Decision Science Letters 13 (2024) 337–350

Contents lists available at GrowingScience

Decision Science Letters

homepage: www.GrowingScience.com/dsl

Analysis of peat rural environmental risk using PROMETHEE method in Riau Province, Indonesia

Ardika Perdana Fahly[a*], Akhmad Fauzi[b], Bambang Juanda[c] and Ernan Rustiadi[d]

[a]*Regional and Rural Development Planning Study Program, Faculty of Economics and Management, IPB University, Indonesia*
[b]*Department of Resources and Environmental Economics, Faculty of Economics and Management, IPB University, Indonesia*
[c]*Department of Economics, Faculty of Economics and Management, IPB University, Indonesia*
[d]*Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Indonesia*

C H R O N I C L E

Article history:
Received: October 10, 2023
Received in revised format: November 20, 2023
Accepted: February 4, 2024
Available online: February 4, 2024

Keywords:
Environmental Risk
Peat Rural
Sustainable Development
PROMETHEE
Shannon Entropy

A B S T R A C T

Future global economic stability is under significant threat from environmental risks. Peat rural areas are particularly susceptible due to their elevated levels of hazard, vulnerability, and limited capacity. Recognizing these risks is crucial for promoting sustainable development via low-carbon initiatives in peat areas. This study analyzes the environmental risk in peat rural areas within Riau Province. The PROMETHEE approach was utilized, integrating with Shannon Entropy weighting for data analysis. The findings reveal that three regencies are exhibiting favorable environmental risk and six regencies facing adverse conditions. The criteria influencing showcase various positive and negative contributions across each regency. The sensitivity analysis demonstrates that droughts, unmanaged waste disposal, and local wisdom display wider weighted stability intervals within each dimension, underscoring the robust ranking of environmental risks. Recognizing environmental risk can serve as a foundation for decision-makers to formulate sustainable development policies especially in peat rural areas.

1. Introduction

In the 15th edition of the World Economic Forum 2020 report on global risks, the most significant threat anticipated to impact the global economy in the future is linked to the environment. The identified environmental risks posing a threat to the global economy encompass extreme weather events, insufficient action on climate change, biodiversity loss, natural disasters, and disasters stemming from human activities (World Economic Forum, 2020). The primary environmental consequences of climate change, such as rising sea levels and abnormal weather patterns, subsequently give rise to compounded and persistent environmental risks. Initial environmental risks often trigger secondary environmental risks, such as disruptions in agricultural productivity, food supply, air quality, disturbances in terrestrial and marine ecosystems, damage to infrastructure and resources, and economic losses (Chen et al., 2023).

In addition to the degradation of natural resources and human-induced disasters, social and economic pressures also arise from climatic factors, like drought, and non-climatic factors, such as earthquakes, tsunamis, and volcanic eruptions in Indonesia. According to InaRisk disaster risk statistics (http://inarisk.bnpb.go.id), hydrometeorological disasters dominate, with drought ranking first in terms of its impact on the environment, economy, population exposure, and hazard area. The escalating growth in population and lifestyle changes, triggering a surge in food demand, have resulted in intensive exploitation of terrestrial resources. Consequently, there has been extensive land conversion, deforestation, and the depletion of certain wetlands for economic purposes. Land degradation, as highlighted by AbdelRahman (2023), poses a

* Corresponding author.
E-mail address: ardika_perdana@apps.ipb.ac.id (A. P. Fahly)

doi: 10.5267/dsl.2024.2.003

significant challenge to food security, livelihood sustainability, ecosystem services, and biodiversity conservation. These actions are intricately connected to climate change, with agriculture and deforestation contributing to a 23% increase in greenhouse gas emissions (Smith et al., 2014). Notably, the rapid conversion of tropical peatlands and the associated environmental risks demand special attention (Evans, 2021).

Peatlands or peat areas are gaining considerable attention amid the escalation of climate change and global warming. These ecosystems are notably delicate, and their impairment often results from failures in land management (Syahza et al., 2020). Presently, widespread peat extraction through drainage for agricultural and forestry purposes is observed. The utilization of swamp draining in these areas contributes to biodiversity loss, diminished water and mineral storage capacity, leading to heightened instances of flooding, and increased water pollution (Renou-Wilson, 2018). Numerous activities involving peat drainage for economic development have led to the release of substantial amounts of stored carbon. Natural peat ecosystems, characterized by dome layers 8 to 12 meters deep, have the capacity to store over 7 tonnes of carbon per hectare (Gunawan et al., 2020). Excessive drainage and recurrent fires are pivotal factors contributing to greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Disturbances to these ecosystems prompt the release of CO_2 emissions (Surahman et al., 2018).

Deforestation and the degradation of peatlands, along with associated risks, pose significant challenges in developing regions with peaty characteristics. In addition to drainage, errors in peatland management include clearing land for plantations or agriculture through burning. Burning peatlands during clearing is estimated to release 88 tonnes of carbon per hectare into the atmosphere (Leng et al., 2019). Peatland fires contribute substantially to greenhouse gas emissions (Field et al., 2016). According to the Indonesia National Carbon Accounting System (INCAS), between 2001 and 2012, 1.89% of the peatland area was nationally degraded, with an average of 355,101.4 hectares of peatland burned annually and total emissions reaching 901,228,446 tonnes of CO_2e (http://incas.menlhk.go.id/data/national-data/). Projected with a base year of 2012 using dynamic simulation, the Business as Usual (BAU) scenario suggests a gradual reduction in peatland degradation in the upcoming years, aligning with the decrease in peatland area, eventually reaching a minimum point in the long run, as illustrated in Fig. 1.

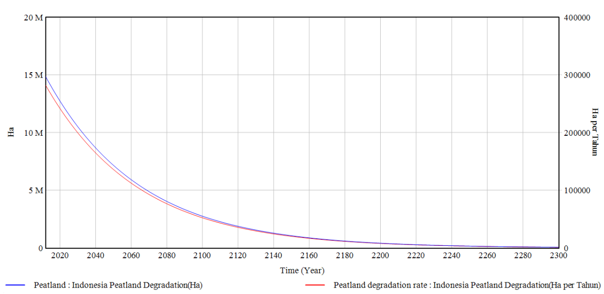

Fig. 1. Indonesia Peatland Degradation, *Business as Usual* Scenario Base Year 2012
Source: (Processed by the author, 2012 INCAS data report)

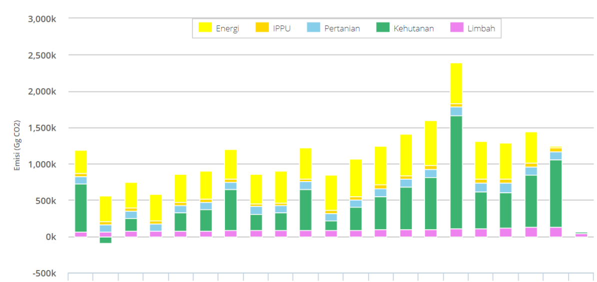

Fig. 2. Emissions from 5 sectors in Indonesia 2000-2020
Source: signsmart.menlhk.go.id (2021)

Between June and November 2015, forest and land fires in Indonesia ravaged 2.6 million hectares of land, emitting a total of 1,565,579 gigagrams of CO_2 from the forestry sector (Glauber et al., 2016). A substantial portion of this devastation, accounting for 53% of the burned area, occurred on peatlands (Saharjo & Novita, 2022). The repercussions of this fire event extended across environmental, economic, tourism, and education sectors, resulting in losses amounting to USD 16.1 billion (Glauber et al., 2016). The fires predominantly took place in dry and degraded peatlands, influenced by socioeconomic and political factors in conjunction with climatic conditions. This underscores the forestry/land sector's significant role as a major contributor to emissions in Indonesia during that year (see Fig. 2). Anticipated climate change further amplifies the vulnerability of peatlands to global-scale fires. Projections indicate a reduction in relative humidity during the burning season in virtually all regions abundant in peatlands, potentially escalating the likelihood of peat fires (Turetsky et al., 2015).

