S = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i \sum_j \left(d_{ijk}2 - o_{ijk}2\right)^2}{\sum_i \sum_j o_{ijk}2}\right]}$$

Where: S - stress; m - number of attributes; d_{ijk} - the distance of the Euclidians in the i, j, k^{th} dimension; 0_{ijk} - origin point values in the i, j, k^{th} dimension.

4. Sensitivity analysis and Monte Carlo analysis. The sensitivity analysis was conducted to see which attributes were the most sensitive contributing to the sustainability index. The effect of each attribute is seen in the form of changes in the root mean square (RMS) ordination, especially on the X-axis or on the accountability scale. A higher RMS change value due to the loss of a certain attribute brings a greater the role of the attribute in the formation of the sustainability index value, or, the more sensitive the attribute is in the management of small-scale gold mining. To evaluate the effects of random errors on the process estimating the value ordination of small-scale gold mining

management, a Monte Carlo analysis was used. According to Kavanagh & Pitcher (2004), the Monte Carlo analysis is useful for studying the following: (1) the effect of the attribute scoring error caused by the imperfect understanding of the conditions of the research location, or the misunderstanding of the attributes, or the way of scoring the attributes; (2) the effect of the variation in scoring due to differences in opinion or judgment by different researchers; (3) stability of the iteration of the MDS analysis process; (4) data entry errors or missing data; (5) the high "stress" value from the sustainability index (stress value is acceptable if <25%). It was further stated that the Monte Carlo analysis was used to estimate the effect of error at the 95% confidence interval. The Monte Carlo index value is compared with the MDS index. The value of stress and the coefficient of determination (R^2) function to determine whether or not the attributes are added and reflects the accuracy of the dimensions being studied with the actual situation.

Small scale gold mine management model scenario was constructed by using a prospective analysis approach. The prospective analysis was used to determine important factors in gold mining in a sustainable manner. The utility of prospective analysis is in preparing the strategic actions that need to be taken and see if changes are needed in the future (Bourgeois & Jesus 2004). The prospective analysis stages are (Yusuf et al 2016): 1) defining objectives; 2) identifying attributes; 3) determining expert responses; 4) compiling questionnaires; 5) providing assessments; 6) analyzing data with the help of prospective analysis software; 7) interpreting outputs. Prospective analysis assessment guidelines refers to Bourgeois & Jesus (2004) (Table 1).

Table 1

Prospective analysis assessment guidelines

Score	*Description*
0	No influence
1	Low influence
2	Moderate influence
3	Strong influence

Note: source: Bourgeois & Jesus (2004).

The assessment guidelines are then designed in a questionnaire for an assessment of the relationship between attributes. The data from the expert's assessment will be inputted in the prospective analysis software. After obtaining the key factors, an analysis of the influence and dependency matrix was carried out to see the position of each factor in the sustainable gold mining development model.

Results and Discussion

Land degradation. The results of observations at a traditional gold mining location in the field found that mining activities cause damage to land/soil such as soil degradation, and landslides (erosion). According to Pokorny et al (2019), the occurrence of intensive erosion is caused by taking sand in alluvial deposits. The following results were obtained after the evaluation of the criticality level of the land (Table 2).

Table 2

Analysis results of land degradation

Critical land class	*Area (Ha)*	*Proportion (%)*
Very critical	4,973.97	5.6
Critical	24387.35	27.47
Rather critical	23213.4	26.15
Potentially critical	29227.38	32.92
Not critical	6971.23	7.85

The level of land damage in the gold mining location is classified as heavily damaged, reaching 59.22%. The mining activities have the potential to increase the threat of abrasion. The occurrence of intensive erosion (abrasion) is due to the taking of sand from the river (Ong et al 2019). In addition, mercury pollution occurs as a result of the river water panning process. The increase in critical land area is the simultaneous impact of various factors, including: biophysical conditions, socio-economic and cultural factors related to land use, and policy factors that do not consider sustainability aspects (Yankson & Gough 2019).

Aquatic biota. The results of the analysis are presented in Table 2.

Table 2

Results of abundance, diversity and dominance analysis

Species	*Abundance*	*Diversity*	*Dominance*
Phytoplankton	67.155	0.21	1.71
Zooplankton	1,734	0.19	1.2
Benthos	2.464	0.40	0.79

Based on the table above, the abundance value of phytoplankton was 67.155 ind L^{-1}, the abundance of zooplankton was 1.734 ind L^{-1}, and the abundance of benthos was 2.464 ind m^{-2}. The abundance of phytoplankton found was in the medium category, thus the waters of the Kuantan River were categorized as having medium fertility. Meanwhile, the abundance of benthos is lower. Based on species identification results, 7 phyla of phytoplankton, 7 phyla of zooplankton and 5 classes of benthos were obtained (Figure 1).

