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Spatial-Economic Assessment and Loss Valuation of Land Fire Risks: Supporting Green Economy Frameworks in Balikpapan

Khaerun Nisa SH[1], La Ode Muhammad Iksan Yusuf[2]
[1]Accounting, Universitas Negeri Makassar, Jl. Pendidikan I No. 27, 90222, Indonesia.
[2]Economic Development, Universitas Negeri Makassar, Jl. Pendidikan I No. 27, 90222, Indonesia.
Email Correspondence: khaerun.nisa@unm.ac.id
ORCID ID: https://orcid.org/0009-0003-6234-2620

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ABSTRACT

As a buffer city for the Capital City of Nusantara (IKN), Balikpapan faces increasing exposure to forest and land fires (karhutla) alongside accelerated infrastructure development and wildland-urban interface (WUI) expansion. However, conventional risk assessments focus primarily on biophysical mapping without integrating microspatial clustering or multidimensional economic loss metrics. This study analyzes fire spatial dynamics, quantifies land cover-based economic losses, and evaluates proactive mitigation fiscal feasibility from 2024 through July 2026. Integrating GIS overlap analysis, Economic Loss Intensity (ELI), Index of Fire and Economic Loss (IELK), and a three-year Cost-Benefit Analysis (CBA), results reveal spatially clustered patterns. South Balikpapan emerged as the primary hotspot, accounting for 58% of incidents (29 cases, IELK score 1,000), 7.4720 ha affected, and IDR 330.35 million in losses, with an ELI of IDR 44.21 million/ha. CBA demonstrates that mitigation financing of IDR 240 million yields a positive NPV of IDR 1.05 billion and a BCR of 5.64. Combining economic valuation with CBA optimizes mitigation priorities and investment efficiency.

Keywords: Forest And Land Fire Risk, Spatial Cluster, Wildland-Urban Interface, Economic Loss Intensity, Cost-Benefit Analysis

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INTRODUCTION

The dynamics of the global economy are currently facing systemic challenges due to environmental instability triggered by a combination of extreme climate change, phenomenon The Child, and massive land-use transformation (Sun et al., 2024). These environmental pressures create macroeconomic uncertainty and degrade productive assets in global supply chains (Tamasiga & Onyeaka, 2026). In the context of the tropical landscape, Indonesia occupies a central position as one of the largest forest and land fire hotspots in the world (Soleh et al., 2026), where periodic fire incidents trigger ecosystem degradation, high carbon emissions, as well as significant financial losses to the public and private sectors (Amankwah-Amoah & A. Debrah, 2025). Unsustainable economic activity and expansion of land exploitation have been proven to significantly increase the risk of ecological disasters leading to a decline in regional productive capabilities (Sukumaran, 2022).

Escalation of forest and land fires shows very high pressure on key areas in Indonesia (Suhardono et al., 2024). Based on monitoring by the Meteorology, Climatology, and Geophysics Agency (BMKG) as of August 1, 2026, a massive accumulation of hotspots was identified throughout Indonesia with the main dominance centered on the island of Kalimantan, reaching 1,419 hotspots with a moderate level of confidence and 86 points (Figure 1). The concentrated distribution of hot spots in Kalimantan confirms the high spatial vulnerability of the region to the threat of forest and land fires that have the potential to extend to residential areas and strategic infrastructure.