Drawing lessons from the devastating forest fires in 2015, the Government of the Republic of Indonesia issued Presidential Regulation Number 1 of 2016, establishing the Peatland Restoration Agency (BRG) to spearhead efforts in rejuvenating peatland ecosystems. BRG's mandate includes coordinating and facilitating peatland restoration in seven priority provinces: Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, and Papua. The targeted restoration area for BRG in these seven provinces is 2,492,509 hectares, comprising 684,638 hectares of protected areas, 1,410,926 hectares of licensed cultivation areas, and 396,945 hectares of unlicensed cultivation areas (Badan Restorasi Gambut, 2016). Research conducted by BRG and its partners in 2020, focusing on estimating the reduction in greenhouse gas emissions through restoration interventions in priority areas covering 12.6 million hectares from 2016-2019, indicated a decrease in emissions by 300.87 million tonnes of CO_2 equivalent (Gunawan et al., 2020). Restoration efforts contribute to enhancing vital ecosystem services provided by peatlands, including carbon storage, water quality improvement, and biodiversity support (Glenk & Martin-Ortega, 2018). Riau Province is prioritized for peat restoration, aligning with its commitment to low-carbon and sustainable development in Indonesia. The concept of low-carbon development represents a new platform focusing on sustaining economic and social growth through activities with low greenhouse gas emissions and minimizing natural resource exploitation (National Development Planning Agency (Bappenas), 2019). Indonesia has pledged to reduce emissions by 2030, with an Enhanced Nationally Determined Contribution (ENDC) target of 31.89% using domestic funding and 43.20% with international assistance ((UNFCCC, 2021)).

Covering an expanse of 9,026,360 hectares, Riau Province boasts approximately 4.97 million hectares (55.09%) designated as peatlands, categorized into 59 Peat Hydrological Units (KHG) according to the Department of Environment and Forestry (2022). Unfortunately, the majority of the peat area in Riau Province is in a degraded condition, with only 0.45% remaining undamaged. Despite ongoing peatland restoration efforts since 2016, the effectiveness in curbing land fires remains suboptimal. Riau Province, being one of a priority province for peat restoration in Indonesia, experiences recurring forest and peatland fires each year. As per data from before the establishment of the Peatland Restoration Agency (BRG) in 2021, the indicative extent of peatland fire scars in Riau Province from 2015 to 2020 amounted to 284,474.16 hectares. The distribution of peatland fires in Riau Province is detailed in Table 1.

Table 1
Indicative area of fire at KHG in Riau Province 2015-2020

Regency	Area of fire at Peat Hidrological Unit (KHG) (Ha)						Total
	2015	2016	2017	2018	2019	2020	
Kuantan Singingi	0	0	0	0	0	0	0
Indragiri Hulu	5.174,18	5.757,38	0	1.633,56	2.889,49	308,98	15.763,58
Indragiri Hilir	5.736,22	10.369,75	3,21	2.403,15	13.430,79	489,52	32.432,65
Pelalawan	12.665,08	12.753,18	572,09	2.232,38	10.982,02	1.801,68	41.006,44
Siak	5.112,56	10.394,87	1.555,95	449,53	2.958,62	453,82	20.925,37
Kampar	4.828,33	380,64		58,67	610,65	3,49	5.881,78
Rokan Hulu	34,64	299,47		47,61			381,72
Bengkalis	38.915,58	9.600,86	247,89	2.487,75	11.404,75	1.685,04	64.341,88
Rokan Hilir	18.746,65	8.092,98	2.959,22	18.923,93	10.897,50	1.108,82	60.729,09
Kepulauan Meranti	3.874,04	5.018,78	38,29	1.705,57	6.254,82	3.989,55	20.881,04
Pekanbaru	693,25			21,15	18,99		733,39
Dumai	8.086,30	5.269,78	94,14	3.399,63	3.288,66	1.258,71	21.397,23
Total	103.866,85	67.937,68	5.470,78	33.362,93	62.736,31	11.099,61	284.474,16

Source: Processed by the author (BRG 2021)

Approximately 51.92% (826 out of 1591) of rural areas in Riau Province exhibit peat characteristics. Generally, rural areas face a higher risk compared to urban areas, primarily due to their relatively elevated levels of exposure and sensitivity, coupled with a comparatively lower adaptive capacity (Anggraini et al., 2021). The percentage of villages encountering natural disasters has risen from 48% in 2014 to 60% in 2018, as reported by the (Indonesia Central Bureau of Statistik, 2018). The vulnerability of rural areas is heightened by issues such as rural water management and the availability of water for plants (Yuliawan et al., 2022). In peatland villages, effective water management and wetting strategies are crucial. Despite recurrent fire disasters, the rural community in peatland areas often places less emphasis on disaster preparedness. After a fire disaster, peatland remains a vital resource for rural residents, who heavily rely on it for their livelihoods, particularly in the cultivation of commodities like palm oil, areca nut, and rubber. The recent trend among rural communities is to engage in extensive monoculture land use rather than adopting paludiculture strategies (Winarno et al., 2020). This shift may result in a diminishing carrying capacity of rural areas, subsequently impacting the production capacity of the region's economic activities (Rustiadi et al., 2017).

In the absence of dedicated peatland policies, the land system is projected to remain a net source of CO_2 throughout the 21st century, even with peatland protection measures in place (Winarno et al., 2020). In the context of rural development or the revitalization of rural areas, the role of governments is pivotal in crafting development plans that can effectively navigate uncertainties. The government's capacity to implement public policies significantly influences the trajectory of sustainable development. Mismanagement of peatland in rural areas is perceived to escalate environmental risks. The initial step in risk governance involves measuring the risks (Renn, 2006). However, there is currently a lack of research analyzing environmental risks in peat rural. This gap is crucial for determining sustainable development priorities, particularly in the realm of risk management related to environmental risks. Development areas can be categorized by environmental risk, providing local governments with a tool to monitor the potential for environmental risk and manage regional environmental risks (Xu & Liu, 2009). In light of the foregoing, this paper aims to analyze environmental risks in peat rural areas, striving to achieve sustainable rural development through a low-carbon development approach in peatland.

2. Method

2.1 Subject of research

This study was conducted in Riau Province, focusing on rural areas situated within peat hydrological units (KHG). The initial phase involved spatial analysis of peat rural in Riau Province, utilizing ArcGIS 10.4.1 software. The rural administration map of Riau Province was overlaid with the Riau Province Peat Hydrological Unit (KHG) map obtained from the Directorate of Peat Ecosystem Damage Control of the Ministry of Environment and Forestry. The spatial analysis identified a total of 826 rurals with peatlands distributed across the nine regencies in Riau Province. Subsequent to the spatial analysis, an analysis of rural environmental risks was conducted, employing aggregated data from village potential statistics that published by Indonesia Central Bureau of Statistic (BPS) for the years 2018, 2020, and 2021. Table 2 outlines the dimensions, criteria, and data utilized in the assessment of peat rural environmental risk.

Table 2
Dimensions, criteria and data sources

Dimension	Criteria	Var	Max/Min	Preference Type	Data Source
Hazard	Percentage of rural with water pollution (%)	C_1	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural with soil pollution (%)	C_2	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural with air pollution (%)	C_3	Min	Type V (Linear)	Village Potential, BPS
	Percentage of landslide events in rural (%)	C_4	Min	Type V (Linear)	Village Potential, BPS
	Percentage of flood events in rural (%)	C_5	Min	Type V (Linear)	Village Potential, BPS
	Percentage of tidal wave events in rural (%)	C_6	Min	Type V (Linear)	Village Potential, BPS
	Percentage of forest and land fire events in rural (%)	C_7	Min	Type V (Linear)	Village Potential, BPS
	Percentage of drought events in rural (%)	C_8	Min	Type V (Linear)	Village Potential, BPS
	Percentage of abrasion events (%)	C_9	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural with river water polluted by sewage (%)	C_{10}	Min	Type V (Linear)	Village Potential, BPS
Vulnerability	Percentage of rural with community dependency on forest area (%)	C_{11}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural that community practices land burn for agricultural purposes (%)	C_{12}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural that adjacent the sea (%)	C_{13}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural with mangrove damage from the rural that has mangrove (%)	C_{14}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of community primary income from agriculture, forestry and fishing sector (%)	C_{15}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural with the most families unmanage waste disposal (%)	C_{16}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural in slum settlement (%)	C_{17}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of damage agricultural land (%)	C_{18}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of population affected by disaster (%)	C_{19}	Min	Type V (Linear)	Village Potential, BPS
	Percentage of rural have no village-owned forest (%)	C_{20}	Min	Type V (Linear)	Village Potential, BPS
Capacity	Percentage of rivers existence in rural (%)	C_{21}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of embung, lakes, or water reservoirs in rural (%)	C_{22}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural with community initiatives to planting trees on critical land, mangroves, and other areas (%)	C_{23}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural that rivers, embung, and canals have normalized (%)	C_{24}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural have strong communal cooperation (%)	C_{25}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural have disaster early warning system (%)	C_{26}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural that waste recycling is practiced by community (%)	C_{27}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural that have local wisdom related to nature/environment (%)	C_{28}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural disaster mitigation facilities (%)	C_{29}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural have awareness in nature and environment conservation (%)	C_{30}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural have social forestry program (%)	C_{31}	Max	Type V (Linear)	Village Potential, BPS
	Percentage of rural have green open space (%)	C_{32}	Max	Type V (Linear)	Village Potential, BPS

Source: Modification from (Davis et al., 2004).