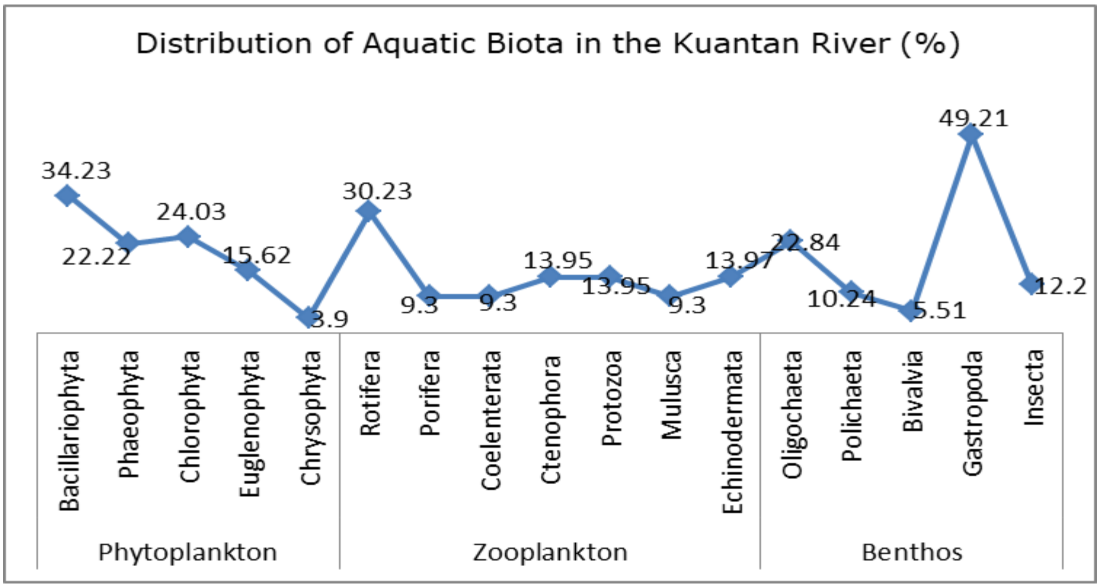

Figure 1. Aquatic biota in the Kuantan River, Riau.

The identification results showed that Bacillariophyta dominanted the phytoplankton (34.23%). Bacillariophyta acts as a producer and is widespread in freshwater, sea water and also in moist soils (Barus 2004). Rotifera dominated the zooplankton (30.23%). Rotifers are a phylum of the kingdom Animalia, most of its members live freely and are planktonic (Sachlan 1982). It is estimated that there are 2000 species that have been identified and most (about 95%) live in fresh water such as lakes, ponds, surface water films on mosses and other semi-terrestrial plants (Wilhm & Dorris 1968). The results of benthos identification showed that Gastropods were dominant (49.21%). Gastropods are often found in various environments, such as in land, sea and freshwater (Ulmaula et al 2016).

Sustainability status of small-scale gold mining. The sustainability index of small-scale gold mining included 5 aspects: ecological aspects, economic aspects, socio-cultural aspects, infrastructure and technology aspects and legal and institutional aspects. The evaluation results of the sustainability index for the 5 aspects are presented in Table 3.

Table 3

Sustainability index of small-scale gold mining in Kuantan Singingi District

Aspects	*Index*	*Category*	*Stress*	R^2	*Monte Carlo Analysis*	*Difference*
Ecology	41.16	Less sustainable	0.1209	0.969	40.71	0.45
Economy	49.22	Less sustainable	0.1187	0.973	48.89	0.33
Socio-cultural	30.93	Less sustainable	0.1219	0.972	32.89	1.96
Infrastructure and technology	38.55	Less sustainable	0.1277	0.972	39.51	0.96
Legal and institutions	40.66	Less sustainable	0.1292	0.966	41.22	0.56

Note: 0-20 index value - not sustainable; 20.01-50 index value - less sustainable; 50.01-75 index value - sufficiently sustainable; 75.01-100 index value - sustainable (Pitcher 1999).

The results show that all aspects are categorized as less or not sustainable. This can be seen from the sustainability index less than 50%. According to Pitcher (1999), the ordination value (sustainability index) less than 50% shows unsustainability, and a value higher than 50% shows sustainability. These results are acceptable considering the value of stress in all aspects was lower than 20%. The stress value is a measure of the lack of fit between the data and the measurement results or model. According to Sugiyono (2015), when the stress value is close to 0, the resulting output is more similar to the actual situation, and a lower stress value shows a better/suitable model. This can also be seen from the difference between the sustainability index (ordination value) and the Monte Carlo value ranging from 0.33 to 1.94%, or less than 5%. Pitcher & Preikshot (2000) state that the difference between the Monte Carlo value and the ordination value should be maximum 5%. This value indicates that the effect of the error on the relative scoring is very small. Graphically, the index of the f5 aspects of sustainability is described in Figure 2.

