FOLLOWING FRONTIERS OF THE FOREST CITY:

Unravelling Disaster Risks Information at Ibu Kota Nusantara (IKN) and Beyond

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interlude

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PREFACE

Disaster risk management is becoming increasingly crucial as the world experiences unprecedented urban development and environmental challenges. "Following Frontiers of the Forest City: Unraveling Disaster Risk Information at IKN and Beyond" seeks to bridge the gap between innovative urban planning and the importance of disaster resilience, particularly in light of expanding cities and emerging environmental threats. This connection is essential, as urban growth frequently overlooks vital factors such as climate vulnerability, potential natural disasters, and the overall resilience of infrastructure. There is a pressing need to develop cities that not only thrive but also withstand various threats. The concept of a "Forest City" represents a holistic approach to urban planning by integrating green spaces, sustainable architecture, and eco-friendly practices, thereby enhancing livability and minimizing the impact of disasters. This trend underscores the necessity of ensuring that disaster risk information is both accessible and actionable.

At a time when bolstering resilience is crucial, this book makes a significant contribution to the ongoing dialogue surrounding disaster risk reduction and sustainable urbanization. It synthesizes knowledge of risk information, ecological conditions, and hazard dynamics to present a comprehensive perspective on disaster risks, including forest fires and floods. This book delves into the interplay of spatial analysis, remote sensing, and advanced analytical tools to examine how environmental variables contribute to disaster events. It also discusses how these insights can inform more adaptive and sustainable strategies. Beyond addressing the scientific and technical dimensions, the book aims to offer practical approaches that will foster a vision for a resilient and sustainable future for IKN and its surroundings.

We extend our heartfelt gratitude to the Ministry of Education, Culture, Research, and Technology (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi) and the Indonesia Endowment Fund for Education (Lembaga Pengelola Dana Pendidikan - LPDP) for their financial support through the PRPB funding scheme, part of the Merian Fund, Cooperation Indonesia - The Netherlands. This funding has been crucial in supporting the Following Frontiers of the 'Forest City' research consortium to produce knowledge related to sustainable and inclusive urbanization in Kalimantan and beyond.

We hope this book will serve as both a reference and an inspiration for researchers, policymakers, and communities committed to building resilience and sustainability in IKN and beyond.

Authors

GLOSSARY

Deforestation	The permanent removal or clearing of forests for non-forest land uses, such as agriculture, settlements, or other purposes which leads to a significant loss of forest cover (FAO, 2020).
Elevation	Elevation is the height of a point measured above a reference surface which is typically sea level. In the geospatial context, elevation information is a fundamental element in several applications, such as topographic mapping, spatial planning, and disaster risk analysis (Prasetyo, 2014).
Ecohydrology	Ecohydrology is an innovative approach that integrates ecological and hydrological aspects to manage water resources sustainably.
Erosion	The concept is defined as the erosion of soil or rock by water, wind, or human activities, which can reduce soil fertility and increase risk of disasters (Morgan, 2009).
Forest City	The urban proposals integrate infrastructures and local vegetation from the ecosystem used in the building process. The ecosystem of city is dominated by forest vegetation and has achieved integrated urban and rural development through ecological constructions (Liaio, 2021).
Frontier	An area or source of unusually abundant natural resources and land relative to labor and capital. "Transitional spaces where political authorities and social and environmental relations of the recent past are currently being challenged by new

	enclosures, territorializations, and property regimes" (Peluso and Lund, 2011 in Hein et al., 2016).
Hydrometeorology Disaster	Hydrometeorological disasters are events caused by atmospheric and hydrological phenomena, such as floods, droughts, storms, and landslides. These disasters occur due to disruptions in the hydrological and atmospheric cycles affecting climate and environmental stability (Sari et al., 2023).
IKN	Ibu Kota Nusantara (The new capital city of Indonesia in East Kalimantan).
Inclusive city	A city that provides equal access to social, economic, and political opportunities for a wide variety of urban residents without prejudice to economic status, gender, race, ethnicity, or religion (Elias, 2020).
Indigenous communities/ people	"Distinct social and cultural groups that share collective ancestral ties to the lands and natural resources where they live, occupy or from which they have been displaced" (World Bank, 2022).
Infiltration	The movement of water from the surface into the soil is essential for maintaining the balance of the hydrological cycle and reducing runoff (Ward & Trimble, 2004).
Megathrust	A collision zone between tectonic plates that has the potential to generate large earthquakes with high destructive power (Lay & Kanamori, 1981).
Remote sensing	A technology that enables the collection of data related to the surface of the Earth using satellites or aircraft without direct contact (Lillesand, Kiefer & Chipman, 2015).

Sedimentation	The process of depositing materials such as sand, silt, or gravel by the action of water or wind, which can influence river and coastal morphology (Walling & Fang, 2003).
Transmigration	"The transfer of population in Indonesia from the islands of Central Java, Madura, Bali, and Lombok to the outer islands under government sponsorship" (MacAndrew, 1978).
Urbanization	"The process wherein urban living patterns supersede rural living patterns" (Murayama & Estoque, 2020). "The transformation of a lightly populated open country or rural areas into dense concentrations of people, characterized by the expansion of population from central cities and the migration of people from other areas" (Grolier, 1987).
Zero Burning	Land management that does not use open burning approaches to clear logging residues (Nugroho, 2012). The process has the ability to reduce greenhouse gas emissions produced from burning biomass (Dwijanarko et al., 2020).

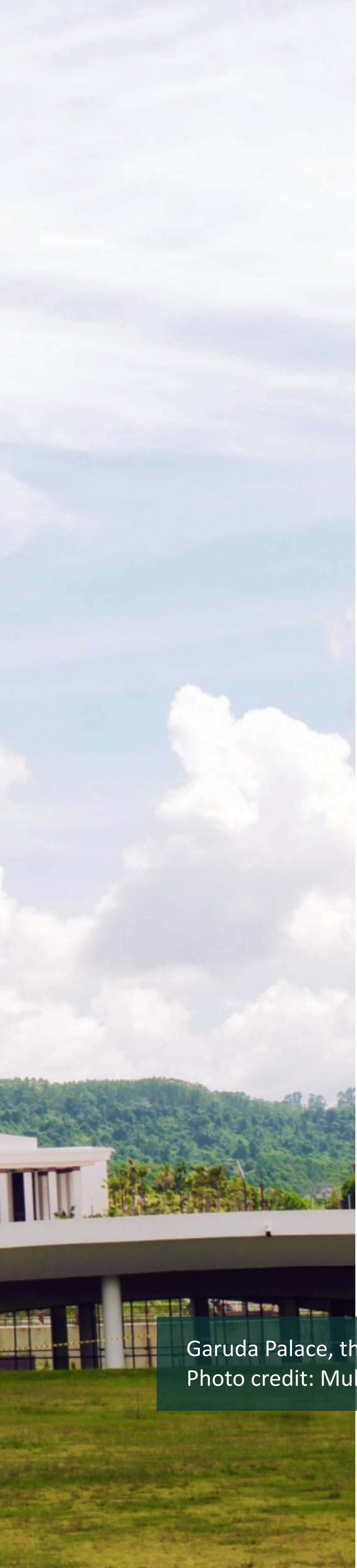
ABBREVIATIONS

AATHP	Agreement on Transboundary Haze Pollution
ARI	Acute Respiratory Infections
ASEAN	Association of Southeast Asian Nations
BAPPENAS	Badan Perencanaan Pembangunan Nasional (National Development Planning Agency)
BGI	Blue Green Infrastructure
BMKG	Badan Meteorologi, Klimatologi, dan Geofisika (Meteorology, Climatology, and Geophysics Agency)
BNPB	Badan Nasional Penanggulangan Bencana (The National Disaster Management Agency)
BPBD	Badan Penanggulangan Bencana Daerah (Regional Disaster Management Agency)
BPS	Badan Pusat Statistik (Central Statistical Agency)
CHIRPS	Climate Hazards Center InfraRed Precipitation
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
ESDM	Kementerian Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources)
ENSO	El Niño-Southern Oscillation
GEE	Google Earth Engine
GIS	Geographic Information System
GRDP	Gross Regional Domestic Product
IKN	Ibu Kota Nusantara
IoT	Internet of Things
IRBI	Indeks Risiko Bencana Indonesia (Indonesia Disaster Risk Index)
KIPP	Kawasan Inti Pusat Pemerintahan (IKN core area)
LNG	Liquefied Natural Gas

LST	Land Surface Temperature
MASL	Meters Above Sea Level
MoEF	Ministry of Environment and Forestry
MMP	Masyarakat Mitra Polhut (Forestry Police Partner Community)
MPA	Masyarakat Peduli Api (Fire Care Community)
MRP	Mega Rice Project
NDVI	Normalised Difference Vegetation Index
OSM	Open Street Map
PKN	Pusat Kegiatan Nasional (National Activity Centres)
PVMBG	Pusat Vulkanologi dan Mitigasi Bencana Geologi (Centre for Volcanology and Geological Hazard Mitigation)
PUPR	Pekerjaan Umum dan Perumahan Rakyat (Ministry of Public Works and Public Housing)
RBI	Risiko Bencana Indonesia (the Indonesian Disaster Risk)
RDP	Regional Development Plan
RWH	Rain Water Harvesting
TIM	Topographic Index Modification
TWI	Topographic Wetness Index
UNDRR	United Nations Office for Disaster Risk Reduction
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WSUD	Water-Sensitive Urban Design
WRI	World Resources Institute

1 Introduction

The relocation of the capital city from Jakarta to Ibu Kota Nusantara (IKN) in the Penajam Paser Utara and Kutai Kartanegara Regencies of East Kalimantan was officially announced by the Government of Indonesia in 2019 and the celebration was conducted during the Independence Day on 17 August 2024. The IKN area envisions a “Forest City” that retains 75% of the area as green space and the construction of government and commercial buildings with strict compliance with strict environmentally friendly principles (Ibu Kota Nusantara, 2025). The main reason for the relocation was for the alleviation of the environmental problems of Jakarta such as the pollution experienced due to over-exploitation of resources (Erlis Saputra, 2019) which led to increasing hydrometeorological disaster risks (Susanti et al., 2022). The selection of the site for the new capital city was based on the consideration of disaster risk in the region. The IKN in Penajam Paser Utara and Kutai Kertanegara Regencies selected has a stable geological formation, low seismic activities, and a relatively low risk for natural disasters (Putri, 2022).



Garuda Palace, the Presidential Palace at IKN
Photo credit: Muhammad Qoirul Purwanto

The East Kalimantan landscape has experienced significant transformation mainly due to land-based extractive industries which have been the main source of income for the region (BPS, 2023b). The process has led to the harvest of forests to serve other sectors with a specific focus on agricultural expansion of oil palm (van der Laan, 2016). This is observed from the fact that a substantial portion of forest areas are presently occupied by monoculture oil palm plantations (Auriga, 2019). Reports showed that East Kalimantan lost a significant portion of the primary forest cover between 2001 and 2012 (Margono et al., 2014) and the areas have been continuously decreasing. The layers of complexity in the landscape dynamics were further increased by the development of the new capital city.

The massive conversion for other land cover or use affected the unique biodiversity-rich tropical forests of East Kalimantan (Spencer et al., 2023), including the indigenous people (E. Saputra et al., 2023; Erlis Saputra et al., 2022) which further increased the Eco-environment Vulnerability Index (Kurniawan et al., 2022). An example is the recurrent occurrence of forest fires due to land clearing and peat drainage during the process of establishing new plantations (Syaufina, 2018). In 2015, significant fire events were recorded in the region which led to adverse impacts on social activities and the environment (Budisulistiorini et al., 2018; Forsyth, 2014; Hansen & DeFries, 2007b; Varkkey, 2015). Recently, there were hydrometeorology-related disasters such as landslides, floods, forest fires, and extreme weather events that affected more than 14,000 inhabitants in 2021 (BPS, 2022a, 2022b; Kumalawati et al., 2023).

Climate change can intensify disaster events on the heavily extracted landscape of East Kalimantan and impede the process of sustainable urbanization in IKN (Shimamura & Mizunoya, 2020). The events can further damage important infrastructures in city and disrupt the functions of roads, buildings, and water distribution pipes (Heo et al., 2024). There is also the possibility of experiencing substantial urban environmental damages and degradation to green and blue infrastructures (Rachmawati et al., 2024). These impacts can cause a significant economic burden for recovery through the diversion of budget allocation for sustainable development projects to achieve long-term goals (Nguyen et al., 2024).