2.2 Research stage and technique of analysis

The evaluation and decision-making processes in environmental risk assessment are becoming increasingly intricate, involving extensive information (de Almeida et al., 2015). For instance, decisions that entail risk mitigation inherently require the application of optimization theory (Eiselt et al., 2023). The utilization of the Multiple Criteria Decision Analysis (MCDA) methodology, specifically through the Preference Ranking Organization Methods for Enrichment Evaluation (PROMETHEE), has been widely adopted in various studies focused on environmental risk analysis. This method has found application in areas such as crisis-driven drinking water supply strategies (Ghandi & Roozbahani, 2020), air quality assessments (Yu et al., 2020), multi-risk evaluations encompassing seismic and flood hazards (Soldati et al., 2022), and environmental impact assessments (Ramu et al., 2022).

However, no research has yet delved into the analysis of environmental risks in rural peat using the PROMETHEE method. Therefore, the objective of this study is to employ the PROMETHEE method to identify environmental risks in rural peat, considering the multi-hazard and multi-criteria nature of the context. PROMETHEE, initially developed by J. P. Brans & Vincke (1985), is an outranking-based multi-criteria technique grounded on a binary relationship between two alternatives (Fauzi, 2019). The relationship between option “a” being at least equal to option “b” (or vice versa) relative to a set of predetermined criteria is termed the “outranking relation” or preference index, denoted as π = (a, b). The preference index is calculated as the weighted average of preference functions for six different criteria types, utilizing a Linear V-type criterion preference function in this research.

PROMETHEE relies on a decision matrix comprising options and criteria pertinent to environmental risk in rural peat, encompassing hazard, vulnerability, and capacity. In the risk literature, the exposure component is often considered an intermediary element, leading to a comprehensive understanding of risk as an interaction between hazard, vulnerability, and capacity, as expressed in the following equation.

$$Risk\ =\ Hazard\ x\ Vulnerability - Capacity$$

This implies that as the system's capacity to manage the hazard increases, the risk it poses diminishes, and conversely, as the system's capacity decreases, the risk increases (Fauzi, 2021).

The data is utilized to execute the PROMETHEE program within a single scenario, indicating that it is not compared with other scenarios that might alter the data. Once this decision matrix is acquired, the preference function for outranking is established. The preference functions and weights for each criterion are adjusted proportionally. In this analysis, criteria related to hazard and vulnerability indicators are categorized as "bad indicators," resulting in a minimum preference (min). Conversely, criteria associated with the capacity indicator are considered "good indicators," leading to a maximum preference (max). The steps of this analysis are illustrated in Fig. 3.

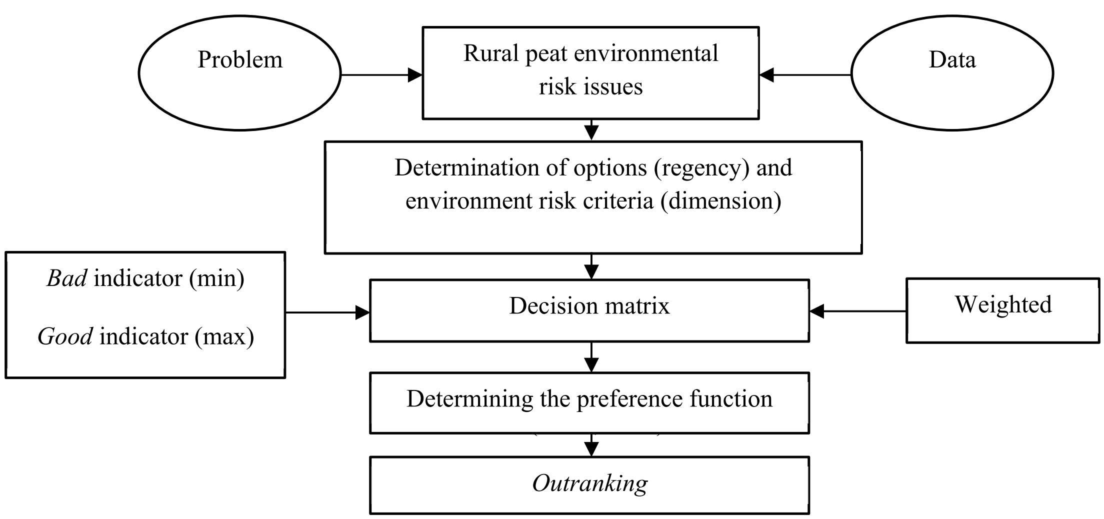

Fig. 3. The steps of the analysis

Shannon entropy is employed to assign weights to each criterion in this analysis. Shannon's entropy method is considered objective as it relies on mathematical calculations by Shannon in (1948). Several researchers have incorporated Shannon entropy in their PROMETHEE analyses (Mogaji & Atenidegbe, 2023; Safari et al., 2012). The weighting process begins by calculating the value X_{ij}, followed by determining the value P_{ij} using the equation:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (1)$$

where X_{ij} : Criteria that make up environmental risks
i : criteria
j : regency
m : the number of regency in Riau Province with peat areas, 9 regencies
P_{ij} : weight of each criterion of each regency

To calculate the entropy value, the equation:

$$E_j = -k \sum_{i=1}^{m} P_{ij} * \ln P_{ij} \quad (2)$$

where $k = \frac{1}{\ln m}$

To calculate the weighting of each indicator using the equation:

$$W_j = \frac{(1 - E_j)}{\sum_{j=1}^{n}(1 - E_j)} \quad (3)$$

The determination of the selected option (*outranking*) in PROMETHEE is then calculated based on a value $\phi^+(a)$ which is called *outgoing flow* and $\phi^-(a)$ or *incoming flow* (influenced). The *outranking* calculation for each alternative is as follows:

$$\phi^+(a) = \frac{1}{(N-1)} \pi_A(a, b) \quad (4)$$

$$\phi^-(a) = \frac{1}{(N-1)} \pi_A(b, a) \quad (5)$$

Difference between $\phi^+(a)$ and $\phi^+(a)$ is then calculated as *net flow* or

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad (6)$$

Then geometric analysis was carried out on each dimension of environmental risk using *Geometrical Analysis for Interactive Aid* (GAIA) proposed by Brans and Mareschal (1994). GAIA analysis has a basic assumption that each alternative a is not determined by the value of the criteria but is determined by a vector of monocriteria directions, where:

$$S_i = \frac{1}{N-1} \sum_{j=i} [P_j(a_{1,}a_2) - (P_j(a_{2,}a_1)] \quad (7)$$

Each alternative can be represented in a k-dimensional vector with vectors R^k:

$$q_i = [(S_1(a_i), S_2(a_i), \ldots, S_k(a_n))] \quad (8)$$

Typically, sensitivity analyses conducted by optimization solvers aim to examine how variations in the criteria within the objective function impact changes in the objective function's value. This analysis involves varying each criterion within a reasonable lower and upper bound. Another form of sensitivity analysis explores how alterations in the criteria affect changes in the actual solution.

3. Results and discussion

3.1. Dimensions Analysis of Environmental Risk

The hazard dimension in this study comprises 10 criteria, all having a minimum preference, signifying that the best condition aligns with the alternative or region demonstrating low hazard. The outcomes of the outranking analysis using PROMETHEE reveal that within the hazard dimension, Kepulauan Meranti stands out as the region with the best condition or the lowest hazard value for peat rural environmental risk, boasting a net flow value of 0.5068. The subsequent rankings are as follows: Siak (0.2834), Bengkalis (0.2238), Kampar (0.0134), Pelalawan (-0.0013), Indragiri Hilir (-0.0239), Rokan Hulu (-0.3074), Indragiri Hulu (-0.3272), and Rokan Hilir (-0.3676) (refer to Fig. 4). When grouped into two categories, Kepulauan Meranti, Siak, Bengkalis, and Kampar regency fall into the “low” category, whereas Pelalawan, Indragiri Hilir, Rokan Hulu, Indragiri Hulu, and Rokan Hilir districts are categorized as “high” in the hazard dimension.