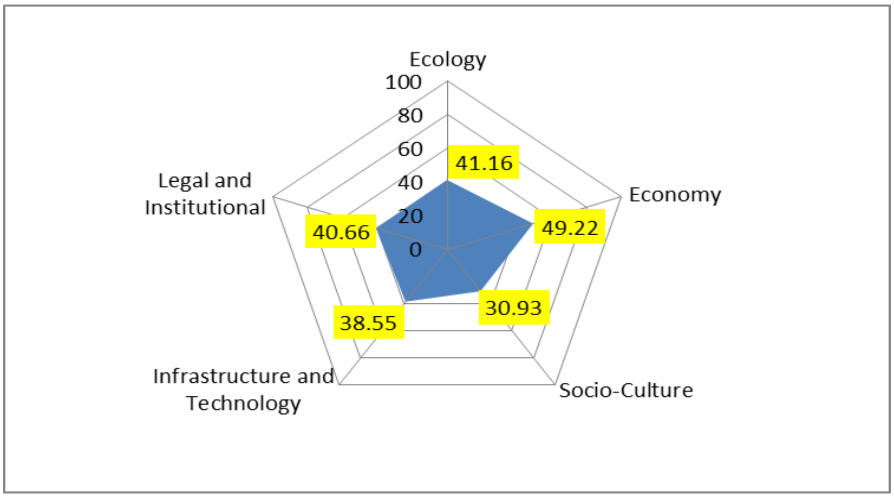

Figure 2. Sustainability index of five dimensions in small scale gold mining.

The results of the analysis show that, overall, the management of small-scale gold mining in Kuantan Singingi District is less sustainable, with index values ranging from 30.93 to 41.16%. The lowest sustainability index is the socio-economic aspect (30.93%) followed by the Infrastructure and technology aspect (38.55%), the legal and institutional aspect (40.66%), the ecology aspect (41.16%) and the economy aspect (49.22). The 5 aspects are categorized as less sustainable. This means that the management carried out is classified as poor. In order to know the leveraging attributes that affect the level of sustainability of small-scale gold mining management in Kuantan Singingi District, a leverage analysis was carried out. Table 4 presents the results.

Table 4

Leverage attributes for small-scale gold mining

No	*Leverage attribute*	*RMS (%)*
1	Water pollution	0.97
2	Land improvement and restoration	1.01
3	Coordination of the parties	1.10
4	Interactions between institutions	1.15
5	Health	1.79
6	Contributions to the locally-generated revenue	1.82
7	Performance of rural community services	1.84
8	Community awareness of the environment	1.85
9	Availability of land transportation facilities and infrastructure	3.62
10	Environmentally friendly gold mine planning	3.80

Note: RMS - Root Mean Square.

Figure 3 shows that there are 2 attributes with an extreme RMS value compared to other attributes, namely: environmentally friendly gold mine planning (3.8) and availability of land transportation facilities and infrastructure (3.62). Thus, these 2 attributes are key attributes in the management of small-scale gold mining in Kuantan Sengingi.

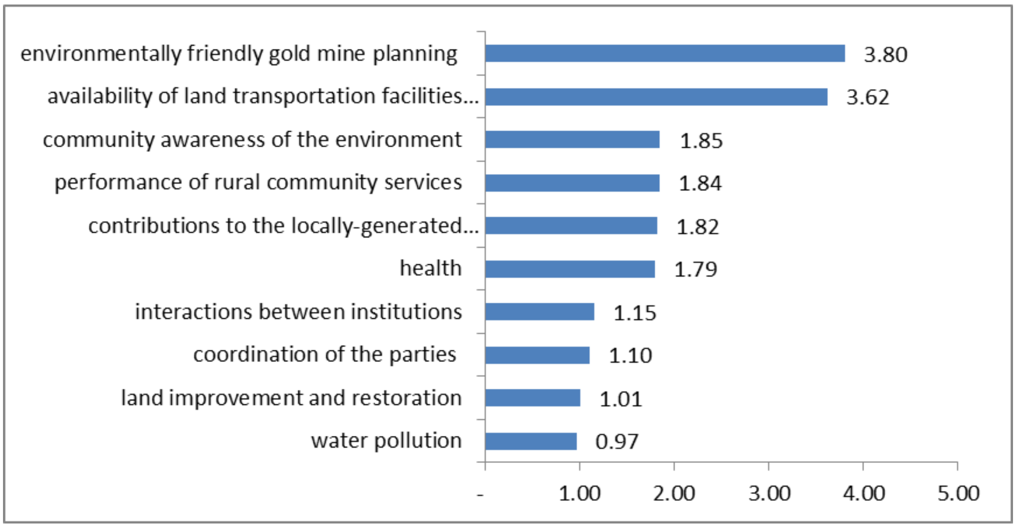

Figure 3. Leverage attributes of small-scale gold mining.