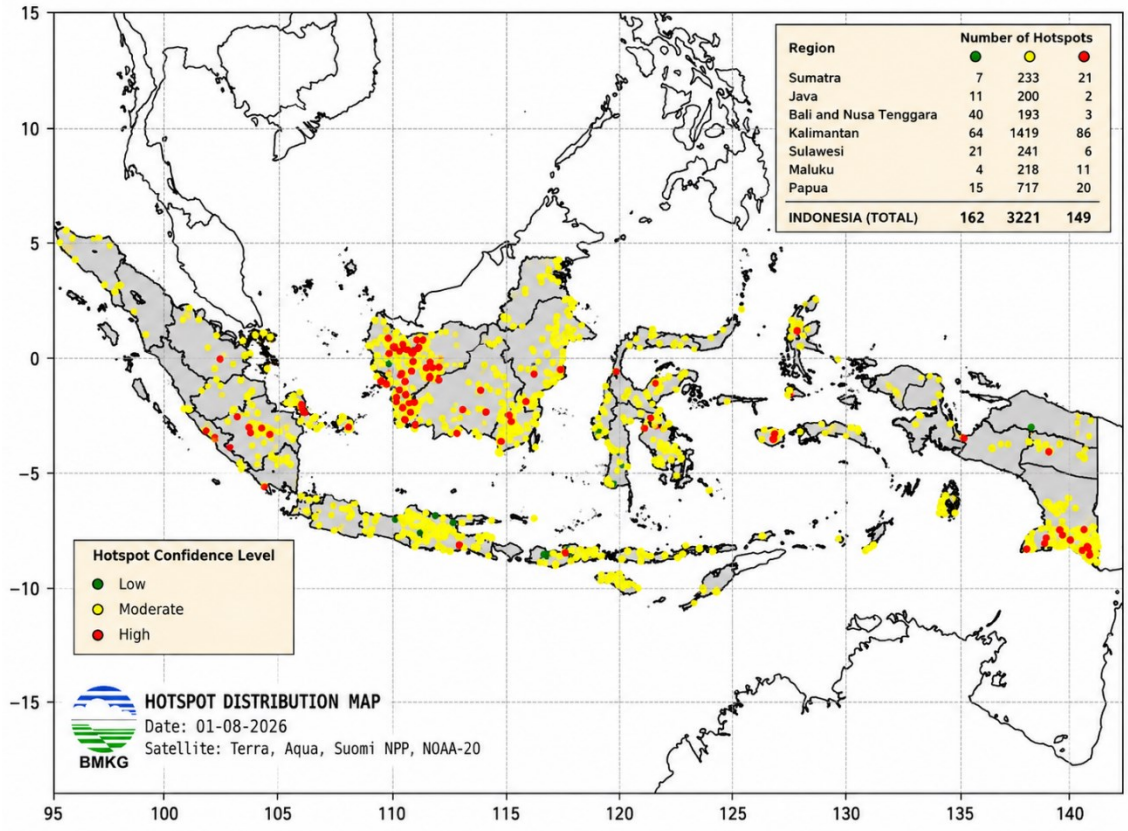

Figure 1. Map of hotspot distribution in Indonesia as of August 1, 2026 based on BMKG satellite monitoring.

The dynamics of vulnerability to forest and land fires have a direct impact on Indonesia's strategic areas, such as Balikpapan City in East Kalimantan Province which plays a vital role as the main buffer city of the Capital City of the archipelago (IKN). With a landscape

consisting of a mosaic of forests, mangroves, shrubs, plantations, and settlements (Kadri & Kintani, 2026), Balikpapan is experiencing an acceleration of infrastructure development and rapid expansion of urban areas (Rachmawati et al., 2024). This dynamic spatial arrangement heightens land fragmentation and expands the zone wildland-urban interface, which ultimately increases the probability of triggering fires due to excessive human activity (Guo et al., 2024). From a development economics perspective, the rate of land conversion and the high density of urban activities that are not balanced by resilient environmental governance will increase the potential risk of ecological disasters and regional economic losses cumulatively (Deng et al., 2024).

Although the forest and land fire literature is rapidly evolving, applied evaluation frameworks remain methodologically fragmented: spatial analyses focus on mapping physical hazards without integrating the vulnerability of exposed assets (Parvar et al., 2024), conventional economic assessments assume losses are linear to burned area while ignoring Economic Loss Intensity (ELI) heterogeneity triggering monetary underestimation bias (Asif, 2025) and regional mitigation policies rarely implement Cost–Benefit Analysis (CBA) explicitly to prove the ex-ante fiscal efficiency of preventive allocations over ex-post reactive spending (Colonico et al., 2022). To address this gap in Capital City of Nusantara (IKN) buffer areas, this study offers an integrated methodology connecting physical risk mapping, Index of Fire and Economic Loss (IELK) composite indicators, location-based ELI valuation, and CBA modeling in alignment with the Green Economy Framework. Consequently, the objectives of this research are to analyze the spatial distribution of GIS-based fire risk classes, quantify Total Economic Loss (TEL) and ELI per hectare, classify area severity using the multidimensional IELK index, and evaluate the economic feasibility of proactive fire mitigation investments through CBA modeling.