The provision of information related to disaster risks in urban areas can contribute to the process of sustainable urbanization. The understanding of the vulnerabilities and risks associated with urban areas is also capable of contributing to the development of risk-informed planning and mitigation strategies. The process can ensure the integration of disaster risk reduction into urban development plans to enhance resilience and sustainability (Macatulad & Biljecki, 2024). Moreover, advanced technology has the capacity of contributing significantly to the enhancement of disaster management through improved data collection, analysis, and early warning systems to inform decision-making and support sustainable urbanization (Elshoukry, 2024). There is also a need to disseminate information through effective communication channels to enhance community engagement and preparedness (Muhame et al., 2024).

2 Understanding Risk Information

Risk information in the context of disaster and territorial governance refers to data and knowledge processed to understand the potential hazards, vulnerabilities, exposures, and capacities of an area or community. This information serves as the basis for making informed decisions related to mitigation, preparedness, emergency response, and post-disaster recovery efforts. The term “information” is defined as the data processed with a context to provide value for the recipient. In risk management, the provision of relevant information is capable of developing appropriate actions, policies, or strategies. The United Nations Office for Disaster Risk Reduction (UNDDR, 2015) showed that risk information covered all data and knowledge related to natural hazards, exposure levels, socio-economic vulnerability, and community capacity to respond to potential disasters. Philosophically, the term “information” originates from the Latin 'informare' which is interpreted as “to give form” or “to shape”. Floridi (2011) explained that information was not a static entity but a

Mining Area in Muara Jawa
Photo credit: Wisnu Hasan

process of shaping understanding, constructing meaning, and developing structure in human knowledge. The trend shows that statistical data on rainfall or earthquake frequency can only be classified as risk information after interpretation to provide actions in the form of risk maps, early warning systems, or zoning policies. Therefore, risk information is often produced through the interaction between scientific data, social values, and spatial context. The understanding of this philosophical basis is important to ensure risk information is not treated merely as a technocratic product but as a reflective tool for building community resilience.

The concept of risk information has grown significantly over time due to the continuous development in disaster management. Initially, it was interpreted strictly as technical scientific reports about potential natural hazards such as earthquake intensity or flood discharge. The definition is perceived to be reactive due to the lack of consideration for the social and institutional dimensions of risk. The influence of international frameworks such as the Hyogo Framework for Action (2005-2015) and the Sendai Framework for Disaster Risk Reduction (2015-2030) in the early 2000s started to shift the understanding of risk information. The concept is currently viewed as part of a broader risk governance system that includes risk communication, public participation, as well as the integration of spatial and social data into the decision-making process.

Multidimensional approaches to risk assessment are increasingly being adopted but there is a strong argument that the dependence of the process solely on physical aspects remains relevant and applicable in several disaster contexts, specifically during the early stages of spatial and technical decision-making. The preference for the approach is associated with several reasons and the first is that physical data is objective, measurable, and systematically computable, leading to an ease in mapping risks quantitatively and visually. This is possible because variables such as rainfall, slope, soil type, and land use can be easily collected and analyzed through geospatial approaches. Mohammady et al. (2012) and (iswajeet & Saro (2007) also reported that advances in remote sensing and GIS technology enabled accurate and efficient spatial modelling of risk. The second is that the approach is resource-efficient in terms of time, cost, and effort. Several areas with limited capacity for social or economic data use biophysical data as a practical and reliable option. For example, Tien Bui et al. (2012) showed that physically-based approaches proved effective in spatial planning and disaster risk zoning in developing countries. The third is that disasters do not occur without certain triggers and physical environmental conditions. For example, landslides are highly dependent on land slope, rainfall, and soil characteristics. The trend shows that assessments based on physical variables are a logical step in detecting and anticipating disaster events (Kamp et al., 2008; Yilmaz, 2009). The final aspect is that physical-based risk information has high technical evidentiary value in terms of structural mitigation policies and infrastructure development. Akgun et al. (2008) explained that geospatial risk models developed based on topographic and geological data could provide more accurate and technically responsible decision support for critical infrastructure projects.

Social and economic dimensions are important for framing the overall vulnerability but only a physical-based risk approach is sufficient to provide the basis for robust, efficient, and scientific mitigation policies in several operational, technical, and early decision-making contexts. Risk information obtained through biophysical variables such as rainfall, slope, soil type, and land use can provide a clear initial picture of potential hazards, specifically when visualized through geospatial technology. This approach enables quick and accurate presentation of data to support spatial planning and the establishment of disaster-prone zones.

The approach was systematically adopted in Indonesia through the development of the InaRISK platform and the Indonesian Disaster Risk Index (IRBI) by the National Disaster Management Agency (BNPB). The InaRISK is an interactive map-based disaster risk information system supported by Geographic Information System (GIS) and Internet of Things (IoT) (Suharini et al., 2023). The system integrates three main components, including hazard, vulnerability, and capacity but practically depends more on spatial and biophysical data as the main basis for mapping. This was in line with the observation of Shortridge et al. (2017) that risk could be reliably estimated without socio-economic data provided spatial and biophysical data were available and used systematically. The trend shows that the physical approach is a valid, efficient, and adaptive scientific basis for building early warning systems and risk zones.

The report of the Indonesian Disaster Risk Book (RBI) by BNPB (2023) showed that the initial and main components of hazards in InaRISK were based on objective environmental and geological data such as land use, rainfall intensity, historical disaster events, topography, and soil classification. This approach is very useful, specifically in areas where socio-economic data is limited, by allowing valid risk analysis to support mitigation policies, infrastructure development, and spatial planning (Azizah et al., 2022; Silfira & Rahman Saleh, 2023). Moreover, InaRISK supports the utilization of scientific information in the decision-making process, both at the central and regional levels. The platform also ensures disaster risk reduction planning and programs (BNPB, 2025) while expanding public participation through the provision of risk visualizations that are easily accessible and understood by different stakeholders. This shows that ideal disaster risk information systems can holistically integrate social, economic, and institutional dimensions but the physical-based approach remains a strategically valuable and technically feasible foundation for initial implementation.

3 Kalimantan Island and Its Environmental Challenges

Kalimantan is one of the five major islands in Indonesia considered relatively geologically stable compared to others such as Sumatra, Java, and Sulawesi. However, some major challenges are identified in terms of natural disasters with a specific focus on hydrometeorological aspects even though the region is not directly located in an active subduction zone (Wahyuningtyas & Pratomo, 2015). The challenges are closely related to climatic conditions and increased human activities. The trend of disaster events in Indonesia has significantly increased in the last decade, specifically from 2014 to 2023. This is observed from the 5,400 disasters recorded across the country according to the BNPB Disaster Data Book 2023. Approximately 99.35% were identified as hydrometeorological disasters caused by meteorological and hydrological factors such as high rainfall, strong winds, extreme temperatures, and changes in hydrological conditions on the land surface and rivers. This category includes floods, landslides, extreme weather, as well as forest and land fires (BNPB, 2024).

Mahakam Bridge
Photo Credit: Gery Novrian

The continuous occurrence of disaster events is associated with increasingly complex environmental pressures, specifically due to land use change, uncontrolled urbanization, and over-exploitation of natural resources. In several areas such as Kalimantan, massive deforestation for plantations and mining reduces the ability of forest areas to absorb and store water. This has led to a dramatic increase in risk of floods and landslides, particularly during the rainy season when rainfall intensity becomes more unpredictable due to global climate change.

The BNPB Disaster Data Book 2023 showed that the three most frequent types of disasters were forest and land fires with 2,051 events, extreme weather at 1,261, and floods with 1,255. The trend is an indication that climate change and environmental degradation have increased risk of Indonesia to ecological and climate-related disasters, with Kalimantan identified as one of the most at-risk regions. The observation was consistent with the results of several previous research by Djalante (2018), Fuady et al. (2021), and Kusumastuti et al. (2014) that showed the inability of the infrastructure and disaster risk mitigation system in the country to keep pace with the acceleration of climate change and environmental damage.

Indonesia is geologically situated at the intersection of the four major tectonic plates in the world, including the Eurasian which covers the Asian Continent, the Indo-Australian, the Pacific, and the Philippine Sea. The conditions show the Indonesian region is very tectonically active which leads to the constant threat of earthquakes and volcanic activity in several areas. The Ministry of Energy and Mineral Resources (ESDM,

2020) reported that 127 active volcanoes were spread along the Ring of Fire, and 70 were classified as very active and continuously monitored by the Centre for Volcanology and Geological Hazard Mitigation (PVMBG). In 2024, 19 mountains were in Level II (Alert) status which signaled an increase in volcanic activity considered capable of potentially leading to eruptions at any time (Dewi, 2024).

Geological disasters such as earthquakes are increasing in the country and the number was reported by Sabtaji (2020) to be at an average of 6,512 per year from 2009 to 2019. This is equivalent to approximately 543 earthquakes per month or 18 per day. Moreover, the data from BMKG showed a further increase from 2021 to 2023. The report identified 2021 as the year that recorded the highest number of earthquakes in the monitoring history with 11,386 events and 27 were classified as destructive. There were 10,792 events in 2022 and the number increased to 10,983 in 2023 with 219 large-sized at ≥5.0 magnitude, 861 were experienced by the public, and 10,570 were classified as small.

Indonesia is highly vulnerable to tsunamis with 416 events recorded in the territory based on the Indonesian Tsunami Catalogue 2017. Most tsunamis occurred in southern Indonesia, particularly along the coasts of Sumatra, Java, Bali, and Nusa Tenggara which are considered to have proximity to active subduction zones such as the megathrust. Moreover, submarine volcanic eruptions could cause tsunamis as reported in the 2018 Sunda Strait event which was triggered by the eruption of Mount Anak Krakatau (Anwar, 2021).

Kalimantan is relatively safe from significant seismic and volcanic activity threats but not free from disaster risks. This is observed from the frequent occurrence of major challenges associated with hydrometeorological disasters such as floods, landslides, as well as forest and land fires compared to geological disasters. The ecological characteristics of Kalimantan which include several areas with peatlands, extensive rivers, and large forests lead to the high sensitivity of the region to climate change and human activities.

The report from the (BNPB, 2024) showed that Kalimantan experienced 1,709 disaster events in 2023 and was the region with the third highest number after Java and Sumatra. In terms of percentage, Java Island had 34% of the total events followed by Sumatra 25%, Kalimantan 22%, Sulawesi 10%, Bali-Nusa Tenggara 6%, and Maluku-Papua 3% based on the national disaster distribution. Disasters in Kalimantan were mostly dominated by forest and land fires with 1,288 events, floods 278, landslides 69, extreme weather 63, as well as earthquakes and high waves or tsunamis which were relatively rare (Figure 1).

Forest and land fires were found to be the most dominant disaster on the island of Kalimantan in 2023 (Figure 1). This can be because Kalimantan has a vast forest area specifically in Central Kalimantan which covers approximately 7.1 million hectares of natural forest. According to UNDRR (2024), Kalimantan experienced the highest rates of extensive and repeated fire incidents and this showed that the region had a very high rate of disaster. The main causes of forest fires were divided into two categories, including natural and anthropogenic

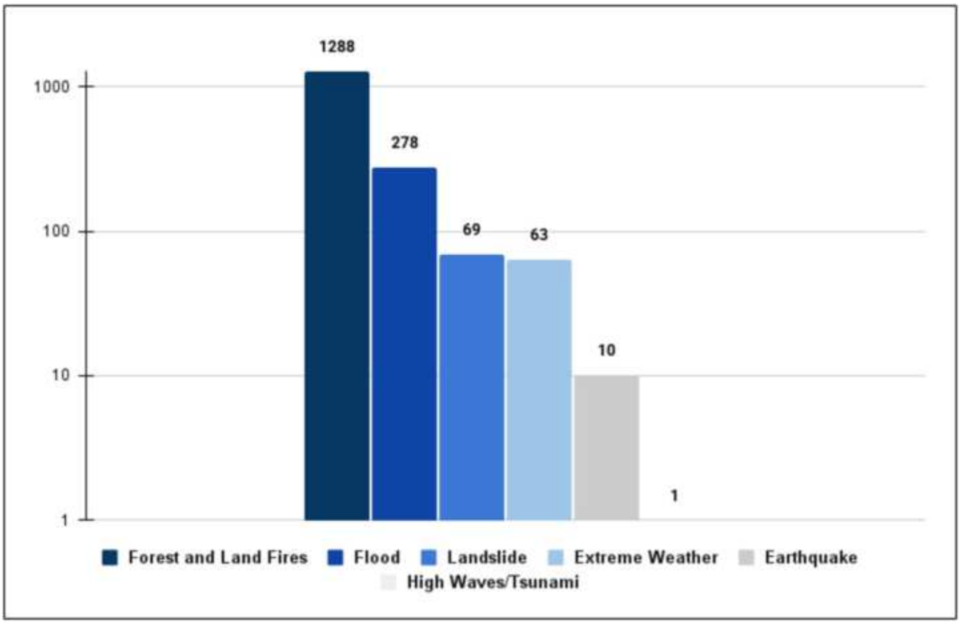


Figure 1. Number of Natural Disaster Events in Kalimantan by Type of Disaster in 2023

Source: Data from BNPB in BPS statistics of East Kalimantan, 2023

factors (Susanti et al., 2022). The natural factor is related to the long dry season with high temperatures and low humidity naturally which makes peatlands highly flammable.