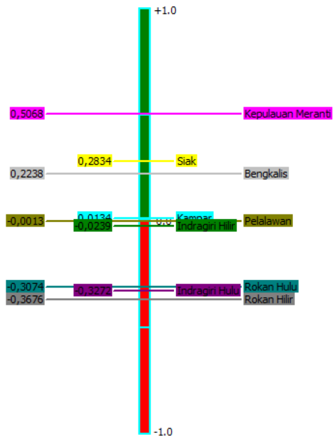

Fig. 4. Outranking results of hazard dimension

Fig. 5. GAIA hazard dimension

The GAIA analysis depicted in Fig. 5 divides into four quadrants, each representing criteria as driving forces for reducing the environmental hazard value. Kampar, Siak, and Pelalawan exhibit minimal occurrences of forest and land fires, abrasions, and tidal waves. In contrast, Kepulauan Meranti and Bengkalis share in the same quadrant, displaying negative values for abrasions and tidal waves, along with low scores for landslides, droughts, floods, air pollution, and river water pollution. Indragiri Hilir and Rokan Hilir showcase optimal values, specifically for soil pollution, contributing to the overall minimum hazard. In Indragiri Hulu and Rokan Hulu, there is no dominant criterion providing the best value for the hazard dimension, indicating the absence of criteria from the hazard dimension that significantly contribute to reducing hazard values.

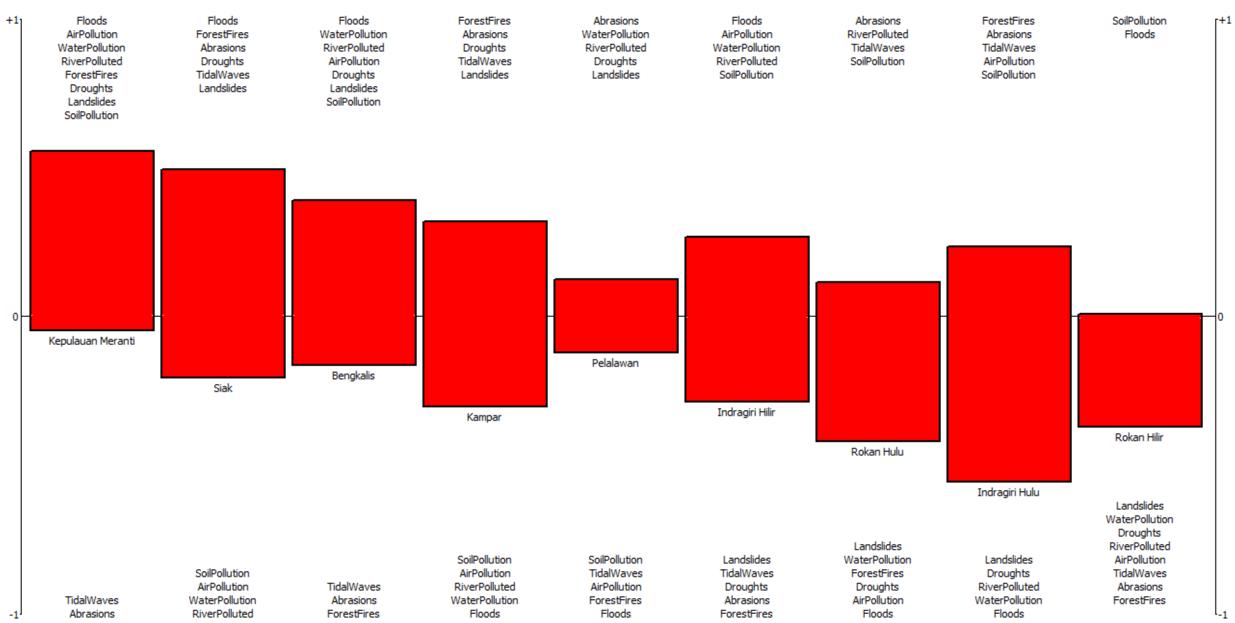

Fig. 6. Rainbow diagram of hazard dimension

In addition to establishing a ranking order using net flow scores, the analysis of the hazard dimension also outlines the contribution of each criterion to the score obtained for each region. Each block in the analysis illustrates criteria arranged based on the π+ and π- values, as depicted in Fig. 6. For Kepulauan Meranti, only two hazard criteria, specifically the abrasions and tidal waves criteria, are identified as bad criteria. Conversely, the remaining hazard criteria in the Kepulauan Meranti region exhibit favorable values. In contrast, Rokan Hilir Regency, characterized by the highest hazard values, shows that 8 out of the 10 hazard criteria contribute negatively to the hazard value. Both the soil pollution and floods criteria make a positive contribution to the hazard dimension in the Rokan Hilir. In regions situated along the coast (Bengkalis, Rokan Hilir, Indragiri Hilir, and Kepulauan Meranti), the abrasions criterion displays a negative contribution to the hazard dimension. Forest and land fires exacerbate environmental hazards in 5 out of the 9 regencies.

Another dimension considered in assessing peat rural environmental risk is vulnerability. Analysis of vulnerability dimension in the current study, encompasses 10 criteria, all assigned minimum preference. The results reveal that the regency with the lowest vulnerability value is Bengkalis, boasting a net flow value of (0.3982). Following this, Kampar (0.2945), Indragiri Hulu (0.1354), Kepulauan Meranti (0.0975), Siak (0.0688), Rokan Hulu (-0,0251), Pelalawan (-0.1366), Indragiri Hilir (-0.3807), and Rokan Hilir (-0.4520) are ranked accordingly, as illustrated in Fig. 7. If grouped into two categories, Bengkalis, Kampar, Indragiri Hulu, Kepulauan Meranti and Siak regency grouped into the “low” vulnerability category with positif value (π+), while Rokan Hulu, Pelalawan, Indragiri Hilir, and Rokan Hilir regency are categorized have "high" environmental vulnerability with negatif value (π-).

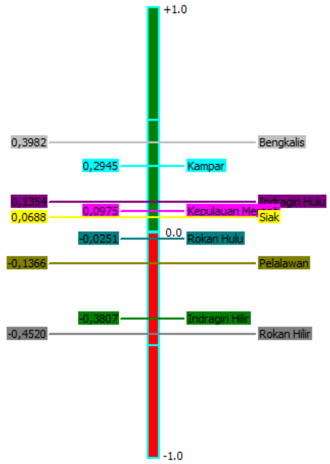

Fig. 7. Outranking results of vulnerability dimension

Fig. 8. GAIA of vulnerability dimension

Derived from the GAIA analysis in Fig. 8, Rokan Hilir and Indragiri Hilir have community primary income in the agriculture, forestry, and fishing sector as driving factor to vulnerability value. Bengkalis and Pelalawan fall into a quadrant where the existence of village-owned forests contributes to the minimum value of environmental vulnerability. Siak and Rokan Hulu, sharing a quadrant, exhibit minimum values for vulnerability in contribution of better waste management, low damage of agricultural land, and minimum of the population affected by disasters. Kampar and Indragiri Hulu have low vulnerability values caused by the regions are not adjacent with the sea and having minimum damage of mangroves.