LITERATURE REVIEW

Forest and land fires in tropical landscapes are driven not only by global climate variability such as El Niño, but are also massively accelerated by land cover transformation and anthropogenic encroachment (Lingga et al., 2024), which expands the wildland-urban interface (WUI) and creates emerging vulnerability hotspots within buffer zones (Guo et al., 2024). Although conventional physical risk mapping primarily focuses on hazard identification through spatial analysis (Makumbura et al., 2024), contemporary spatial paradigms require the integration of asset exposure and vulnerability variables to accurately delineate risk zones in strategic urban areas (Parvar et al., 2024). Unmitigated physical risks directly trigger economic and ecological shocks that suppress long-term productivity and degrade physical and natural capital (Amankwah-Amoah & Debrah, 2025), a condition further exacerbated by unsustainable economic activities and high population density that diminish environmental carrying capacity (Sukumaran, 2022). Consequently, impact assessments can no longer rely solely on calculating total burned area; instead, they demand a spatially heterogeneous framework utilizing ELI and TEL to quantify real monetary losses per hectare across direct use, indirect use, and ecosystem service values (Zhuang et al., 2024).

Responding to high potential losses forest and land fires, the transition to a green economy framework requires active government intervention through policies and public spending oriented towards environmental conservation (Hariyanti et al., 2024). Fiscal expenditure focused on environmental protection and ecosystem preservation functions has been empirically proven to be able to reduce the level of disaster risk while maintaining the sustainability of local economic growth (Husein & Iuchi, 2025). In the realm of public asset governance, green economy instruments can be combined with sustainable financing schemes to support long-term climate mitigation (Raihan & Sarker, 2026). Without sustainable preventive interventions, reactive disaster management financing will actually burden regional budgets and trigger uncertainty and inefficiency of

fiscal allocation (Calcaterra et al., 2026). Therefore, mitigation investment decision-making requires quantitatively tested financial feasibility evaluation tools.
The CBA formulation comes as an analytical framework for comparing preventive cost allocations ex-ante, such as the construction of canal blockage infrastructure, integrated patrols, and an early warning system against potential economic losses that can be avoided (Colonico et al., 2022). Through parameter calculation Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Internal Rate of Return (IRR), CBA modeling provides scientific certainty for policymakers that the fiscal allocation for forest and land fire prevention is not a cost burden, but a form of efficient and economically profitable public investment (Van Coile et al., 2026). To bridge the gap between spatial physical risk mapping and monetary loss valuation, a multidimensional composite indicator such as IELK is needed. This index integrates the weight of spatial physical vulnerability with the intensity of economic losses into a single integrated scale, thus enabling policymakers in strategic areas, such as Balikpapan City and IKN buffer areas, to prioritize intervention areas in a precise, efficient, and evidence-based manner (Soleh et al., 2026).

RESEARCH METHOD

Study Area and Data

This research was carried out in Balikpapan City, East Kalimantan Province, which is located at the coordinates of 1°00′–1°30′ S and 116°30′–117°00′ E with an area of about 50,330 ha. Balikpapan City was chosen because it has a strategic position as the main buffer area of the Capital City of the Archipelago (IKN) with heterogeneous landscapes that include forests, mangroves, shrubs, plantations, and settlements. The observation and collection period of historical data on forest and land fire incidents (karhutla) covers the period from January 2024 to July 2026.

Data Collection

The research data consisted of secondary data and spatial data obtained from the Balikpapan City Regional Disaster Management Agency. The data on forest and land fires included 50 historical incidents (*n=50)* with variables including the time of the incident, the location of the sub-district/sub-district administration, the area affected (A, ha), and the estimated estimate of direct economic losses (DL_i, Rp). The spatial data included a risk map of forest and land fires in Balikpapan City.

Spatial Risk Analysis

Spatial risk analysis was carried out using Geographic Information System (GIS) to identify the level of vulnerability and risk distribution of forest and land fires. The classification of risk levels is divided into three classes (low, medium, and high) according to the standards and criteria of disaster risk assessment of the National Disaster Management Agency (BNPB) (Perka BNPB, 2012). Data on the distribution of actual forest and land fire incidence points further in-*Overlay* by evaluating the level of forest and land fire risk zones.