However, most forest fires in Kalimantan were associated with human activities in the form of land clearing through burning by companies holding concession licenses (Saharjo & Hasanah, 2023). The preference for burning was because the approach was considered faster and more cost-effective than the application of heavy equipment and the employment of a larger number of laborers (A. W. Putri, 2019). The practice is further exacerbated in the community by the people who offer financial incentives to residents to set fires intentionally. This shows economic factors as the primary driver for the action despite the awareness about the negative environmental impact (Farisa, 2021). Pamungkas et al. (2024) also identified carelessly discarded cigarette butts as a significant contributor to forest fires in Kalimantan.

Moreover, the conversion of forested areas to plantations was another significant factor because companies and people often used burning approaches to clear land quickly and affordably. The impacts of forest fires are far-reaching, both locally and internationally. The cases in Kalimantan trigger a haze crisis which further leads to air pollution in addition to environmental destruction and biodiversity loss. The impact extends beyond Indonesia to neighboring countries such as Malaysia, Singapore, and Brunei Darussalam. International environmental organizations such as Greenpeace have warned the Indonesian government regarding the increasing cases of forest fires between 2015 and 2019. The report “Synchronization of Short-Term Development Programs and Financing 2018-2020 Integrated Regional Development with PUPR Infrastructure Kalimantan Island” showed that forest and land fires in Kalimantan occur almost every year with relatively high intensity during the dry season (Sosilawati et al., 2016). The situation often leads to different negative impacts at all levels, ranging from local to national and regional.

The second most frequent disaster in Kalimantan Island is flooding with 278 events recorded in 2023 (Figure1). Kalimantan is known as the “Island of a Thousand Rivers” which reflects the existence of several rivers flowing through the region. The term is a common descriptor of the region and also reflects the geographical reality as an extensive and winding river network naturally acting as a drainage system for surface water (Anastasya & Wilantika, 2023; Susilowati, 2011). The number of rivers can mitigate risk of flooding but Kalimantan remains threatened by disaster due to natural conditions and human activities. Previous research showed that the island tended to have flat topography and the historical development of cities and communities along the river systems exacerbated risk of flooding (Satar, 2022). Furthermore, the occurrence of heavy rainfall throughout the year particularly during the rainy season is a significant trigger for flooding. The inundation is also increased by the poor urban drainage systems while land conversion due to plantation and mining expansion reduces soil absorption. These processes increase surface runoff which leads to the overflow of major rivers such as the Mahakam and Barito Rivers. Another important observation is that Kalimantan is largely dominated by peat soils and is expected to absorb large amounts of water. However, the degradation caused by land drainage and forest fires has reduced the capability of the soil to hold water which accelerates flood flows and worsens the impact.

Landslides and extreme weather are the other frequent disasters in Kalimantan with 69 and 63 events recorded respectively in 2023 (Figure 1). The occurrence of landslides is typically in areas with steep slopes because uncontrolled land use change such as the development of agriculture and settlements in hilly areas renders the soil highly unstable, specifically when combined with high rainfall (Darmatazia et al., 2022). The instability of soil conditions increases risk of landslides, particularly when natural vegetation which normally stabilizes the soil is removed through mining and extensive land clearing (Dirgantara & Rahayu, 2023).

Climate change triggers extreme weather such as strong winds, rainstorms, and tornadoes. The impact includes damage to infrastructure, disruption of electricity and transportation, as well as increased risk of flooding and landslides due to high-intensity rain in a short period. The mitigation of the two disasters requires reforestation of landslide-prone areas, the use of terracing approaches and strengthening infrastructure to withstand extreme weather. There is also a need for the improvement of land use monitoring and early warning systems to minimize the impact of future disasters.

Kalimantan experienced 10 earthquake events in 2023 (Figure 1) because of the several active faults that are capable of triggering mild to medium earthquakes despite the relatively low tectonic activity in the region compared to the others in Indonesia. According to Adip Mustofa, a geologist from Lambung Mangkurat University (ULM), earthquakes in Kalimantan are caused by the shifting of rock faults on the Pacific plate (Aritonang, 2024). The region is also located between five of the active tectonic plates in the world whose movement can trigger seismic activity (Rusmilawati et al., 2019). Several major faults such as the Lupar-Adang and the Mangkalihat were formed due to the collision between the Indian and Eurasian Plates in addition to the activity in the South China Sea. The Adang Fault is still active but relatively few earthquakes have been recorded (Soeria-Atmadja et al., 1999). This tectonic activity triggers earthquakes and has the potential to cause high waves and tsunamis but such events are rare in Kalimantan.

Only one high wave event was recorded in the waters around Kalimantan in 2023 due to atmospheric disturbances such as tropical storms (Figure 1). This phenomenon disrupted fisheries and marine transportation activities in addition to an increase in the abrasion within coastal areas. Approximately 90% of tsunamis in Indonesia are generally caused by submarine tectonic earthquakes (Reid & Mooney, 2023). Kalimantan has similar potential due to the presence of active faults such as the Sangkulirang and Mangkalihat which can trigger nearby seismic activity.

The analysis of the patterns related to natural disasters in Kalimantan Island showed that forest and land fires, floods, and landslides were the main threats recurring continuously and dominating the number of cases recorded in the region. The trend is in line with the report of the BNPB that forest and land fires as well as floods were the most dominant natural disasters in Kalimantan. Tawakal (2022) also emphasized that the region was very prone to the three due to the geographical conditions and human activities exacerbating risk.

Natural disasters provide physical traces and trigger multidimensional impacts on different aspects of community life. From a social perspective, disasters stretch community ties due to the relocation of residents and trigger changes in existing

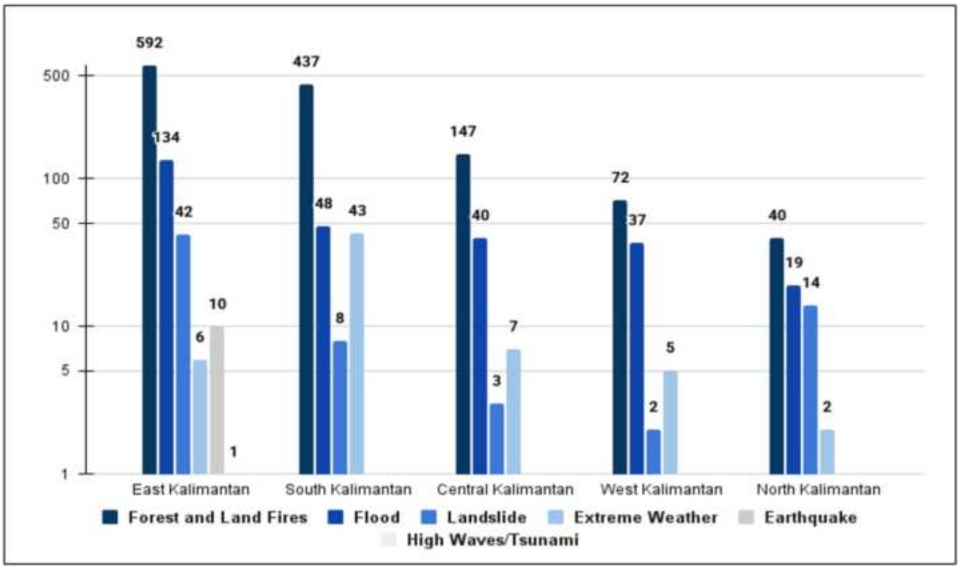


Figure 2. Number of Natural Disaster Events by Province in Kalimantan Island in 2023

Source: Data from BNPB in BPS statistics of East Kalimantan, 2023

lifestyles and local traditions. The disruption of daily activities due to haze limits outdoor activities and forces the use of masks which further reduces comfort. Moreover, the psychological impacts often overlooked require special attention, specifically for children and vulnerable groups experiencing prolonged trauma (Aulia, 2022). From an economic perspective, natural disasters lead to the loss of livelihoods for people who depend on forest products through the disruption of supply chains and reduced employment opportunities. Forest fires also allow massive exploitation of land for commercial purposes without adequate supervision which further increases economic inequality and slows the recovery of affected areas (Pamungkas et al., 2024). An example was the massive floods experienced in South Kalimantan in January 2021 which led to significant economic losses up to Rp1.349 trillion in the education, health, infrastructure, fisheries, community productivity, and agriculture sectors (Murti, 2021).

Landslides which are often associated with heavy rainfall can damage agricultural land, roads, and public facilities. This cuts off transportation access and hampers the distribution of goods and services. The long-term impacts also include decreased investment and reduced employment opportunities which slow regional economic growth (Aulia, 2022). Another example of the natural disasters in East Kalimantan with a significant impact was the massive flood recorded in Mahakam Ulu Regency in May 2024 (Sucipto, 2024). It was identified as the worst in history by submerging approximately five districts with water levels reaching two to four meters which led to the isolation of thousands of residents, damage to infrastructure, and power outages in different areas. The consequences hampered the daily activities of the residents and the effectiveness of emergency response efforts.

Disasters such as fires, floods, and landslides increase land degradation and threaten biodiversity from an environmental perspective. This is because fires force species out of their habitats and increase risk of pests on agricultural and residential land. Moreover, dense haze pollutes local air and spreads to neighboring countries which triggers regional cooperation through the ASEAN Transboundary Haze Pollution Agreement (AATHP) for forest land regulation (Pamungkas et al., 2024). Floods also cause runoff that pollutes water sources and damages forests while landslides destabilize slopes and destroy erosion-bearing vegetation. Land use change and lack of vegetation cover are capable of increasing risk as observed in South Kalimantan where forest cover has dramatically decreased.

The health impacts are very significant because air pollution from fire smoke causes a spike in cases of acute respiratory infections (ARI) and other respiratory disorders. For example, ARI cases increased significantly due to forest fire in 2015 in Central Kalimantan (Y. Astuti et al., 2022). Polluted post-disaster environments also serve as breeding grounds for infectious diseases such as dengue fever and leptospirosis. Furthermore, biomass smoke contains harmful substances including carbon monoxide, aldehydes, ozone, nitrogen oxides, carbon dioxide, and hydrocarbons which have a negative effect on health. The evacuation process during floods and landslides can also increase cases of diarrhea, dermatitis, and other skin diseases worsened by poor sanitation.

The report from BNPB (2024) showed that five provinces in Kalimantan experienced disasters with diverse characteristics in 2023 as presented in Figure 2 and this reflected the complexity of environmental challenges on the island. South Kalimantan was recorded as one of the provinces with a high rate with 536 events and the most were forest and land fires at 437 or approximately 81.5%. Flooding was also a serious problem with 48 events followed by landslides with eight and extreme weather 43. The recurrent fires were closely related to land conversion for plantations and the timber industry (Basani, 2018; Erlina et al., 2021). The loss of the ecosystem due to deforestation increased risk of more severe disasters in the future. Meanwhile, West Kalimantan recorded a lower number of events at 116 consisting of forest and land fires with 72 followed by floods 37, landslides were two, and extreme weather was five. The province has an extensive river network including the Kapuas River which often overflows during the rainy season and causes flooding in different areas. This shows the need for watershed management as the key to disaster mitigation in West Kalimantan (Wahyuningtyas & Pratomo, 2015).