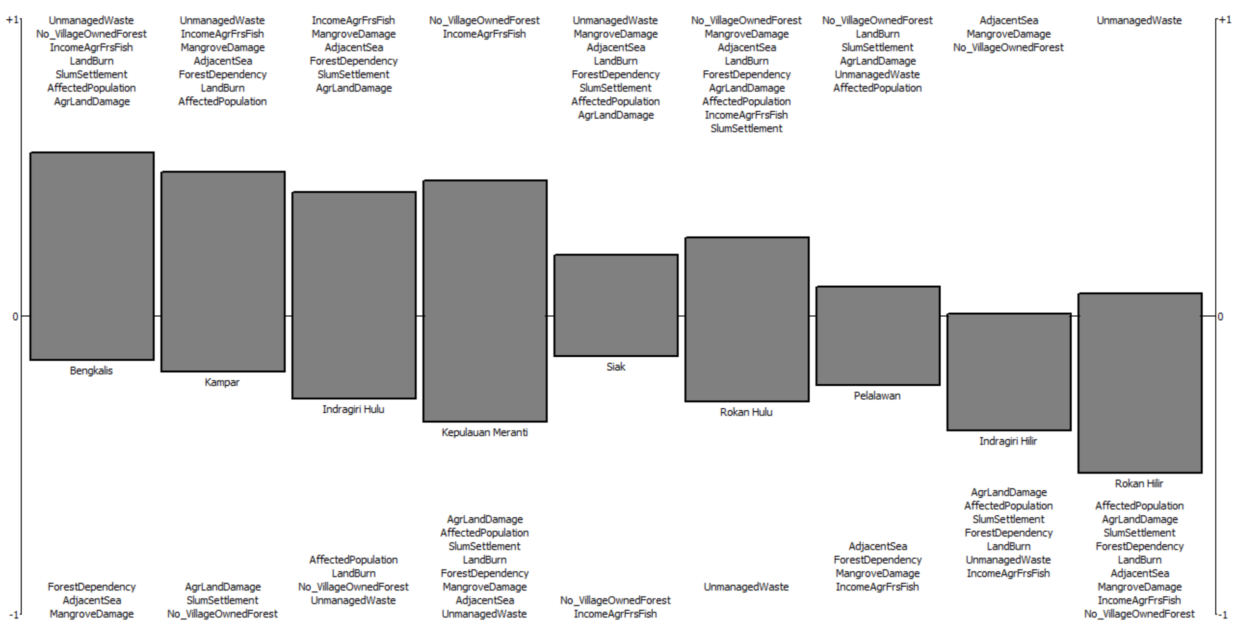

Fig. 9. Rainbow diagram of vulnerability dimension

The positive and negative contributions depicted in the rainbow diagram for the vulnerability dimension (Fig. 9) reveal that in Rokan Hulu, there is a notable criterion making a negative contribution (as a bad indicator) to the vulnerability dimension, specifically unmanaged waste. In contrast, Rokan Hilir stands out as the least favorable, with only unmanaged waste criteria give a positive value for vulnerability value. The damage of mangrove contributes negatively to the vulnerability dimension in Bengkalis, Pelalawan, Kepulauan Meranti, and Rokan Hilir. Kampar, Siak, and Indragiri Hulu have a minimum village-owned forest that results in a negative value for vulnerability, but this criteria give positive value for Indragiri Hilir.

The forthcoming analysis of environmental risk based on capacity dimension. This dimension encompasses 12 criteria. The value preference is assigned to the good indicator value (maximum). The results obtained from the outranking analysis using PROMETHEE indicate that Bengkalis is the region with a commendable capacity value for reducing the environmental risk of peat rural, boasting a net flow value of (0.5390), as presented in Fig. 10. The subsequent rankings are as follows: Kepulauan Meranti (0.4381), Indragiri Hilir (0.3663), Siak (0.0686), Rokan Hulu (-0.0779), Indragiri Hulu (-0.2121), Rokan Hilir (-0.2842), Pelalawan (-0.3478), and Kampar (-0.4900). Bengkalis, Kepulauan Meranti, Indragiri Hilir, and Siak fall into the "high" category, while Rokan Hulu, Indragiri Hulu, Rokan Hilir, Pelalawan, and Kampar fall into the "low" category for the capacity dimension.

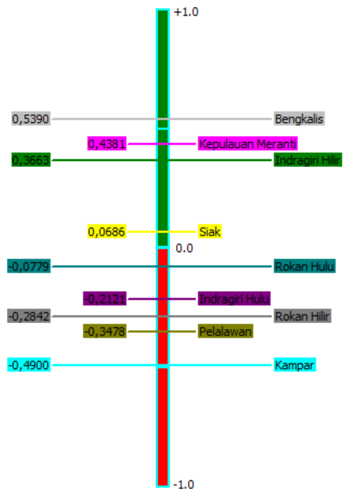

Fig. 10. *Outranking* results capacity dimension

Fig. 11. GAIA of capacity dimension

Based on the GAIA analysis in Fig. 11, for Kampar, Rokan Hilir, Indragiri Hulu, and Pelalawan regency, there are no dominant criteria to provide the best value in the capacity dimension. Rokan Hulu and Indragiri Hilir fall into a quadrant with a dominant rivers existence criteria. Kepulauan Meranti and Bengkalis are driven by awareness in nature and environtment conservation, social forestry, green open space, and waste recycling values. And then local wisdom, disaster early warning system and waste recycling are dominant factor for affecting capacity dimension in Siak.

The rainbow diagram representing criteria of capacity dimension in Fig. 12 displays positive and negative contributions. In Bengkalis regency, the existence of a river stands out as a negative contributor to the capacity dimension, marking it as a detrimental indicator. The system of disaster warning is deficient in Kepulauan Meranti and Siak, contributing negatively to the capacity dimension. However, this criterion yields positive contributions to Pelalawan and Rokan Hulu. Indragiri Hilir, Indragiri Hulu, Rokan Hilir, and Kampar exhibit minimum disaster warning system and awareness in nature, further diminishing their capacity dimension values.

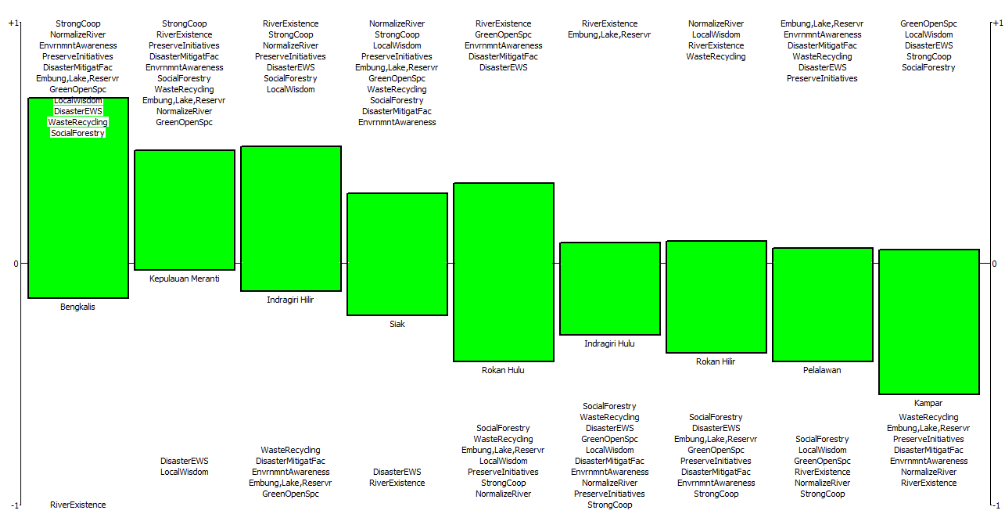

Fig. 12. Rainbow diagram of capacity dimension

Based on the accumulation of all dimension of environmental risk in peat rural areas, the results of the environmental risk analysis are led by the Bengkalis region with a net flow value of (0.4261) as presented in Fig. 13. The subsequent rankings are Kepulauan Meranti (0.2815), Siak (0.0989), Kampar (-0.0366), Indragiri Hilir (-0.0529), Indragiri Hulu (-0.0587), Rokan Hulu (-0.0843), Pelalawan (-0.1961), and Rokan Hilir (-0.3778).

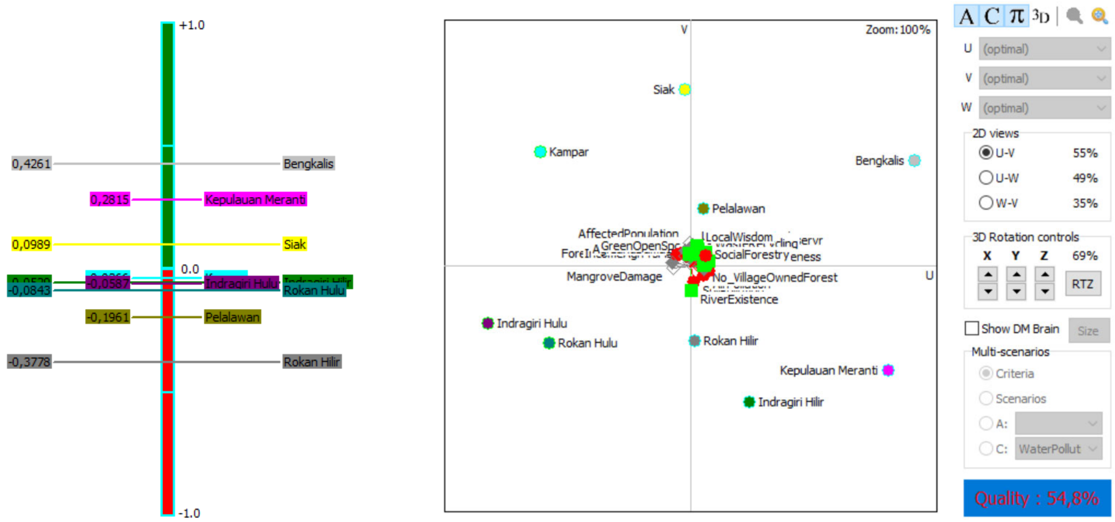

Fig. 13. Outranking and GAIA of Peat Rural Environmental Risk in Riau Province

Based on the GAIA analysis in Fig. 13, several quadrants depict the dominant criteria influencing the reduction of environmental risk in each region. The positive and negative contributions of each criterion in the environmental risk analysis of peat rural areas in Riau Province can be observed in Fig. 14. For the Bengkalis region, identified as an area with low environmental risk, the largest contribution to the low level of environmental risk is derived from a positive contribution in the vulnerability and capacity dimension, while the negative contribution is predominantly caused by the vulnerability dimension. Conversely, almost all criteria contribute negatively to Rokan Hilir, making this region the one with high environmental risk in peat rural areas. Seven of nine regencies have vulnerability dimension as positive contributor to minimize environmental risk, while the capacity dimension as the primary leverage in two regencies. Furthermore, the vulnerability dimension in five of nine regencies contributes negatively to the environmental risk value, while the rest is caused by the capacity dimension (see Fig. 14).