Economic Loss Assessment

The economic loss assessment is calculated to evaluate the accumulation of direct financial impacts as well as the intensity of losses per unit of land area (Yang & Jung, 2026). Then TEL is calculated by summing the direct losses of all events using the equation:

$$TEL = \sum_{i=1}^{n} DL_i$$

The intensity of ELI is calculated to obtain the value of losses per hectare (IDR/ha):

$$ELI = \frac{TEL}{A}$$

Description: TEL = *Total Economic Loss* (IDR); DL_i = Direct economic loss in the first incident (IDR); *n* = Total forest and land fire incidents (n = 50); ELI = Intensity of economic loss per hectare (IDR/ha); A = Total area affected (12.5314 ha).

Fire and Economic Loss Clustering

To integrate the indicators of occurrence frequency (*N*), area of affected area (*A*), and economic loss (*L*) into one composite variable, indexing was carried out using the Index of Fire and Economic Loss (IELK). Each indicator was normalized first using the Min–Max Normalization method:

$$X_{norm} = \frac{X - X_{min}}{X_{min} - X_{min}}$$

The IELK value is calculated by aggregating all normalized indicators using equal weighting:

$$IELK = \frac{N_{norm} + A_{norm} + L_{norm}}{3}$$

IELK grade categories are classified into three severity clusters: Low (0,00 - 0,33), Medium (> 0.33 - 0.66), and Height (> 0.66 - 1.00) (BNPB, 2021).

Cost–Benefit Analysis

Furthermore, a Cost–Benefit Analysis (CBA) evaluated the feasibility of proactive fire mitigation against avoided economic losses (Mokhtari et al., 2017). Indirect and ecological damages were estimated via the Benefit Transfer approach with a 2.0x disaster-loss multiplier to capture broader economic impacts (Sumaila et al., 2020). Assuming 75% mitigation effectiveness (*n*), a three-year cost allocation (*C*) of IDR 240.00 million, and an 8% annual social discount rate (*r*), key feasibility metrics were computed, including Present Value of Benefits (PVB), Present Value of Costs (PVC), Net Present Value (NPV), and Benefit–Cost Ratio (BCR).

$$PVB = \sum_{i=0}^{n} \frac{B_t}{(1+r)^t} \quad dan \quad PVB = \sum_{i=0}^{n} \frac{C_t}{(1+r)^t}$$

$$NPV = NVB - PVC \; dan \; BCR = \frac{PVB}{PVC}$$

Description: B_t = Benefit of potential losses avoided in year *t* (IDR); C_t = Cost of mitigation program in year *t* (IDR); *r* = Discount rate (8%); *t* = Period of year (2024 – 2026*). An

intervention program is declared economically feasible if the NPV is > 0 and the BCR is > 1.0.

RESULTS

Distribution of Forest and Land Fire Incidence

During the period from January 2024 to July 2026, there were 50 incidents of forest and land fires in Balikpapan City. The fires covered a total affected area of 12.5314 ha with an estimated estimated economic loss of Rp576.77 million. The temporal trend distribution of forest and land fires and their estimated impact are presented in Table 1.

Table 1. Distribution of economic events and losses 2024-2026

Year	Genesis (*n*)	Affected area (ha)	Total loss (IDR)	Average/incidence (IDR)	Loss/ha (IDR)
2024	31	9.7450	487,250,000	15,717,742	50,000,000
2025	12	1.5814	79,070,000	6,589,167	50,000,000
2026*	7	1.2050	10,450,000	1,492,857	8,672,199

Note. The data for 2026 covers the January–July observation period.

2024 will be the period with the highest level of fire intensity, covering 31 incidents or around 62% of the total observed incidents. The area burned in that year reached 9.7450 ha and triggered losses of up to Rp487.25 million. This figure accounted for around 84.5% of the total economic losses during the three years of observation. In 2025, the frequency of fires will decrease significantly to 12 incidents with a total affected area of 1.5814 ha and a loss value of Rp79.07 million. Most incidents in 2025 will be small-scale, although there was one fairly large incident in West Balikpapan that hit an area of 1 ha with losses reaching around Rp50 million. Meanwhile, in the January-July 2026 period, 7 incidents were recorded with an affected area of 1.2050 ha and a loss of IDR 10.45 million. Losses in 2026 have not presented a complete annual loss considering the observation period in January-July.