Figure 2 indicates that Central Kalimantan experienced 197 disaster events throughout 2023, with forest and land fires accounting for 147 which was approximated at 74.6%. Floods occurred 40 times, landslides were three events, and extreme weather was seven. As a province with extensive peatlands, Central Kalimantan faces a major challenge because peatland fires are difficult to control due to embers that can remain below ground for months (Pinem, 2016). These threats show the need for a systematic and long-term management approach in the region. North Kalimantan is on the border of Malaysia and is identified to have recorded 75 disaster events in 2023. The largest was forest and land fires with 40 events followed by floods 19, landslides 14, and extreme weather two. Despite the relatively lower number of events, the impact of fires in these border areas is often transboundary and affects neighboring countries (Azaria et al., 2024; Pratiwi & Nugroho, 2020). This shows that fire management in Kalimantan is expected to be a national concern and an international issue.

The report from BNPB (2024) showed that East Kalimantan Province recorded the highest number of disaster events of 785 throughout 2023. Forest and land fires dominated with 592 (75.4%) followed by floods at 134 (17.1%), landslides 42, earthquakes 10, and extreme weather occurred six times. The high risk of disasters was due to the extent of flammable forests and peatlands as well as high rainfall in some areas. Moreover, the strategic position of the province contributes to the complexity experienced with a specific focus on the planned relocation of the new capital city to the region. This is possible because large infrastructure developments can potentially increase environmental pressures without sustainable spatial policies. Therefore, the IKN Master Plan emphasizes the importance of mitigating flood and landslide risks through a strict management system. Land conversion and increased urbanization can also worsen erosion and reduce water absorption which further increases risk of flooding in new urban areas (Hutapea, 2004). This shows the need for the prioritization of a balance between economic growth and environmental sustainability in the development efforts implemented in East Kalimantan.

National Search and Rescue Agency (BASARNAS) Boat
Photo credit: Ari Susanti

4

East Kalimantan and Natural Hazards

East Kalimantan Province is one of the regions located in the eastern part of Kalimantan Island and directly borders Malaysia. The province covers approximately 129,066.64 km² with a population estimated at 3.6 million. It was the second-largest province after Papua with an area of 194,489 km² or approximately 6.8% of the total in Indonesia before the division of the province in 2012 (BPS, 2023a). Currently, East Kalimantan is strategic to national development due to the designation of the region as the location of the new Capital City, IKN. The province administratively consists of seven regencies and three cities. The regencies include Paser with the capital located at Tanah Grogot, West Kutai at Sendawar, Kutai Kartanegara at Tenggarong, East Kutai at Sangatta, Berau at Tanjung Redeb, Penajam Paser Utara at Penajam, and Mahakam Ulu at Long Bagun. Meanwhile, the three cities in the province are Balikpapan, Samarinda, and Bontang.

BPS (2025) reported that East Kalimantan has a diverse aquatic ecosystem in the form of hundreds of rivers that flow through the

Living with Floods in Sepaku, East Kalimantan
Photo credit: Muhamad Rifki Rafida

regencies and cities. The rivers provide natural resources and serve as the primary transportation route in addition to roads. The province also has several large lakes, including Semayang and Melintang in Kutai Kartanegara Regency with an estimated area of 13,000 and 11,000 hectares respectively. Manufacturing and mining are the most important economic sectors and the processing industry is strongly associated with the exploitation of natural resources such as coal, petroleum, and natural gas. The industry has a significant contribution to the Gross Regional Domestic Product (GRDP) and serves as the primary driver of regional economic development. Balikpapan City is popular as the center of the oil and gas industry due to the presence of oil refineries and several multinational energy companies. Meanwhile, Bontang City is home to the largest liquefied natural gas (LNG) processing plant in Indonesia operated by PT Badak NGL. Another important information is that Kutai Kartanegara and East Kutai regencies are the major centers of coal mining as observed by the presence of several mining companies operating in the region.

The industrial and mining activities have adverse impacts on the environment and increase risk of disasters. For example, surface mining causes drastic landscape changes, reduces water catchment areas, and increases carbon emissions which further contribute to global warming. The empirical data provided by the Strategic Plan of the Regional Disaster Management Agency (BPBD) of East Kalimantan Province showed that the bio-geophysical changes from global warming and climate change as well as the degradation of natural resources and the environment increased disaster risk in the region. These phenomena have led to droughts which were worsened by El Niño, extreme rainfall from La Niña triggering floods and landslides, as well as risk of forest and land fires. Further impacts identified include a reduction in food availability and an increase in the outbreaks of pests and diseases. East Kalimantan BPBD data showed variation in the frequency of disaster events in each regency and city from 2018 to 2022. Samarinda City had the highest number with 737 events followed by Balikpapan 503, East Kutai 327, Kutai Kartanegara 294, Berau 269, Penajam Paser Utara 262, Paser 232, Bontang 202, West Kutai 131, and Mahakam Ulu recorded the lowest with 23. The region has low seismic activity but remains vulnerable to other natural disasters such as forest fires and floods (BPBD Provinsi Kalimantan Timur, 2024).

Flood is part of the primary threats with a specific focus on the two regencies of Penajam Paser Utara and Kutai Kartanegara where IKN is being developed. This shows the importance of disaster mitigation efforts in planning the IKN development in order to reduce the threat of floods and landslides caused by land-use changes reducing water catchment areas. Therefore, the implementation of an efficient water management system is necessary with a focus on the construction of reservoirs, integrated drainage channels, and increasing green areas as natural water absorbers.

Forest fires often experienced during the dry season need to be anticipated through a technology-based monitoring system and strict regulations on land clearing. This is necessary because

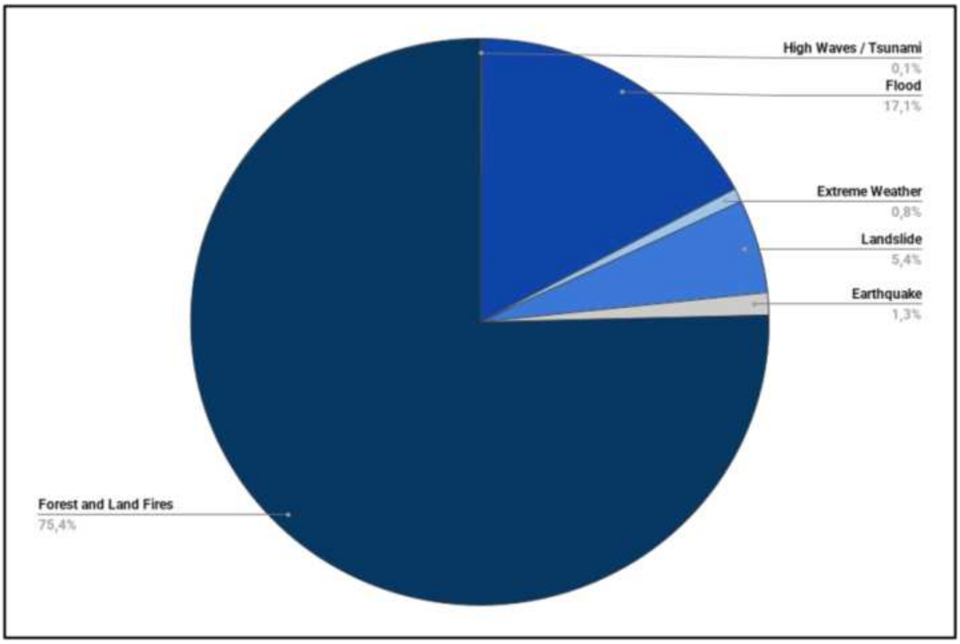


Figure 3. Share of Natural Disaster Events in East Kalimantan by Type of Disaster in 2023

Source: BNPB of East Kalimantan, 2023

the development of IKN as a sustainable city requires a mature and environmentally based approach to disaster risk mitigation and adaptation. Therefore, IKN can become a modern and advanced model city with resilience to a wide range of future natural disaster risks.

4.1 Fire Disasters

4.1.1 General Information

Forest and land fires in East Kalimantan Province have been an alarming phenomenon since the early 1980s and the largest events were recorded in the 1982-1983 period. According to FWI/GFW (2001), the fires were triggered by inadequate forest management policies during the Soeharto Era and the El Niño climate phenomenon that exacerbated drought conditions. The fires burned approximately 210,000 km² of land which covered almost the entire province and lasted for months up to May 1983. The massive fire events led to a continuous increase in the frequency and the scale of burned areas. Furthermore, the high rate of deforestation over the past three decades is identified as one of the main factors worsening risk of forest fires in East Kalimantan. This was confirmed from the observation of Shafitri et al. (2018) that deforestation removed protective vegetation cover and also changed soil and microclimate characteristics causing further increase in the susceptibility of the region to fires.

The deforestation data recorded between 2013 and 2019 showed that the rate of forest loss in East Kalimantan was relatively stable but continued to increase at a significant level (BPS, 2024a). The trend shows that the current management effort is insufficient (Ramadhany, 2023) because the drivers of deforestation such as land clearing for oil palm plantations, mining, and infrastructure development persist despite the implementation of different preventive programs. Moreover, BNPB (2024) showed that forest and land fires were the most dominant disaster in East Kalimantan with a total of 592 events. The number was observed to have increased compared to the previous year which showed a concerning trend. The provincial government responded by declaring emergency alert status and strengthening inter-agency coordination. The Ministry of Environment and Forestry (MoEF) reported that the area affected by fires from January to March 2024 included 552.73 hectares on peatlands and 5,460.93 hectares on mineral lands. The area covered continued to increase up to 13,225 hectares in June 2024 with the majority (94%) found on mineral land. Another important data reported was that the number of fire incidents recorded during the period was 120 (Puspa, 2024).

The root cause analysis showed that human activities were the primary drivers of disaster based on their contribution of 54.5% to the total. Some of the activities include land clearing by burning, uncontrolled agricultural activities, and community negligence. The analysis further showed that biophysical factors such as hot, dry, and windy weather conditions contributed 45.5% (Novita & Vonnisa, 2021; Ramadhany, 2023). Kutai Kartanegara Regency was identified as riskiest area with high hotspots followed by East Kutai Regency. Furthermore, the Terra/Aqua satellite detected 64 hotspots in Kutai Kartanegara and 105 in East Kutai between January and April 2024 with 4,020.14 and 1,769.46 hectares of fire areas, respectively. Another survey by BMKG Balikpapan also reported 167 hotspots in April 2024 (Arumanto, 2024).

Forest fires have a wide-ranging and complex impact on the environmental, health, economic, and social aspects of the region. From an environmental perspective, the destruction of tropical rainforests which serve as the habitat for unique flora and fauna causes a decline in biodiversity and threatens the sustainability of the ecosystem. The loss of the humus layer due to burning degrades soil fertility conditions also disrupts local agricultural activities and forest regeneration processes. This is mainly because ecosystem recovery particularly in burned peatlands can take years or even decades.

Large amounts of carbon emissions released through forest fires contribute significantly to global warming and climate change. This is because fire smoke degrades air quality and triggers haze that threatens public health. Haze pollutants increase risk of respiratory problems such as ARI, bronchitis, and cardiovascular diseases. Vulnerable groups such as children, the elderly, and people with chronic diseases are most affected. Poor air quality also limits visibility, endangers land and air transportation, and disrupts the daily activities of the people.

Forest fires cause significant damage when analyzed from an economic perspective. This was observed from the losses recorded during the 1982-1983 fires which were estimated at US$9 billion (FWI/GFW, 2001). There was also a drastic decline in the productivity of the agriculture, plantation, and forestry sectors in addition to the loss of forest cover. Moreover, the incomes of farmers and planters declined and the situation worsened local poverty. Logistics and trade disruptions caused by the haze also affected neighboring countries such as Malaysia and Singapore. Forest fires also forced several residents to evacuate considering the exposure to smoke and fire while those who stayed experienced reduced livelihoods and financial hardship. There were cases of death due to land fires as observed in Palaran, Samarinda, Manggar, East Balikpapan Districts during the 2019 event where residents died from burns while trying to extinguish the fire (Metro Kaltim, 2019). The trend shows that forest fires extend beyond being an ecological disaster to functioning as a serious threat to human safety and well-being. Therefore, the efforts to address forest fires need to be prioritized nationally through a multi-sectoral approach, including the government, communities, academia, and the private sector.