Scenarios of the small scale gold mining management model (SSGM). The scenario formulation is based on a prospective analysis of the 10 leveraging attributes of the sustainability of small-scale gold mining management. The scenario was analyzed with a system approach and expert adjustment related to the relationship between these attributes. The results show the position of each attribute in the prospective quadrant (Figure 4).

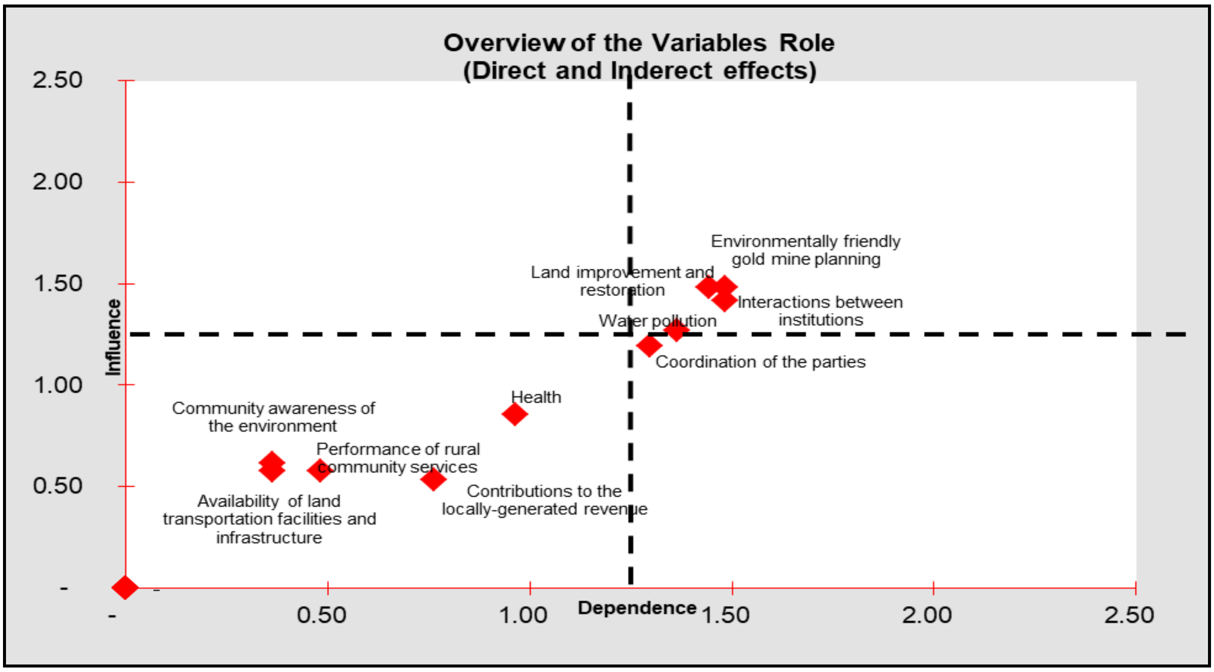

Figure 4. Attribute position (influence and dependence).

There are 5 main leverage attributes obtained: a) environmentally friendly gold mine planning; b) interactions between institutions; c) land improvement and restoration; d) water pollution; e) coordination of the parties. These 5 factors (the main leveraging attributes) form the basis for the formulation of strategies/scenarios to improve the management of small-scale gold mining. According to Lasut et al (2010), these strategies are expected to provide wider opportunities for the community to be able to use natural resources sustainably. In addition, structuring the organization and system of social and economic relations is expected to create opportunities for communities to participate in protecting natural resources from threats that come both from within and from outside.

The formulation of strategies to improve the sustainability of small-scale gold mining management in Kuantan Singingi District are environmentally friendly mining management through environment-based mine planning and environmental pollution control, and increasing coordination between institutions and increasing the role of stakeholders.

Conclusions. The study has determined that the land damage in the gold mining location is classified as heavily damaged, reaching 59.22%. The dominant aquatic biota in phytoplankton is Bacillariophyta (34.23%), Rotifera in zooplankton (30.23%) and Gastropoda in benthos (49.21%). Overall, the management of small-scale gold mining in Kuantan Singingi District is less sustainable, with index values ranging from 30.93% to 41.16%. There are 5 main leverage attributes obtained: environmentally friendly gold mine planning, interactions between institutions, land improvement and restoration, water pollution, and coordination of the parties. The formulation of strategies to improve the sustainability of small-scale gold mining management in Kuantan Singingi District are: environmentally friendly mining management through environment-based mine planning and environmental pollution control, and increasing coordination between institutions and increasing the role of stakeholders.

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