Spatial Concentration of Fire Occurrence

The spatial distribution of forest and land fire incidence varies significantly between sub-districts in Balikpapan City. The concentration of the main events identified is in South Balikpapan and East Balikpapan Districts. Based on Table 2, details of spatial distribution and economic impact.

Table 2. Incidence clusters by sub-district

Districts	Genesis (*n*)	Area (ha)	Total loss (IDR)	Average incidence (IDR)
South Balikpapan	29	7.4720	330,350,000	11,391,379
East Balikpapan	9	3.8500	186,000,000	20,666,667

West Balikpapan	1	1.0000	50,000,000	50,000,000
North Balikpapan	8	0.1590	8,350,000	1,043,750
Central Balikpapan	3	0.0504	2,520,000	840,000

South Balikpapan is the main hotspot for forest and land fires with 29 incidents (58% of the total incidents) and contributed losses of IDR 330.35 million. The accumulation points of forest and land fire incidents are mainly centered in Sepinggan Village at 15 points, and Sepinggan Baru at 8 points, with several major incidents such as fires in the 1 ha area in the two villages in April 2024.

East Balikpapan ranks second with 9 incidents and a total loss of IDR 186 million. Although the frequency of incidents is lower than South Balikpapan, the average loss per incident in East Balikpapan is much higher, reaching IDR 20.67 million/incident. This indicates that the high frequency of fires is not always directly proportional to the magnitude of the economic impact per incident.

In West Balikpapan District, although only 1 incident was recorded (Kariangau Village, September 2025), the area burned reached 1 ha with a direct loss value of IDR 50 million. As for North Balikpapan (8 incidents) and Central Balikpapan (3 incidents), fires tended to be micro-scale of 0.002–0.01 ha per incident in locations such as Karang Joang, Muara Rapak, Batu Ampar, and Graha Indah.

Cluster of Event Intensity and Economic Losses

To integrate the indicators of frequency (N), affected area (A), and economic loss (L), the IELK calculation is carried out using Min–Max normalization. The results of the grouping of areas based on IELK values are presented in Table 3.

Table 3. IELK index and classification of forest and land fire intensity clusters per sub-district

Districts	EACH	Cluster
South Balikpapan	1.000	Height
East Balikpapan	0.452	Medium
North Balikpapan	0.094	Low
West Balikpapan	0.091	Low
Central Balikpapan	0.024	Low

Note. Low (0.00 - 0.33), Medium (> 0.33 - 0.66), and High (> 0.66 - 1.00)

South Balikpapan is classified into the High cluster (IELK = 1.000) because it consistently dominates all parameters (number of incidents, area burned, and loss value). East Balikpapan District is in the Medium cluster (IELK = 0.452), while North Balikpapan, West Balikpapan, and Central Balikpapan Districts are classified as Low (IELK < 0.33). The application of this composite index confirms the importance of a multidimensional approach in mapping disaster mitigation priorities (Mavhura et al., 2021).

Spatial Risk Mapping of Forest and Land Fires

The mapping results show that the medium to high risk areas dominate the southern and eastern areas of the city, which are directly adjacent to the centers of development and residential activities. On the other hand, the northern and western parts tend to be dominated by low to medium risk classes. The spatial distribution of the risk class of forest and land fires in Balikpapan City is presented in Figure 2.