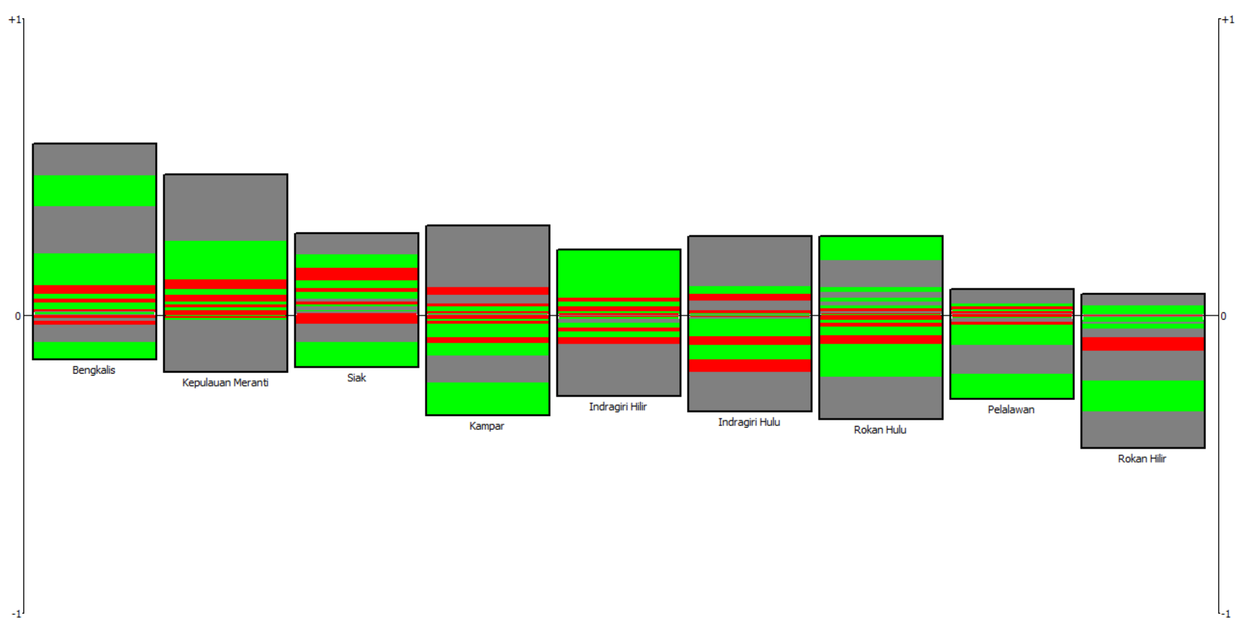

Fig. 14. Rainbow diagram of Peat Rural Environmental Risk in Riau Province

Base on PROMETHEE analysis, the environmental risk conditions of peat rural in Riau Province by regency can be classified as follows Table 3.

Table 3
Classified of environmental risk dimension

Regency	Hazard	Vulnerability	Capacity	Environmental Risk
Bengkalis	Low	Low	High	Low
Kepulauan Meranti	Low	Low	High	Low
Siak	Low	Low	High	Low
Kampar	Low	Low	Low	High
Indragiri Hilir	High	High	High	High
Indragiri Hulu	High	Low	Low	High
Rokan Hulu	High	High	Low	High
Pelalawan	High	High	Low	High
Rokan Hilir	High	High	Low	High

There are three regencies in a favorable condition or with low environmental risk in peat rural: Bengkalis, Kepulauan Meranti, and Siak. On the other hand, six regencies fall into the unfavorable category or exhibit higher environmental risk, including Kampar, Indragiri Hilir, Indragiri Hulu, Rokan Hulu, Pelalawan, and Rokan Hilir.

3.2. *Sensitivity Analysis*

The weights utilized in the PROMETHEE evaluation criteria signify the prioritization of the assessment. In situations of bounded rationality and incomplete information during weight assignment, the resulting rankings may exhibit reduced stability. Hence, it becomes imperative to conduct an interval stability test (or sensitivity test) to gauge the impact of variations in criteria weights on the final ranking. The robustness of the ranking is confirmed if variations in weights do not alter the order (Schwartz & Göthner, 2009). The sensitivity analysis yields valuable insights into the potential impact of changes in one criterion on others. Fig. 15 displays the entropy weights derived from the processed data in this study. Within the hazard dimension, the flood and forest fire criteria carry the highest weights. Meanwhile, in the vulnerability dimension, the criteria for primary income in the agriculture, forestry, and fishing sector, along with unmanaged waste, have the greatest weights. Conversely, in the capacity dimension, the river existence and strong cooperation criteria bear the highest weights. On average, the vulnerability dimension exhibits higher weights compared to both the hazard and capacity dimensions.

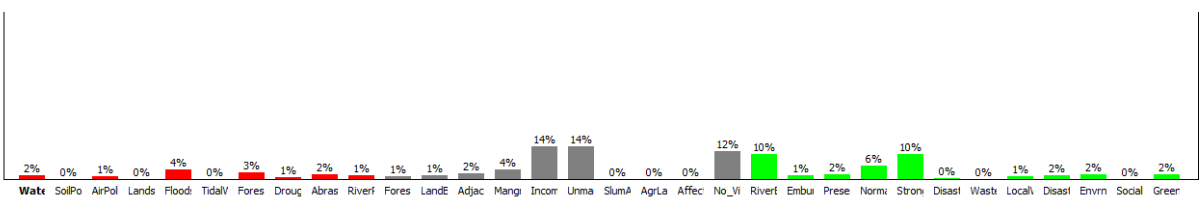

Fig. 15. Entropy weights bar each criterion of environmental risk dimension

The sensitivity test conducted in this study yields weighted stability intervals. The rankings' stability within the environmental risk will remain unchanged if the variations in the weights assigned to the criteria fall within this interval. However, adjusting the weights up to 100% for each criterion will result in a change in ranking order, as shown in Table 4.

Table 4
Weighted stability intervals of environmental risk criteria

Dimension	Criteria	Weighted Stability Intervals (WSI)	Interval range	Rank order if criteria weighted adjusted to 100% (From low to high environmental risk regency)
Hazard	Water pollution	1,20% - 2,97%	1,77%	Bengkalis, Kepulauan Meranti, Indragiri Hilir, Pelalawan, Rokan Hilir, Rokan Hulu, Siak, Kampar, Indragiri Hulu
	Soil pollution	0,00% - 1,48%	1,48%	Indragiri Hulu, Indragiri Hilir, Rokan Hulu, Rokan Hilir, Kepulauan Meranti, Bengkalis, Siak, Kampar, Pelalawan
	Air pollution	0,47% - 2,66%	2,19%	Kepulauan Meranti, Indragiri Hilir, Bengkalis, Indragiri Hulu, Rokan Hilir, Pelalawan, Kampar, Siak, Rokan Hulu
	Landslides	0,00% - 7,02%	7,02%	Pelalawan, Siak, Kampar, Bengkalis, Kepulauan Meranti, Indragiri Hulu, Indragiri Hilir, Rokan Hilir, Rokan Hulu
	Floods	3,80% - 5,95%	2,15%	Siak, Kepulauan Meranti, Indragiri Hilir, Bengkalis, Rokan Hilir, Pelalawan, Kampar, Rokan Hulu, Indragiri Hulu
	Tidal waves	0,00% - 0,72%	0,72%	Indragiri Hulu, Siak, Kampar, Rokan Hulu, Bengkalis, Pelalawan, Indragiri Hilir, Kepulauan Meranti, Rokan Hilir
	Forest and land fires	1,84% - 3,11%	1,27%	Kampar, Indragiri Hulu, Siak, Kepulauan Meranti, Pelalawan, Rokan Hulu, Bengkalis, Indragiri Hilir, Rokan Hilir
	Droughts	0,00% - 10,06%	10,06%	Kampar, Kepulauan Meranti, Siak, Bengkalis, Pelalawan, Rokan Hilir, Indragiri Hilir, Indragiri Hulu, Rokan Hulu
	Abrasions	0,63% - 2,38%	1,75%	Indragiri Hulu, Pelalawan, Siak, Kampar, Rokan Hulu, Kepulauan Meranti, Bengkalis, Indragiri Hilir, Rokan Hilir
	River water polluted by sewage	0,95% - 3,34%	2,39%	Bengkalis, Kepulauan Meranti, Rokan Hulu, Indragiri Hilir, Pelalawan, Rokan Hilir, Kampar, Siak, Indragiri Hulu