Several strategic actions are included in the East Kalimantan Provincial Development Plan 2024 – 2026 to reduce forest degradation and fires. These include forest community-based patrols, educating the community to prevent forest destruction, and establishing and developing the Forestry Police Partner Community (MMP). Forest patrol program has been operational since 2019 with a primary focus on fire-prone areas in conservation forests and highly flammable peatlands. Moreover, the prevention of forest and land fires is facilitated by providing suppression facilities and infrastructure, including field equipment, fire extinguishers, hoses, and monitoring drones as well as water pumps. The other prevention strategies designed are community patrols, socialization of awareness about the dangers of forest fires, as well as the establishment and development of Fire Care Communities (MPA).

MMP and MPA are considered important initiatives that require the direct participation of local communities. MPA is significant to the detection of early symptoms of fire events and performing basic suppression using the provided tools such as light fire extinguishers, water hoses, and portable pumps. The use of drones as monitoring tools also increases the effectiveness of early fire detection by enabling a quick response before the spread. However, the implementation of the activity has not been optimal despite several efforts. The main obstacle is the limited number of Forestry Police personnel and members of MMP and MPA. This lack of human resources and equipment affects the effectiveness of patrols and fire suppression, particularly in East Kalimantan which is a vast and challenging-to-reach area. Therefore, capacity building, advanced training, and strengthening inter-agency coordination are key focuses for improving forest fire management system in the future.

4.1.2 Factors Affecting Fire Disasters

Forest and land fires in East Kalimantan are a complex phenomenon associated with the interactions between natural and anthropogenic factors. The occurrence, spread, and intensity of fires are influenced by the factors. This can be explained through a fire triangle theory approach that includes heat, fuel, and oxygen with four types of fire-triggering factors related to the anthropogenic, topographic, vegetation, and climatic aspects (Barros-Rosa et al., 2022; Vasilakos et al., 2009; You et al., 2017). The factors contributing to the occurrence of forest and land fires in East Kalimantan are described as follows.

A. Natural factors

The natural factors influencing the occurrence of natural disasters such as forest and land fires are defined as the events that occur naturally without human intervention. Some of these include extreme weather conditions or natural processes triggering the emergence of hotspots which are explained as follows.

(a) Climatic conditions and extreme weather

Indonesia has a tropical climate characterized by two distinct rainy and dry seasons. Rainfall decreases dramatically and causes vegetation to dry out which increases risk of fire during the dry season, specifically the El Niño phenomenon (Field et al., 2009). This is possible because high temperatures have a profound effect on the hydrology of a region. Areas with high air temperatures are more susceptible to fires (Dyer, 2009). Moreover, the strong winds often experienced during the dry season can speed up the spread of fire and allow an immediate increase from small to larger intensity (Bowman et al., 2009).

(b) Vegetation conditions and biomass

The type of vegetation in an area determines risk of fire. This is possible because vegetation is a closely related factor in the fuel element of the fire triangle theory (Chuvieco et al., 2010; P. Zhao et al., 2021). Areas with dense vegetation tend to have a higher risk of experiencing fires. Moreover, the differences in the ability of plants to retain moisture content lead to variation in the chances of fire occurrence. This shows the possibility of using a vegetation index that represents the degree of greenness as an effective approach to predict the relationship between plants and fire occurrences. The plants with high vegetation index values tend to be fire resistant due to the high moisture content (Jensen, 2007). However, certain ecosystems such as peatlands have a high risk of fire due to their ability to store large amounts of carbon (Page et al., 2002). The peatlands that have dried out can ignite and burn below the surface and the process leads to difficulties in extinguishing the fire for weeks or even months (Turetsky et al., 2015).

(c) Topography and Land Characteristics

Topography is important due to the influence on the physical characteristics of an area in responding to fire events with a focus on the approach of spreading and the intensity (Conedera et al., 2011). The topographic characteristics also influence the distribution of the local climate such as sunlight, temperature, and others. Some of the main topographic factors with substantial impact on fire occurrence include:

- Slope

  Fires tend to spread faster up the slope because the heat dries the vegetation at the top before the fire reaches the location (Rebain, 2015).
- Elevation

  Lowland areas such as peat swamps are more susceptible to fires due to changes in hydrology. Meanwhile, higher-elevation areas have a lower fire risk due to lower temperatures and higher humidity (van der Werf et al., 2009).
- Wind direction and pattern

  Valley-mountain and tunnel wind effects in areas with narrow valleys or hill gaps can increase wind speeds and speed up fire spread (Sharples et al., 2012).

- Hydrology and Drainage Systems

  Areas with pristine river systems and wetlands tend to have higher moisture levels which are capable of reducing fire risk. However, disruptions to hydrological systems due to the construction of drainage canals or deforestation make soils drier and more flammable (Msiettinen et al., 2016).

B. Anthropogenic factors

The anthropogenic factors influencing the occurrence of natural disasters such as forest and land fires are directly and indirectly related to human activities. In several cases, the main cause is the increased human activities around forest and land areas as observed in the following anthropogenic factors.

(a) Land clearing through burning

Slash-and-burn approaches are widely used to clear land by smallholders and large companies in Kalimantan (Miettinen et al., 2011; Tacconi, 2003). This practice is cheap and quick but has a high risk because uncontrolled fires can spread to other areas.

(b) Human activities and behavior

Human activities are significant primary factors in the occurrence of fires and serve as the main source of triggers due to both intentional and unintentional combustion activities (Ricotta et al., 2018). A common example is the outbreak of fires near roadsides caused by the careless disposal of cigarette butts (Archibald et al., 2013). Another example is the leftover heat from land-clearing burns or the open burning of waste which is sufficient to ignite surrounding vegetation and trigger fire (Kamaludin et al., 2019).

(c) Plantation expansion and deforestation

Deforestation caused by the expansion of oil palm plantations and industrial timber estates increases risk of the landscape to fire (Austin et al., 2019). The removal of forest canopy can reduce moisture levels while the accumulation of woody residue and dry litter serves as a source of highly flammable fuel.

(d) Infrastructure Development and Land Fragmentation

The development of roads and settlements in forests increases human access to previously inaccessible areas. This triggers illegal land-clearing activities that increase risk of fire (Barlow et al., 2016).

(e) Lack of Supervision and Law Enforcement

Land burning restrictions and regulations exist but the implementation is frequently inadequate due to a lack of supervision and a low deterrent effect on illegal burners (Carlson et al., 2013).

(f) Water Management Failures in Peatlands

The efforts to drain peatlands for agricultural or plantation development often lower the water table which consequently causes the peat to dry and become flammable (Page et al., 2011). The Mega Rice Project (MRP) program in Central Kalimantan in the 1990s is an example of how draining peatlands can increase fire risk in the long term (Miettinen et al., 2011).

The factors influencing forest and land fires in East Kalimantan are complex and require the interactions between natural and anthropogenic factors. Extreme climatic and weather conditions such as El Niño increase risk but human factors such as land clearing by burning, deforestation, and draining of peatlands are the main causes of uncontrolled fires. Topographical factors are also important in influencing fire spread patterns because the slope, hydrological system, and wind direction of the landscape can determine the pace. The understanding of these factors allows for comprehensive fire mitigation strategies, including ecosystem-based landscape management, improved law enforcement, and peatland restoration to reduce risk of future fires (Bowman et al., 2020; Flannigan et al., 2009).

4.2 Flood Disasters

4.2.1 General Information

East Kalimantan Province is ranked second among Indonesian regions in terms of the highest frequency of natural disasters. Flood is the most prevalent disaster identified in the region with 134 incidents recorded in 2023 alone (BPBD Provinsi Kalimantan Timur, 2024)). According to BPBD data, a total of 631 flood events occurred between 2018 and 2022 which affected approximately all areas of the region, including major cities such as Samarinda, Balikpapan, and Penajam Paser Utara. This high frequency has led to considerable economic, social, and environmental losses (Satar, 2022).

The province is the fourth largest in Indonesia with an area of 129,066 km² (BPS, 2023a) and its location adjacent to the Makassar Strait and the Sulawesi Sea affects the climate and weather dynamics. The Mahakam Watershed which covers 8.2 million hectares or approximately 41% of the total area of the province is the largest watershed (Karim & Muhid, 2019). The Mahakam river is crucial for the community but also poses a threat, specifically during periods of heavy rainfall when runoff exceeds its capacity. The capacity of the province, Samarinda City, is divided by the Mahakam River and is among the most flood-prone areas in the region. The report from the Meteorology, Climatology, and Geophysics Agency (BMKG) showed the historical occurrence of seasonal floods in city for more than two decades. Sulaiman et al. (2020) also reported that the flood in Samarinda was triggered by high surface runoff and low capacity of drainage channels. The trend showed that hilly topography, high rainfall intensity, and rapid urbanization worsened the flood risks due to the lack of proper spatial planning. Naibaho et al. (2024) also observed that infrastructure development without adequate drainage systems aggravated stormwater management. The most severe flood disaster in East Kalimantan was reported by the Sultan Aji Muhammad Sulaiman Meteorological Station in Balikpapan in May 2024. This was because of the continuous heavy rainfall for over a week that caused water levels to rise between two and four meters in the Mahakam Ulu Regency to displace more than 7,000 residents.

Furthermore, extreme rainfall of 400 mm/day which significantly exceeded the normal average also caused more infrastructure damage in the upstream area of the Mahakam River (Sucipto, 2024).

The flood problem in East Kalimantan is due to a combination of natural and anthropogenic factors. The natural factors that lead to high risk in the region include the topography, the size of the Mahakam watershed, and high rainfall. From the anthropogenic perspective, land use change such as forest clearing for mining and plantations as well as degradation of catchment areas intensifies flood risks (Ramadhany, 2023). The illegal logging for the expansion of oil palm plantations and coal mines further disrupts the hydrological cycle (Austin et al., 2019).

Several cities such as Samarinda, Balikpapan, and Bontang have insufficient drainage systems that cannot handle water runoff (Mauliannur, 2013; Mot, 2016; Pratiwi & Ndraha, 2018). This has led to the inclusion of flood as a major concern in the Regional Development Plan (RDP) 2024-2026 for the province with a specific focus on the cities designated as National Activity Centers (PKN) and Provincial Strategic Areas. Therefore, the flood mitigation efforts are focused on enhancing drainage capacity and promoting the sustainable development of control infrastructure.

Floods have a significant social and economic impact as observed in the total number of 50,672 people affected and displaced as of February 2024 in the data presented by the Central Statistics Agency (BPS, 2024b). Berau Regency recorded the highest number with 21,685 people followed by Paser

14,223, Samarinda City 5,840, and East Kutai 4,155. In May 2023, a flood in Kaubun, East Kutai also caused one death and damaged critical infrastructure. Another recorded in Sangatta in March 2022 affected more than 16,800 people, displaced 2,000, and caused one death (BPBD Provinsi Kalimantan Timur, 2024). Samarinda City also reported damage to 1,722 houses but no fatalities were recorded. Meanwhile, flash floods in Penajam Paser Utara caused economic losses of IDR 2.7 billion. The total losses due to the flood in East Kalimantan over the past two decades were estimated to be in the trillions of rupiah (Satar, 2022). This shows the need to integrate mitigation efforts in the planning for regional development.

4.2.2 Factors Affecting Flood Disasters

Floods are hydrometeorological disasters that occur when water overflows and inundates areas originally considered to be dry. This phenomenon causes material losses, infrastructure damage, and loss of life in addition to far-reaching impacts on social, economic, and environmental systems. Flood typically occurs when the volume of water flowing on the ground exceeds the capacity of natural systems such as rivers, drainage channels, or infiltration ponds to contain and absorb. The triggering factors can be broadly categorized into two which are natural and anthropogenic aspects. The understanding of the two is very important for disaster risk reduction planning and sustainable area management, specifically in flood-prone areas such as East Kalimantan.

A. Natural Factors

Natural factors that contribute to increased flood risk are related to the physical environmental characteristics of a particular area. These include rainfall, topography, soil infiltration capacity, river tides, as well as the processes of erosion and sedimentation. Heavy rainfall is one of the most common causes because high intensity, frequency, and duration can generate a rapid increase in water discharge, specifically when water flow systems such as rivers or drainage are unable to accommodate the volume surge. Moreover, extreme rainfall is often caused by changes in global climate patterns such as the El Niño-Southern Oscillation (ENSO) phenomenon and variations in sea surface temperature which affect the hydrological cycle of different regions (Idati et al., 2020).