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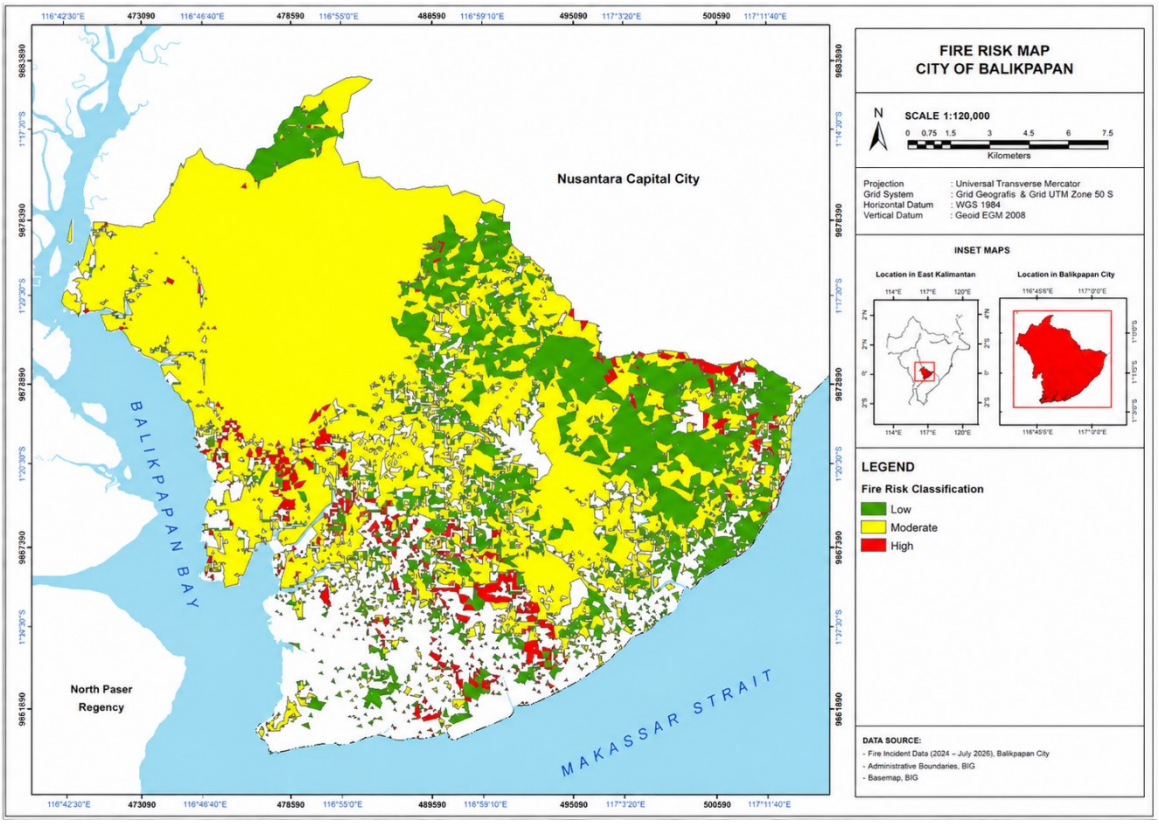

Figure 2. Map of the Balikpapan City Disaster Risk

Economic Loss Assessment

Between 2024 and July 2026, Balikpapan City recorded 50 forest and land fire incidents resulting in IDR 576.77 million in direct economic losses, averaging IDR 11.54 million per incident with an aggregate loss intensity of IDR 46.03 million/ha. Spatially, South Balikpapan registered the highest total economic loss (IDR 330.35 million; ELI of IDR 44.21 million/ha) driven by high incident frequency, whereas East Balikpapan suffered the highest average loss per event (IDR 20.67 million/incident). These spatial disparities prove that economic fire impacts are inherently multidimensional shaped by spatial vulnerability, economic concentration, and exposed asset values rather than burned area alone thereby reinforcing the need to evaluate fire risks simultaneously across frequency, spatial distribution, asset density, and loss intensity.

Cost–Benefit Analysis

The economic feasibility of the investment in forest and land fire prevention mitigation programs is compared to the potential for avoidable losses. The calculation integrates a total direct loss of IDR 576.77 million from 50 incidents (2024–July 2026) as well as an estimated impact of ecological/indirect losses with a multiplier of 2.0 times, so that the total impact of unmitigated losses is estimated at IDR 1,730.31 billion. The modeling assumes a proactive mitigation effectiveness rate of 75%, the cost allocation of prevention program (C) of IDR 240 million over three years, and the social discount rate (r) of 8% per year.

Table 4. Matrix of cost allocation, avoidable losses, and CBA feasibility indicators for forest and land fire mitigation (2024–2026).

Parameters	Jan-Dec 2024 (T0)	Jan-Dec 2025 (Q1)	Jan-June 2026 (T_{2^*})	Aggregate
Direct Economic Loss (IDR)	487,250,000	79,070,000	10,450,000	576,770,000
Total Loss (Direct + Ecological) (IDR)	1,461,750,000	237,210,000	31,350,000	1,730,310,000
Avoidable Benefits / B_t (75%) (IDR)	1,096,312,500	177,907,500	23,512,500	1,297,732,500
Mitigation Program Fee / C_t (IDR)	120,000,000	60,000,000	60,000,000	240,000,000
Discount Factor (r= 8%)	1.0000	0.9259	0.8573	
Present Value Benefit (PVB) (IDR)	1,096,312,500	164,729,167	20,158,179	1,281,199,846
Present Value *Cost* (PV) (IDR)	120,000,000	55,555,556	51,440,329	226,995,885
Net Present Value (NPV) (IDR)				1,054,203,961
Benefit–Cost Ratio (BCR)				5.64