Vulnerability	Community dependency on forest area	0,00% - 1,87%	1,87%	Indragiri Hulu, Kampar, Rokan Hulu, Siak, Indragiri Hilir, Rokan Hilir, Pelalawan, Bengkalis, Kepulauan Meranti
	Community practices land burn for agricultural reasons	0,00% - 2,61%	2,61%	Pelalawan, Rokan Hulu, Siak, Bengkalis, Kampar, Indragiri Hulu, Rokan Hilir, Indragiri Hilir, Kepulauan Meranti
	Adjacent the sea	0,28% - 3,19%	2,91%	Indragiri Hulu, Kampar, Rokan Hulu, Siak, Indragiri Hilir, Pelalawan, Rokan Hilir, Bengkalis, Kepulauan Meranti
	Mangrove damage	2,01% - 4,87%	2,86%	Indragiri Hulu, Kampar, Rokan Hulu, Siak, Indragiri Hilir, Rokan Hilir, Kepulauan Meranti, Pelalawan, Bengkalis
	Community primary income from agriculture, forestry and fishing sector	12,42% - 13,81%	1,39%	Indragiri Hulu, Kepulauan Meranti, Bengkalis, Kampar, Rokan Hulu, Siak, Pelalawan, Rokan Hilir, Indragiri Hilir
	Unmanage waste disposal	12,69% - 22,50%	9,81%	Kampar, Bengkalis, Siak, Rokan Hilir, Pelalawan, Indragiri Hilir, Indragiri Hulu, Kepulauan Meranti, Rokan Hulu
	Slum settlement	0,00% - 0,61%	0,61%	Pelalawan, Indragiri Hulu, Siak, Bengkalis, Rokan Hulu, Rokan Hilir, Indragiri Hilir, Kampar, Kepulauan Meranti
	Damage of agricultural land	0,00% - 2,61%	2,61%	Siak, Rokan Hulu, Pelalawan, Bengkalis, Indragiri Hulu, Indragiri Hilir, Rokan Hilir, Kepulauan Meranti, Kampar
	Population affected by disaster	0,00% - 2,50%	2,50%	Siak, Bengkalis, Kampar, Rokan Hulu, Pelalawan, Rokan Hilir, Indragiri Hilir, Indragiri Hulu, Kepulauan Meranti
	No village-owned forest	10,77% - 13,67%	2,90%	Kepulauan Meranti, Bengkalis, Rokan Hulu, Pelalawan, Indragiri Hilir, Siak, Indragiri Hulu, Kampar, Rokan Hilir
Capacity	Rivers existence	9,80% - 11,21%	1,41%	Indragiri Hilir, Rokan Hulu, Kepulauan Meranti, Indragiri Hulu, Rokan Hilir, Pelalawan, Bengkalis, Siak, Kampar
	Embung, lakes or water reservoir	0,00% - 1,88%	1,88%	Bengkalis, Pelalawan, Siak, Indragiri Hulu, Kepulauan Meranti, Rokan Hilir, Kampar, Rokan Hulu, Indragiri Hilir
	Community initiatives to preserve the critical land, mangroves, and other areas	1,68% - 4,22%	2,54%	Kepulauan Meranti, Bengkalis, Siak, Indragiri Hilir, Pelalawan, Rokan Hilir, Kampar, Rokan Hulu, Indragiri Hulu
	Normalized rivers, embung, and canals	4,58% - 7,19%	2,61%	Bengkalis, Siak, Rokan Hilir, Indragiri Hilir, Kepulauan Meranti, Indragiri Hulu, Pelalawan, Kampar, Rokan Hulu
	Strong communal cooperation	9,68% - 13,20%	3,52%	Bengkalis, Kepulauan Meranti, Indragiri Hilir, Siak, Kampar, Indragiri Hulu, Rokan Hulu, Pelalawan, Rokan Hilir
	Disaster early warning system	0,00% - 5,15%	5,15%	Kampar, Bengkalis, Indragiri Hilir, Pelalawan, Rokan Hulu, Siak, Indragiri Hulu, Rokan Hilir, Kepulauan Meranti
	Waste recycling	0,00% - 3,31%	3,31%	Bengkalis, Siak, Pelalawan, Kepulauan Meranti, Rokan Hilir, Indragiri Hilir, Indragiri Hulu, Kampar, Rokan Hulu
	Local wisdom	0,49% - 11,97%	11,48%	Siak, Bengkalis, Kampar, Rokan Hilir, Indragiri Hilir, Pelalawan, Kepulauan Meranti, Indragiri Hulu, Rokan Hulu
	Disaster mitigation facilities	0,44% - 3,39%	2,95%	Bengkalis, Rokan Hulu, Kepulauan Meranti, Pelalawan, Siak, Indragiri Hilir, Rokan Hilir, Indragiri Hulu, Kampar
	Awareness in nature and environment conservation	0,70% - 3,49%	2,79%	Bengkalis, Rokan Hulu, Kepulauan Meranti, Pelalawan, Siak, Indragiri Hilir, Rokan Hilir, Indragiri Hulu, Kampar
	Social forestry	0,00% - 3,26%	3,26%	Kepulauan Meranti, Bengkalis, Indragiri Hilir, Siak, Kampar, Indragiri Hulu, Pelalawan, Rokan Hulu, Rokan Hilir
	Green open space	0,79% - 2,98%	2,19%	Rokan Hulu, Bengkalis, Kampar, Siak, Kepulauan Meranti, Rokan Hilir, Indragiri Hulu, Pelalawan, Indragiri Hilir

Table 4 illustrates that droughts, unmanaged waste disposal, and local wisdom exhibit wider intervals of each dimension, emphasizing their robust ranking. This analysis categorizes all criteria in the environmental risk analysis conducted in this research as sensitive criteria. Sensitivity analysis proves invaluable for decision-makers, offering insights into the consequences of changes in weightings. As weights are adjusted, the emphasis on a specific criterion may impact other criteria within the environmental risk analysis.

4. Conclusions

Rural development in peatland areas pose some risks, especially environmental risk. These include exposure to floods, fire and spread of pollution. Hence, assessing environmental risk in peat rural area is both important and useful to achieve sustainable rural development. The analysis indicates that three regencies in Riau Province—Bengkalis, Kepulauan Meranti, and Siak—demonstrate a low environmental risk for peat rural. Conversely, six regencies, including Kampar, Indragiri Hilir, Indragiri Hulu, Rokan Hulu, Pelalawan, and Rokan Hilir, are experiencing adverse conditions. The criteria influencing the environmental risk dimension showcase a diverse array of positive and negative contributions across each regency. The sensitivity analysis demonstrates that droughts, unmanaged waste disposal, and local wisdom display wider weighted stability intervals within each dimension, underscoring the robust ranking of environmental risks. The outcomes offer valuable insights for stakeholders to address environmental risk mitigation in peat rural through comprehensive multicriteria and multilocation analysis. This research could be replicated in regions with tropical peatland characteristics in other developing countries, with further studies recommended to enhance criteria and governance strategies for peat rural environmental risk.

References

AbdelRahman, M. A. E. (2023). *An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications*. *Rendiconti Lincei* (Vol. 34). Springer International Publishing. https://doi.org/10.1007/s12210-023-01155-3

Anggraini, E., Rustiadi, E., Syuaib, M. F., Mulyati, H., Widyastutik, Indrawan, R. D., … & Rahman, A. (2021). *Membangkitkan Pertumbuhan Ekonomi Indonesia dari Perdesaan*. IPB Press.

Badan Restorasi Gambut. (2016). Rencana Strategis Badan Restorasi Gambut Tahun 2016 – 2020, (November 2016), 72. Retrieved from https://brg.go.id/wp-content/uploads/2019/04/RENSTRA-OREO-.pdf

Brans, J. P., & Vincke, P. (1985). Note—A Preference Ranking Organisation Method. *Management Science*, *31*(6), 647–656. https://doi.org/10.1287/mnsc.31.6.647

Brans, Jean Pierre, & Mareschal, B. (1994). The PROMCALC & GAIA decision support system for multicriteria decision aid. *Decision Support Systems*, *12*(4–5), 297–310. https://doi.org/10.1016/0167-9236(94)90048-5

Chen, X. M., Sharma, A., & Liu, H. (2023). The Impact of Climate Change on Environmental Sustainability and Human Mortality. *Environments - MDPI*, *10*(10). https://doi.org/10.3390/environments10100165

Davis, I., Haghebaert, B., & Peppiatt, D. (2004). Provention project: Tools for community risk assessment & action planning "Social Vulnerability and Capacity Analysis" Workshop. *Ifrc*, (May), 40.

de Almeida, A. T., Cavalcante, C. A. V., Alencar, M. H., Ferreira, R. J. P., de Almeida-Filho, A. T., & Garcez, T. V. (2015). *Multicriteria and Multiobjective Models for Risk, Reliability and Maintenance Decision Analysis* (Vol. 231). https://doi.org/10.1007/978-3-319-17969-8

Department of Environment and Forestry. (2022). *RPPEG Provinsi Riau Tahun 2021-2050.pdf*.