Topography is another important factor because flat areas or depressions tend to retain rainfall for extended periods and subsequently cause floods. Hilly areas with steep slopes also speed up surface flow which leads to risk of flash floods in lowland areas. Moreover, soil infiltration capacity significantly influences the amount of water that the soil surface can absorb before flowing to the surface. This shows that soils with a dense texture, poor organic matter, or compacted due to the pressure of heavy vehicles or infrastructure development tend to have a low water absorption capacity. This causes rainwater to flow more quickly as surface runoff to form inundation and flood.

Another factor associated with floods is river tides with a specific focus on coastal areas or along major river basins such as the Mahakam River in East Kalimantan. During high tides, the flow of water from upstream is obstructed and causes a buildup of volume in the middle or downstream areas of the river. This situation becomes more critical when high tides coincide with extreme upstream rainfall because the pressure from both directions can lead to tidal or compound flooding.

Erosion and sedimentation processes are further considered important in increasing flood risk. This is because the occurrence of erosion in the upper part of the watershed transports soil particles that eventually settle along riverbeds and drainage channels. The sediment accumulation reduces the capacity of the river to store and convey water over time and this increases the propensity to overflow during periods of high discharge. The process is mostly triggered by the reduction of soil-retaining vegetation such as primary forests (Kodoatie & Sugiyanto, 2002). In the long term, the combination of erosion, sedimentation, and land cover change can significantly worsen flood risks without proper watershed manage-ment.

B. Anthropogenic factors

Human activities or anthropogenic factors are significant to the occurrence of floods in addition to natural factors. This is mostly through land use change and development without considering the carrying and environmental capacities. Forests or green open land are often converted into settlements, industrial areas, or large-scale plantations without considering the existence of water absorption zones. Land surfaces originally absorbing rainwater are replaced with impermeable surfaces such as asphalt, concrete, and buildings which increase the volume of surface runoff (Darmawan et al., 2017). The increase in the runoff eventually leads to an overwhelmed drainage system and a higher potential for overflows. Furthermore, the rapid population growth mostly in urban and riverfront areas has led to the development of settlements without following the zoning regulations and riparian areas. The situation is narrowing rivers, reducing natural vegetation around riverbanks, and increasing the flood potential. This is because rivers are no longer able to accommodate water discharge during the rainy season.

The quality and capacity of drainage systems are another serious challenge. This is because several cities or residential areas in Indonesia have drainage systems that are narrow, shallow, or even clogged with garbage. The accumulation of both organic and inorganic waste causes the flow of water to be obstructed and speeds up the process of inundation during heavy rainfall. The lack of public awareness regarding the proper disposal of waste exacerbates this situation.

Deforestation leads to the loss of vegetation that plays a critical role in retaining water, specifically in the upper watershed. Forests are very important in absorbing rainwater through the tree root system and reducing the speed of surface runoff. The clearing of these forests without adequate reforestation or agroforestry systems allows rainwater to flow directly into rivers. The process increases soil erosion and raises risk of both flash floods and sedimentation.

Infrastructure development such as the construction of embankments, canals, or dams can have unintended negative consequences when not carefully planned. The errors in technical planning or the failure to calculate the flow capacity of rivers are capable of leading to overflow in unanticipated areas. Moreover, the practice of land filling in areas around rivers for residential or commercial development disrupts the natural flow of rivers and increases inundation.

Another equally important issue is weak spatial planning and inadequate law enforcement. Some areas designated as water catchment zones are frequently converted into residential or industrial developments. This shows the weaknesses in integrating environmental aspects into the development decision-making process. For example, there are several cases where basins or riparian areas have been converted into productive areas without considering the long-term implications for disaster risk in East Kalimantan. Zoning and riparian protection regulations are in place but the implementation in the field is often weak due to inadequate supervision and enforcement of the law.

Flood disasters are generally due to complex interactions between natural and anthropogenic factors. Therefore, flood risk mitigation efforts need to be based on a multidisciplinary approach that includes understanding hydrology, risk-based spatial planning, land conservation, and active community

participation in protecting the environment. These efforts are reactive when disaster occurs and also need to be proactive and long-term planned. The implementation of good planning and cross-sector collaboration can minimize flood risks and ensure better environmental sustainability.

Industrial Flow in Balikpapan Bay
Photo credit : Stevie Nissauqodry

5 Delving Into the IKN Region

Post-Mining Transformation in Kutai Kartanegara
Photo credit: Gery Novrian

The focus of this book is on IKN and the surrounding areas. A watershed-based approach was used as the primary spatial and ecological unit of analysis. The preference for the approach is because watersheds are natural geographic units that integrate different environmental components such as topography, hydrology, soil, vegetation, and human activities into a single interconnected system. The watershed boundaries used were defined through physical features in order to provide a more accurate reflection of the interactions between natural processes and human interventions compared to the administrative boundaries. Moreover, the approach provides a suitable framework for understanding the connections between land-use change, surface water flow, and the impacts on risk of floods, landslides, as well as forest and land fires.

The massive and rapid development of IKN requires analyzing the region as part of a wider interconnected ecological landscape and not as an isolated entity. The watershed-based approach enables a comprehensive analysis of the impact of land use change with a specific focus on the upstream to downstream on ecosystem balance. The changes upstream, such as deforestation, large-scale land clearing, and disturbance to natural vegetation directly affect hydrological stability and increase disaster risk downstream which includes the IKN core area (KIPP). Therefore, a deep understanding of watershed conditions is important in supporting spatial planning, disaster risk mitigation, and sustainable urban development.

The approach enables the integration of bio-geophysical and socio-economic data within a single analysis platform. For example, rainfall, soil type, land cover, and social vulnerability of communities living around rivers can be analyzed simultaneously to produce more accurate disaster risk maps. The watershed-based approach can also be a strategic tool in climate change adaptation policy, specifically in addressing the increasing frequency and intensity of extreme weather events such as floods and droughts driven by global climate change.

The limited focus of the analysis on the IKN core area is insufficient to capture the full dynamics of risks. This is due to the transboundary nature of disasters such as forest fires and flash floods which do not recognize administrative boundaries. In reality, fires that start outside IKN can easily spread to the core area due to strong winds and topographic conditions facilitating the propagation as well as the distribution of natural fuels in the form of shrubs, secondary forests, and peat vegetation. The scope of this research was expanded to include watersheds outside the formal boundaries of IKN, specifically where ecology contributed to the hydrological flows into the IKN area.

The areas surrounding IKN such as the upper watersheds of the Tembalang, Tengin, and Sepaku Rivers are dominated by secondary forest ecosystems, peatlands, as well as agricultural and plantation areas. The combination of rich, dry vegetation, and a humid tropical climate provides a high fire-prone situation, specifically during the dry season. The presence of degraded peatlands also increases risk of smoldering fires which are difficult to extinguish and have the capacity to stay for months to cause cross-regional air pollution and extensive ecosystem damage.

The massive development of IKN infrastructure including the construction of main roads, settlements, and public facilities has altered the land use structure around the watershed area. The transformation of infiltration land into impermeable urban areas has also reduced the natural capacity of the soil to absorb rainwater. Therefore, the volume of surface runoff increases sharply and flows into the main rivers. The situation has caused the Sepaku and the Mahakam Rivers in the lower reaches to experience sedimentation loads because the flow from the upstream carries soil particles and ash from the fires. This narrows the river basins and reduces their capacity to hold water during heavy rains.

The situation is exacerbated by weak spatial supervision and land conversion outside IKN. Several ecologically important areas such as riparian forests, swamps, and peatlands are converted without considering the carrying and environmental capacities. This leads to disruption of the local water cycle, increased microclimate temperatures, and loss of natural habitats that act as buffer zones against disasters. In the context of watersheds, degradation in upstream areas puts additional pressure on downstream areas such as the IKN in the form of increased flash flood risks, decreased water quality, and enhanced vulnerability to climate change.

The trend shows the need for a watershed-based approach to serve as risk identification tool and a framework for policy and governance. This research recommends that the development of IKN considers the spatial dimension within the administrative scope and integrates ecosystems across regions to reflect complex ecological realities. The understanding of the interconnections between upstream and downstream areas as well as the impacts of landscape changes within the watershed context can guide the IKN development policies toward providing a resilient, disaster-resistant, and sustainable urban model for the long term.

The research area is geographically located at 115° 45'31.644" - 117° 37'41.6712" East and 0° 17'38.0688" - 1° 41'46.2408" LS which covers 37 districts. The boundaries identified for the area are presented as follows:

North: District Loa Kulu, Muara Badak, Tenggarong, Tenggarong Seberang of Kutai Kartanegara Regency, and District Samarinda Ulu, Samarinda Utara, Sungai Kunjang of Samarinda City.

South: District Batu Sopang, Long Ikis, Muara Komam of Paser Regency

West : District Gunung Purei, Bongan, Siluq Ngurai of Kutai Barat Regency, District Kotabangun, Muara Muntai,

Table 1. Size of District Administrative Areas

District	Regency/City	Area (ha)
Anggana	Kutai Kartanegara	105,306
Babulu	Penajam Paser Utara	42,914
Balikpapan Barat	Balikpapan	19,403
Balikpapan Kota	Balikpapan	1,092
Balikpapan Selatan	Balikpapan	3,858
Balikpapan Tengah	Balikpapan	1,095
Balikpapan Timur	Balikpapan	12,015
Balikpapan Utara	Balikpapan	13,862
Batu Sopang	Paser	226
Bongan	Kutai Barat	410
Gunung Purei	Barito Utara	310
Kota Bangun	Kutai Kartanegara	1,702
Loa Janan	Kutai Kartanegara	69,861
Loa Janan Ilir	Samarinda	2,991
Loa Kulu	Kutai Kartanegara	139,794
Long Ikis	Paser	32,513
Long Kali	Paser	256,088
Muara Badak	Kutai Kartanegara	37,206
Muara Jawa	Kutai Kartanegara	52,042
Muara Komam	Paser	14,535
Muara Muntai	Kutai Kartanegara	48
Palaran	Samarinda	19,242
Penajam	Penajam Paser Utara	89,818
Samarinda Ilir	Samarinda	178
Samarinda Kota	Samarinda	83
Samarinda Seberang	Samarinda	1,027
Samarinda Ulu	Samarinda	1
Samarinda Utara	Samarinda	1,366
Samboja	Kutai Kartanegara	28,221
Sambutan	Samarinda	41,786
Sanga-Sanga	Kutai Kartanegara	6,396
Sepaku	Penajam Paser Utara	10,243
Siluq Ngurai	Kutai Barat	128,540
Sungai Kunjang	Samarinda	625
Sungai Pinang	Samarinda	114
Tenggarong	Kutai Kartanegara	164
Waru	Penajam Paser Utara	61,784

Source: Result of statistical analysis of the distribution in the research area, 2025

Muara Wis, Sebulu of Kutai Kartanegara Regency

East : Makassar Strait

There are a total of 1,234,581.6 hectares and 37 districts in the research area. The size of each administrative area is presented in the following table to provide more detailed information. The table also shows the overlap between administrative areas based on the physical boundaries of the watershed.

Information shows that the largest district is Long Kali in Paser Regency with an area of 256,088 hectares while the smallest is Samarinda Ulu district with just 1 hectare. The districts form an ecological constellation with the IKN area due to the geographic proximity and interconnected environmental systems. A visual representation of the research area and the ecological relationship with IKN is presented in Figure 4.

The IKN constellation map shows that the core area of the Nusantara Capital City is situated in Sepaku District, Penajam Paser Utara Regency. Moreover, the research area covered in this book extends to the surrounding regions, including Balikpapan City, Samarinda City, and Kutai Kartanegara Regency. The districts share similar characteristics in terms of socio-cultural communities and natural resource conditions such as soil type, topography, and vegetation.