DISCUSSION

The pattern of forest and land fires in Balikpapan has accumulated spatially clustered, with the dominance of incidents in coastal and urban areas in the south. The overlapping of GIS proves that the actual fire points are directly adjacent to high-risk zones dominated by shrub cover adjacent to settlements. As a buffer area for the IKN, the massive infrastructure expansion has been proven to trigger land fragmentation and expand the zone WUI. From a comparative perspective, the pattern of spatial clusters strengthens the theory of spatial autorelations of (Anselin, 1995). Increased fire risk in vegetation-settlement boundary zone conceptually reinforces the findings Radeloff et al., (2018) regarding WUI dynamics and environmental vulnerability.

The economic assessment in this study proves that the area burned is not the sole determinant of the amount of financial loss. Through the ELI indicator, the results found that a very limited area of fire (<0.2 ha) in North Balikpapan actually resulted in the highest value of loss per hectare due to the high exposure of residential assets and productive facilities. The grouping based on the IELK composite index also succeeded in mapping South Balikpapan in the high-risk cluster and East Balikpapan in the medium cluster. These empirical findings directly support Soontha & Bhat, (2024), which states that forest and land fire losses are largely determined by the type of land cover and density of the affected assets, not just geographical measures. The use of the IELK composite index to capture multidimensional risks reinforces the view Page et al., (2002). Regarding the importance of including economic assessment variables in spatial risk analysis to prevent estimation bias.

Our CBA evaluation provides quantitative evidence that the allocation of the preventive mitigation budget for three years resulted in a positive NPV and a BCR of 5.64. These results show that each budget allocation for early prevention activities (such as GIS

monitoring, patrols, and the establishment of Fire Care Communities) is economically able to avoid potential losses of up to more than five times the costs incurred. Evidence of fiscal efficiency from the preventive investment confirms the conclusion (Abilasha & Karthikeyan, 2025) and reports (World Bank, 2019), which confirms that the proactive mitigation approach is much more financially profitable than the reactive blackout approach. The use of this potential loss saving effectiveness ratio is also in line with the disaster budget efficiency analysis framework developed by (Mechler, 2016).

The tactical implications of these findings lead to the need to reorient the allocation of mitigation financing budgets based on IELK clusters. The results of the synthesis of spatial risk mapping and ELI are recommended to be formally integrated into the Regional Spatial Plan (RTRW) and Detailed Spatial Plan (RDTR) documents of Balikpapan City to determine buffer zone which limits land conversion in high-risk areas. Macro-wise, the integration of risk mapping into spatial planning instruments supports the Green Economy Framework for IKN buffer areas. The spatial risk-based zoning control strategy is in line with landscape governance recommendations from J. Liu et al., (2025), Policy concepts developed by Yuwati et al., (2026) on the application of economic instruments in the form of environmental incentives to support Zero Burning Policy reinforcing the concept Performance-based governance in community-based forest and land fire management.

CONCLUSION

This study successfully integrates GIS spatial analysis, Economic Loss Assessment, and CBA to evaluate the impact of forest and land fires in Balikpapan City for the period 2024-July 2026. The results of the study confirmed that 50 incidents that devoured an area of 12.53 ha triggered direct losses of Rp576.77 million, with the largest risk concentration being in South Balikpapan District (IELK = 1.000) and loss intensity (ELI = Rp44.21 million/ha). The calculation of economic feasibility proved that the allocation of proactive mitigation investment of Rp240.00 million was very feasible by producing a positive NPV of IDR 1.05 billion and a BCR of 5.64. This finding emphasizes that the area of the burned area is not the only determinant of financial impact, so the integration of economic valuation into spatial risk mapping is a very crucial policy instrument in supporting the Green Economy Framework and spatial planning in Balikpapan City as a strategic buffer area for the IKN that is safe from the kahutlah.

DECLARATION OF CONFLICTING INTERESTS

The authors declare that they have no conflict of interest regarding the publication of this article.

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