Eiselt, H. A., Marianov, V., & Bhadury, J. (2023). *Multicriteria Location Analysis*. Springer Cham. https://doi.org/https://doi.org/10.1007/978-3-031-23876-5

Evans, B. (2021). *Economics of Peatlands Conservation, Restoration and Sustainable Management Economics of Peatlands Conservation, Restoration and Sustainable Management policy report*.

Fauzi, A. (2019). *Teknik Analisis Keberlanjutan*. PT. Gramedia Pustaka Utama.

Fauzi, A. (2021). *Analisis Risiko dan Keberlanjutan Lingkungan*. Tangerang Selatan: Universitas Terbuka.

Field, R. D., Van Der Werf, G. R., Fanin, T., Fetzer, E. J., Fuller, R., Jethva, H., … Worden, H. M. (2016). Indonesian fire activity and smoke pollution in 2015 show persistent nonlinear sensitivity to El Niño-induced drought. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(33), 9204–9209. https://doi.org/10.1073/pnas.1524888113

Ghandi, M., & Roozbahani, A. (2020). Risk Management of Drinking Water Supply in Critical Conditions Using Fuzzy PROMETHEE V Technique. *Water Resources Management*, *34*(2), 595–615. https://doi.org/10.1007/s11269-019-02460-z

Glauber, A. J., Moyer, S., Adriani, M., Gunawan Elitza Mileva, I., Harimurti, P., Farman Izhar, M., … Henry Stirrett Wood, G. (2016). The Cost of Fire An Economic Analysis of Indonesia's 2015 Fire Crisis, (February), 52–53. Retrieved from http://www.globalfiredata.org/index.html.

Glenk, K., & Martin-Ortega, J. (2018). The economics of peatland restoration. *Journal of Environmental Economics and Policy*, *7*(4), 345–362. https://doi.org/10.1080/21606544.2018.1434562

Gunawan, H., Suwarno, A., Afriyanti, D., Sumarga, E., Malik, M., Rahiem, A., … Saad, A. (2020). *Ekonomi Hijau Gambut Indonesia*. Retrieved from https://www.researchgate.net/profile/Dian-Afriyanti/publication/351436418_Ekonomi_Hijau_Gambut_Indonesia/links/60a8d80a45851522bc0aed11/Ekonomi-Hijau-Gambut-Indonesia.pdf

Indonesia Central Bureau of Statistik. (2018). *Statistik Potensi Desa Indonesia Tahun 2018*.

Leng, L. Y., Ahmed, O. H., & Jalloh, M. B. (2019). Brief review on climate change and tropical peatlands. *Geoscience Frontiers*, *10*(2), 373–380. https://doi.org/10.1016/j.gsf.2017.12.018

Mogaji, K. A., & Atenidegbe, O. F. (2023). Development of PROMETHEE-Entropy data mining model for groundwater potentiality modeling: a case study of multifaceted geologic settings in south-western Nigeria. *Acta Geophysica*, (0123456789). https://doi.org/10.1007/s11600-023-01095-4

National Development Planning Agency (Bappenas). (2019). *Low Carbon Development: A Paradigm Shift Towards a Green Economy in Indonesia*.

Ramu, K., Ramachandran, M., Murali, N., & Mani, M. (2022). Environmental Impact Assessment Using PROMETHEE Method. *Environmental Science and Engineering*, *1*(2), 57–65. https://doi.org/10.46632/ese/1/2/2

Renn, O. (2006). *Risk Governance Towards An Integrative Approach*. Switzerland.

Renou-Wilson, F. (2018). *Peatlands. In: Creamer, R., O'Sullivan, L. (eds) The Soils of Ireland.* (R. Schulte, L. O'Sullivan, & R. Creamer, Eds.) (World Soil). Springer. https://doi.org/https://doi.org/10.1007/978-3-319-71189-8_8

Rustiadi, E., Saefulhakim, S., & Panuju, D. R. (2017). *Perencanaan dan Pengembangan Wilayah*. Jakarta: Yayasan Pustaka Obor Indonesia.

Safari, H., Sadat Fagheyi, M., Sadat Ahangari, S., & Reza Fathi, M. (2012). Applying PROMETHEE Method based on Entropy Weight for Supplier Selection. *Business Management and Strategy*, *3*(1), 97–106. https://doi.org/10.5296/bms.v3i1.1656

Saharjo, B. H., & Novita, N. (2022). The High Potential of Peatland Fires Management For Greenhouse Gas Emission

Reduction in Indonesia. *Jurnal Silvikultur Tropika*, *13*(1), 12160.

Schwartz, Michael, & Göthner, Maximilian. (2009). A multidimensional evaluation of the effectiveness of business incubators: an application of the PROMETHEE outranking method. *Environment and Planning C: Government and Policy, 27*(6), 1072–1087. doi:10.1068/c0897b

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N. H., Rice, C. W., Robledo Abad, C., Romanovskaya, A., Sperling, F., Tubiello, F. N., Berndes, F. and O. L. U. (AFOLU). (2014). Agriculture, forestry and other land use (AFOLU). *In O. Edenhofer, R. PichsMadruga, Y. Sokona, JC. Minx, E. Farahani, S. Kadner, K. Seyboth, A. Adler, Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. VonStechow, & T. Zwickel (Eds.), Climate Change 2014: Mitigation of Climate C*, 811–922. https://doi.org/10.4337/9781839101595.00025

Soldati, A., Chiozzi, A., Nikolić, Ž., Vaccaro, C., & Benvenuti, E. (2022). A PROMETHEE Multiple-Criteria Approach to Combined Seismic and Flood Risk Assessment at the Regional Scale. *Applied Sciences (Switzerland)*, *12*(3). https://doi.org/10.3390/app12031527

Surahman, A., Soni, P., & Shivakoti, G. P. (2018). Reducing CO2 emissions and supporting food security in Central Kalimantan, Indonesia, with improved peatland management. *Land Use Policy*, *72*, 325–332. https://doi.org/10.1016/j.landusepol.2017.12.050

Syahza, A., Suswondo, Bakce, D., Nasrul, B., Wawan, & Irianti, M. (2020). Peatland Policy and Management Strategy to Support Sustainable Development in Indonesia. In *Journal of Physics: Conference Series* (Vol. 1655). IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/1655/1/012151

Turetsky, M. R., Benscoter, B., Page, S., Rein, G., Van Der Werf, G. R., & Watts, A. (2015). Global vulnerability of peatlands to fire and carbon loss. *Nature Geoscience*, *8*(1), 11–14. https://doi.org/10.1038/ngeo2325

UNFCCC. (2021). *Updated Nationally Determined Contribution Republic of Indonesia*. *Pemerintah Pusat*.

Winarno, B., Rohadi, D., Herawati, T., Rahmat, M., & Suwarno, E. (2020). Out of fire disaster: Dynamics of livelihood strategies of rural community on peatland use and management. *IOP Conference Series: Earth and Environmental Science*, *487*(1), 0–10. https://doi.org/10.1088/1755-1315/487/1/012008

World Economic Forum. (2020). Global Risks 2020: An Unsettled World. *World Economic Forum*, 8–17.

Xu, L., & Liu, G. (2009). The study of a method of regional environmental risk assessment. *Journal of Environmental Management*, *90*(11), 3290–3296. https://doi.org/10.1016/j.jenvman.2009.05.011

Yu, X., Li, C., Chen, H., & Ji, Z. (2020). Evaluate air pollution by promethee ranking in yangtze river delta of China. *International Journal of Environmental Research and Public Health*, *17*(2). https://doi.org/10.3390/ijerph17020587

Yuliawan, D., Hakim, D. B., Juanda, B., & Fauzi, A. (2022). Classification and Prediction of rural Socio-Economic Vulnerability (IRSV) Integrated with Social-Ecological System. *Desision Science Letters*, *11*, 223–234. https://doi.org/10.5267/dsl.2022.4.001