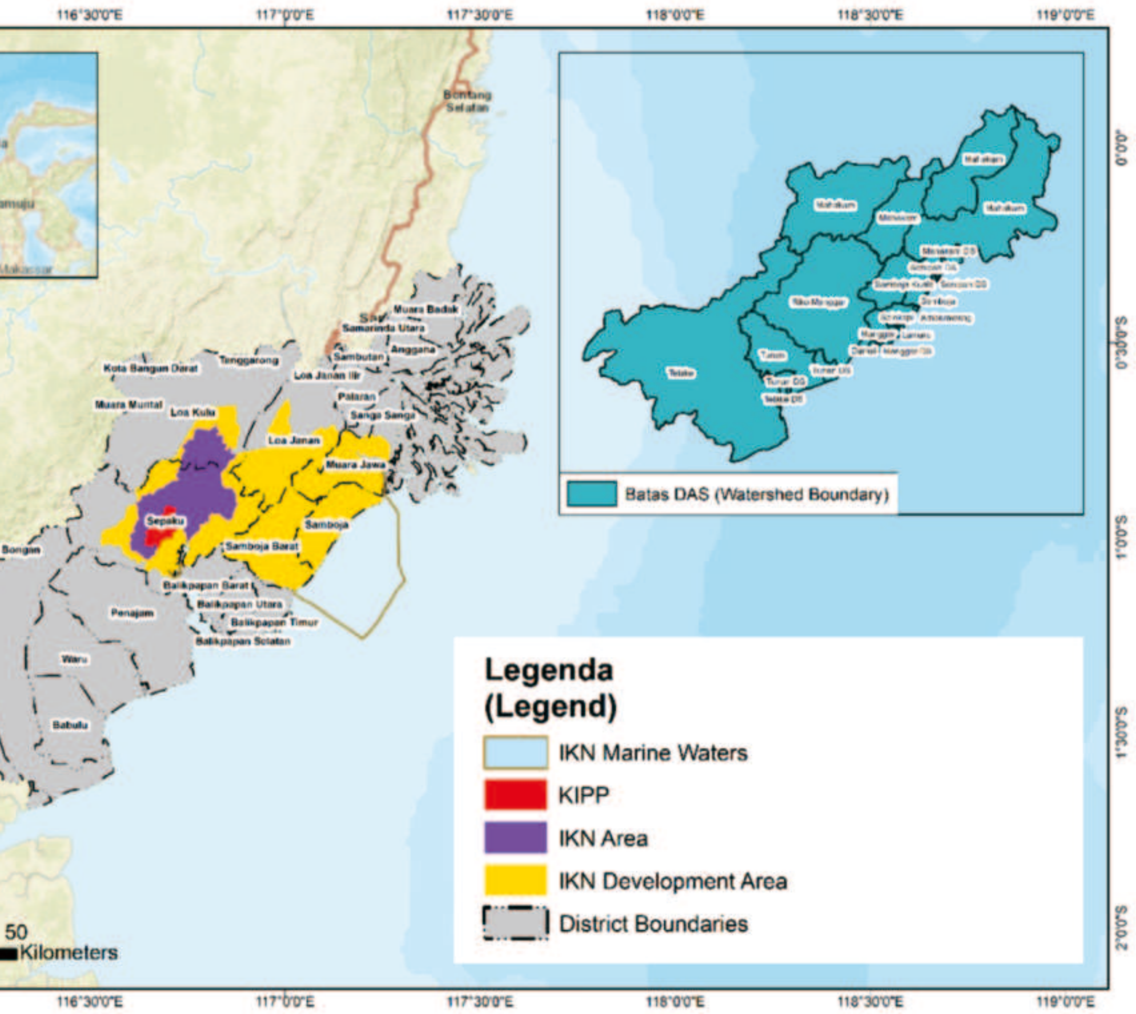


Figure 4. The National Strategic Area of IKN and Its Surrounding Watersheds

Source: Geospatial Information Agency, 2025

6 Disaster Risk Assessment Tools

Landscape of Mentawir Village
Photo credit: Relissiana

This book focused on spatial analysis as a tool to understand the dynamics of disaster risk in the IKN area and surroundings. The objective was to identify key factors that contribute to disaster risk by leveraging spatial data. The results are expected to serve as a basis for designing more targeted mitigation strategies and supporting adaptive and sustainable planning processes. The analysis not only intends to map potential risks but also to create the groundwork for more targeted and effective disaster impact reduction efforts.

6.1 Requirements for Disaster Risk Assessment

This book uses a cloud-based spatial data processing approach with Google Earth Engine (GEE) to assess disaster risk in the IKN area and its surroundings. This is a powerful platform for managing and analyzing large-scale remote sensing data, eliminating the need for local data downloads. It enables real-time, efficient processing supported by a wide array of global datasets, including satellite imagery, climate records, vegetation indices, and digital elevation models (DEM) (Gorelick et al., 2017). Therefore, GEE is particularly well-suited for tropical areas, such as Kalimantan, where environmental dynamics are complex, rapidly changing, and span extensive areas.

While using GEE, the data collection stages differ from those used in InaRISK. InaRISK is a Geographic Information System (GIS) and Internet of Things (IoT)-based information system designed to support real-time, open, and easily accessible national disaster risk assessment (Suharini et al., 2023). The specific explanations of the fire source and flooding trigger variables are provided below.

a. Fire Source Variable

The InaRISK method referenced in the National Disaster Management Agency (BNPB) Regulation No. 2/2012 uses three main parameters — land use, climate (rainfall), and soil type — to assess forest and land fire hazards. The assessment is often conducted through a class-based scoring approach, with each parameter given a weight according to the influence on fire potential. Although this approach has become a national standard, it has limitations in explaining the spatial dynamics of fire, specifically those influenced by human activities and more complex biophysical conditions.

As an alternative, this book developed a high-resolution spatially-based multivariate approach, incorporating four main domains, namely anthropogenic, climatology, topography, and vegetation, which altogether have seven main variables.

1. **Anthropogenic factors:**
   (a) **Distance from main road**: The closer an area is to a road, the higher the probability of human activities that could trigger a fire (Saharjo & Hasanah, 2023).
   (b) **Distance from settlements or populated areas**: Densely populated areas face a higher fire risk due to community land burning practices, specifically during the dry season (Field et al., 2009).
2. **Climatic factor**
   ***Land Surface Temperature* (LST)**: LST is used to identify areas with high temperatures that increase surface fuel dryness (Yulianti et al., 2012).
3. **Topography factors:**
   (a) **Elevation**: Altitude affects air humidity and wind conditions, both of which influence the spread of fire (Menezes et al., 2024).
   (b) **Slope**: Slope affects water flow and the direction of fire spread (Chuvieco et al., 2010).
   (c) ***Topographic Wetness Index* (TWI)**: TWI shows areas with high moisture potential that are generally more resistant to fire (Maniatis et al., 2022).

Some studies also used aspect as a variable, specifically in subtropical and Mediterranean areas where sunlight is more intense on the south or west side of the slope. However, given that the IKN area and its surrounding watersheds is around the equator, sunlight variations based on slope direction tend to be more homogeneous, and the impact on fire risk is relatively small (P. Zhao et al., 2021).

All data were obtained from GEE catalogues, such as Landsat 8 OLI/TIRS and MODIS Terra/Aqua, which provide spectral data in the visible, near infrared, and thermal bands. These data allow the calculation of Normalized Difference Vegetation Index (NDVI), surface temperature, and analysis of land cover dynamics, which are important indicators in the study of forest and land fire (Roy et al., 2014).

b. Flood Variables

The flood hazard assessment approach adopted by the InaRISK platform is based on BNPB Decree No. 2/2012. This approach relies on the Topographic Index Modification (TMI) developed by Manfreda et al. (2011). Flood-prone areas are estimated using a Digital Elevation Model (DEM) analysis based on flow accumulation and slope. Subsequently, the areas were mapped based on certain threshold values and further classified by considering distance from the river and slope through a fuzzy logic method.

However, there are some limitations, such as:

1. Low DEM resolution can potentially obscure micro-topographic details such as localized depressions that are important in flood inundation (Smith et al., 2015).
2. Do not consider changes in land cover and actual rainfall intensity due to climate change.
3. Ignores anthropogenic roles such as urbanization and development without drainage planning.

In response to the limitations, the method in this book incorporated three main variables that affect runoff, namely:

1. **Topography**

   This variable was used to map water flow direction, flow accumulation, and catchment basins using algorithms such as D8 flow direction and flow accumulation from DEM.

2. **Land cover**

   Land cover information was used to assess the surface runoff coefficient. In general, built-up land and intensive plantations such as oil palm have high runoff values compared to natural forests (Wijesekara et al., 2012).

3. **Rainfall**

   Daily to monthly spatial rainfall data were used from datasets such as CHIRPS or IMERG, which allow spatial analyses of precipitation in 5-10 km resolution (Funk et al., 2015). Extreme changes in precipitation patterns due to climate change were also a key consideration.

In general, this approach enriches the understanding of flood and fire risks in the IKN area and surroundings by integrating machine learning-based geospatial methods, including Random Forest for probability prediction, as well as modeling based on biophysical and anthropogenic indicators more adaptive to local conditions. The results not only provide an overview of risk status but also enable more targeted spatial planning and disaster mitigation. Table 2 shows the full list of datasets used, along with the source and spatial resolution.

To obtain a stable representation of environmental conditions without atmospheric disturbances such as clouds, shadows, and extreme temporal variations, the satellite image processing used

Table 2. Spatial Data Sources and Resolutions

Data	Resolution	Source
Distance to road	30 m x 30 m	OpenStreetMap
Distance to populated areas	100 m x 100 m	WorldPop Global Project Population Data
Land surface temperature	1 km x 1 km	MOD11A2.061 Terra Land Surface Temperature and Emissivity
Elevation	30 m x 30 m	NASA SRTM Digital Elevation
Slope	30 m x 30 m	
Topographic wetness index	30 m x 30 m	
Normalized Difference Vegetation Index	30 m x 30 m	Landsat 8 OLI Surface Reflectance (NIR & Red Band)
Land Cover	30 m x 30 m	Landsat 8 OLI Surface Reflectance
Precipitation	5 km x 5 km	CHIRPS

a composite image generation approach based on annual accumulation. The selected data was 2023 satellite imagery processed using two main statistical methods, namely the median function for vegetation and the mean for LST parameters.

The NDVI was calculated from the ratio between the near-infrared (NIR) spectrum and the red spectrum. High NDVI values show healthy and dense vegetation, while low values suggest open or degraded areas. The annual NDVI composite was calculated using the median function, which is statistically stronger against outliers such as the effects of clouds, haze, or reflections from water surfaces (Roy et al., 2014). This allows for a more representative annual vegetation map, crucial in identifying areas with high vegetation dryness, which is an indicator of fire risk.

LST is an important indicator in understanding the thermal conditions of an area. High values often correlate with land drought, low evapotranspiration, and increased fire potential and surface runoff. The LST estimation in this book was conducted using the thermal channels of Landsat images (bands 10 and 11 of Landsat 8), which were then converted using the surface thermal radiation emission algorithm (Chander et al., 2009). The mean function was used to form an annual ESG composite, representing the daily average temperature conditions in a year, assuming that the mean is better suited to describe long-term thermal trends than the median considered more sensitive to instantaneous variability.

This median- and mean-based composite approach provides several advantages:

- Reduces distortion due to clouds and shadows, which is often a major obstacle in optical image-based analyses in tropical areas such as Indonesia (Zhu & Woodcock, 2012).
- Maintains spatial and temporal continuity, making it easier to extract spatial patterns of disaster risk. It also produces a more consistent database for integration into spatial modelling of disaster risk for both forest fire and flood.

The combination of NDVI and LST in one analytical framework opens up opportunities to analyze the interaction between vegetative and thermal factors in triggering disaster risk. Low NDVI combined with high LST, for example, can show areas with dry vegetation and high-water stress, which are potential hotspots for land fire (Chuvieco et al., 2019). Similarly, areas with high LST and low NDVI downstream may show land-use changes that increase surface runoff and flood risk.

6.2 Modeling Disaster Risks

This book identifies and maps environmental variables that contribute to increased disaster risk, particularly forest fire and flood. The analysis was conducted through a spatial-quantitative approach based on remote sensing data and GIS, with the integration of statistical methods and machine learning to strengthen the validity of the results.

The analytical process is structured into several key stages as follows:

1. **Data Acquisition**

   The data used include optical and thermal satellite imagery (Landsat), topographic data (elevation and slope), distance to infrastructure (roads and settlements), and climatological data (precipitation and composite NDVI). All data were compiled for the base year 2023 to ensure temporal uniformity and avoid bias due to annual variability.

2. **Preprocessing**

   Preprocessing stage includes atmospheric correction, cropping of the IKN area and its surrounding watersheds, and generation of annual composites (NDVI and LST) using statistical functions (median and mean) to produce a stable environment representation without disturbances such as clouds and cloud shadows.

3. **Land Cover Classification**

   The land cover variable was classified using a machine learning-based classification approach based on the Random Forest algorithm. The model was trained on 1,200 sample points evenly distributed across 12 land cover classes (100 samples per class). Validation was assessed across 360 field test points (30 points per class), resulting in high model performance with an overall accuracy of 92%, as measured by the confusion matrix. Moreover, model performance was evaluated using additional metrics such as the kappa coefficient and producers/users accuracy to identify potential classification bias in each class.

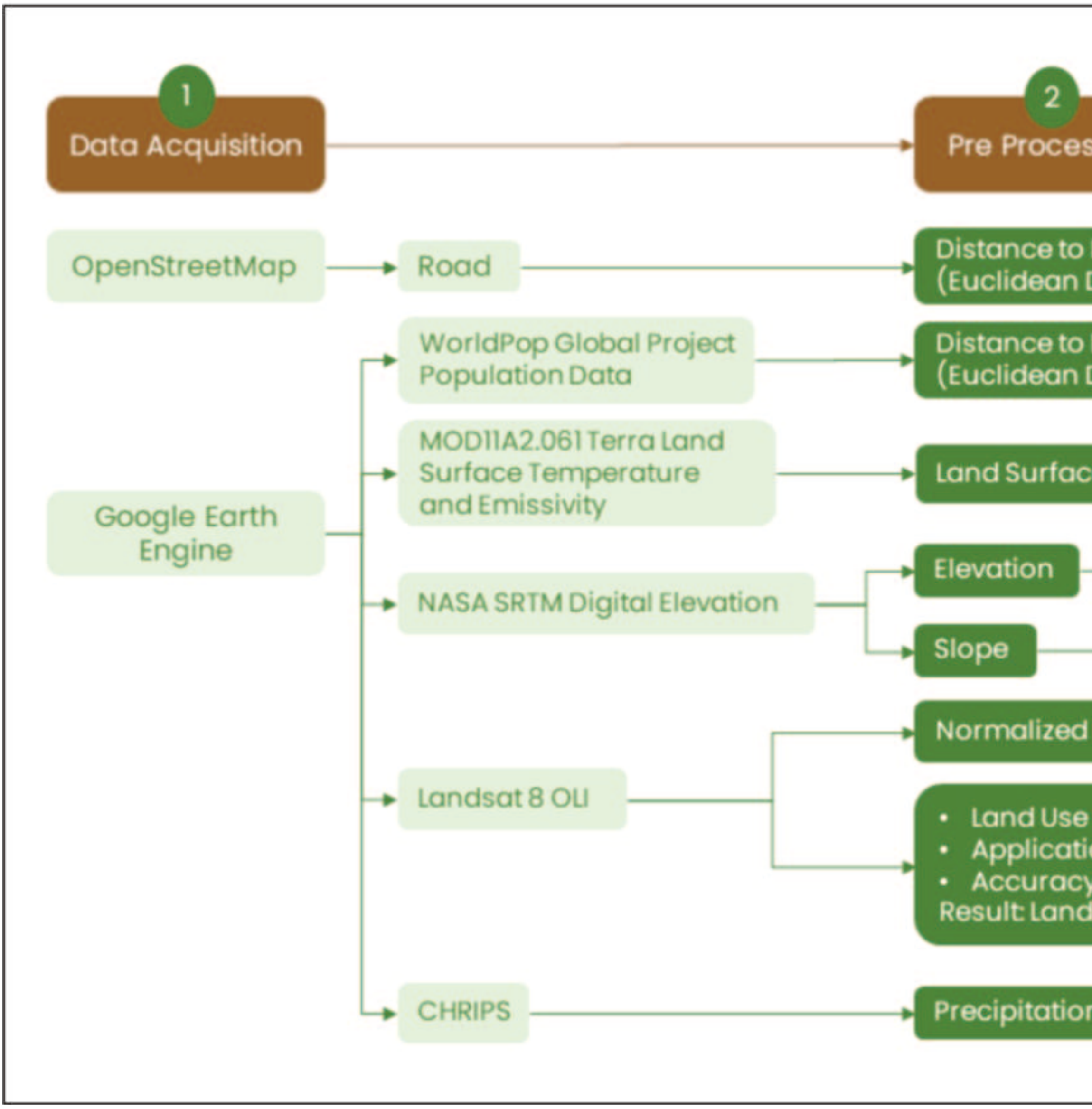
4. **Risk Assessment Based on Environmental Variables**

   Each environmental variable was classified based on risk tiers identified in previous literature and national policies (e.g. from MoEF or BNPB). This classification technique used natural breaks (Jenks) and quantile classification to spatially differentiate risk levels.

5. **Multivariable Interpretation and Integration**

   After the individual classifications, further analysis integrated all variables in a spatial framework to identify areas of high-risk overlap, which became the focus of priority mitigation. Overlay analysis and risk score-based weighting were used to interpret the results.

To support a clearer and systematic understanding, the entire workflow is showed through a flowchart (Figure 5) that outlines the sequential relationship between each stage of the analysis. This diagram offers a structured visualization of the analytical logic, showing the role of each component in contributing to a data-driven disaster risk modeling framework.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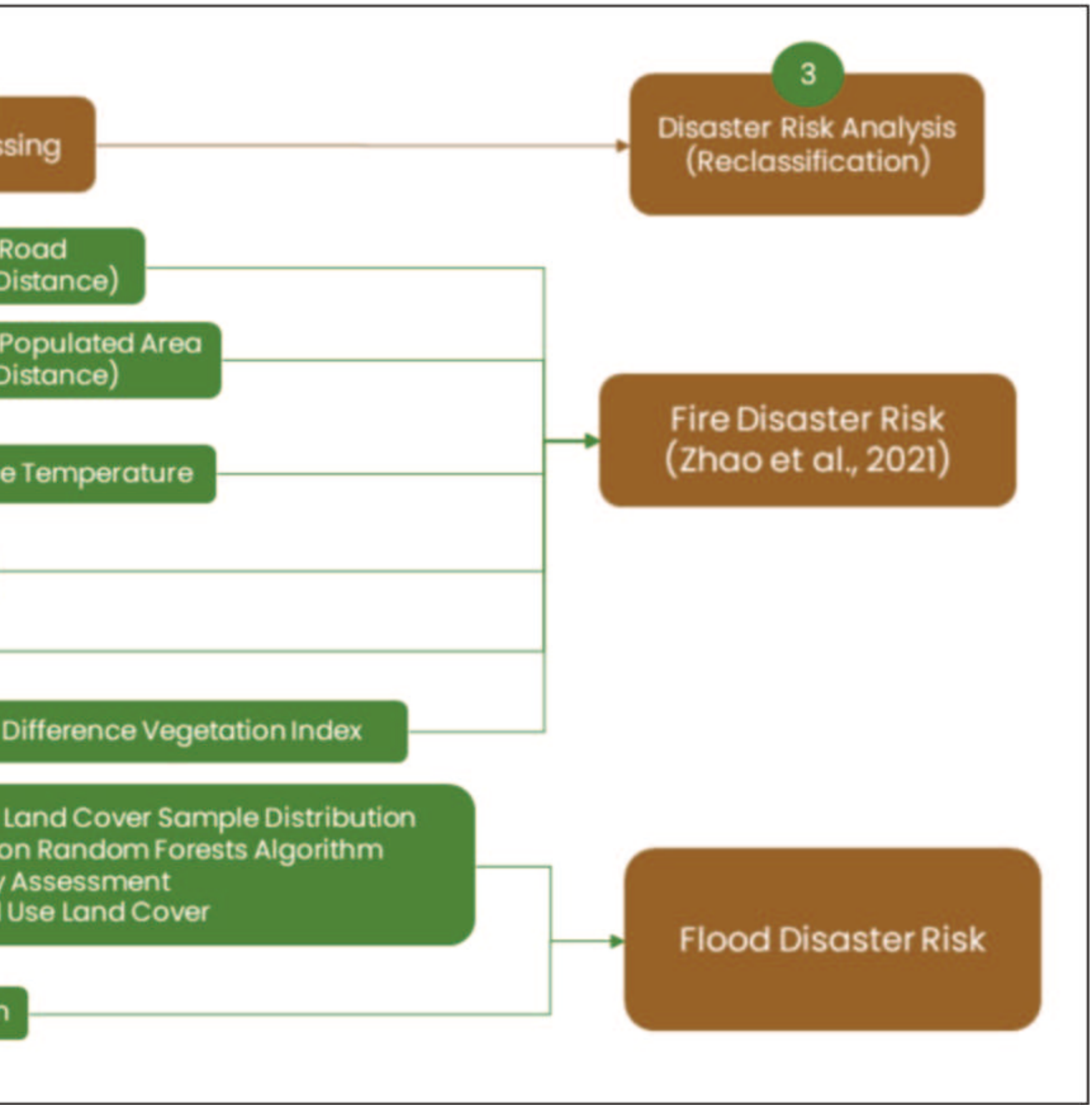


Figure 5. Steps of Disaster Risk Assessment Using Environmental Variables

7 Environmental Variables Contributing to Disaster

The disaster risk models of the IKN and the surrounding area show the various environmental factors that trigger fire and flood disasters. The analysis focused on the spatial characteristics and contribution of each variable (physical and anthropogenic) to increase the area risk of fire and flood disaster. In general, the results are organized into two main sections, namely, forest/land fire and flood.

7.1 Variables Contributing to Fire Disaster

The analysis identified seven main variables contributing to fire potential in the IKN area and its surrounding watersheds, namely:

- **Anthropogenic**: distance to the road and distance to populated area;
- **Climatic**: LST;
- **Topography**: elevation, slope, and TWI;
- **Vegetation**: vegetation index (NDVI).

Some previous studies have considered slope direction as a triggering variable because the orientation of slopes to sunlight can affect vegetation dryness and heat

Supplying the Capital: Sepaku Semoi Reservoir
Photo credit: Ari Susanti

accumulation (P. Zhao et al., 2021). However, since the study site was in the equatorial area with a relatively constant irradiation angle throughout the year, this variable was not included in the model.

7.1.1 Anthropogenic

Human activity is one of the primary factors contributing to forest and land fire. Several studies showed that accessibility and population density significantly contribute to fire risk (Balch et al., 2017; Cochrane, 2003). Accessibility through the road network serves as the main route for humans to reach an area. Areas situated near roads tend to experience greater human activity, which in turn increases the possibility of fire incidents. For example, vehicles travelling through dry areas can generate sparks from the exhaust system or illegal burn litter activities that facilitate the spread of fire (Gaveau et al., 2014).

The presence of settlements signifies concentrated human activity, including the use of fire for cooking, heating, and land clearing through burning. These practices significantly increase fire risk in populated areas due to the frequency and intensity (Archibald et al., 2013). In the context of forest fire in Indonesia, particularly in Kalimantan and Sumatra, numerous reports have linked the ignition sources to human activities, such as land clearing by burning (Tacconi, 2003). Beyond anthropogenic causes, geographical constraints also amplify the impact of fire. Many of the affected areas are remote and inaccessible to firefighting teams. When fire occur in densely populated areas with limited accessibility, suppression efforts are not optimized, allowing fire to spread faster and cause more extensive damage. This underscores the critical need for integrated, spatially informed risk management, institutional preparedness, and spatial planning that prioritizes accessibility for effective disaster response.

A. Distance to populated area

Populated areas serve as hubs of intensive and varied human activities, including domestic routines, commerce, and small-scale industries that can directly or indirectly elevate the risk of forest and land fire. Therefore, proximity to these settlements is a key variable in assessing fire risk.

Areas located near population centers are more likely to experience fire-related activities, both direct and indirect. Anthropogenic activities such as waste burning, the use of fire for domestic purposes (cooking and heating), and land clearing through burning are still prevalent in areas with high population density (Archibald et al., 2013; Giglio et al., 2013). Moreover, the risk of human-induced fire is generally worsened by dry environmental conditions and the abundant availability of natural fuels.

Based on Figure 6, the distance of populated areas can be categorized into five fire risk classes, as follows:

- **< 400 meters** (marked in red), which has a very high level of risk. Areas with this distance are directly under the influence of very intense human activity, hence, the risk of fire increases significantly.
- **400 – 600 meters** (marked in orange) has a high level of

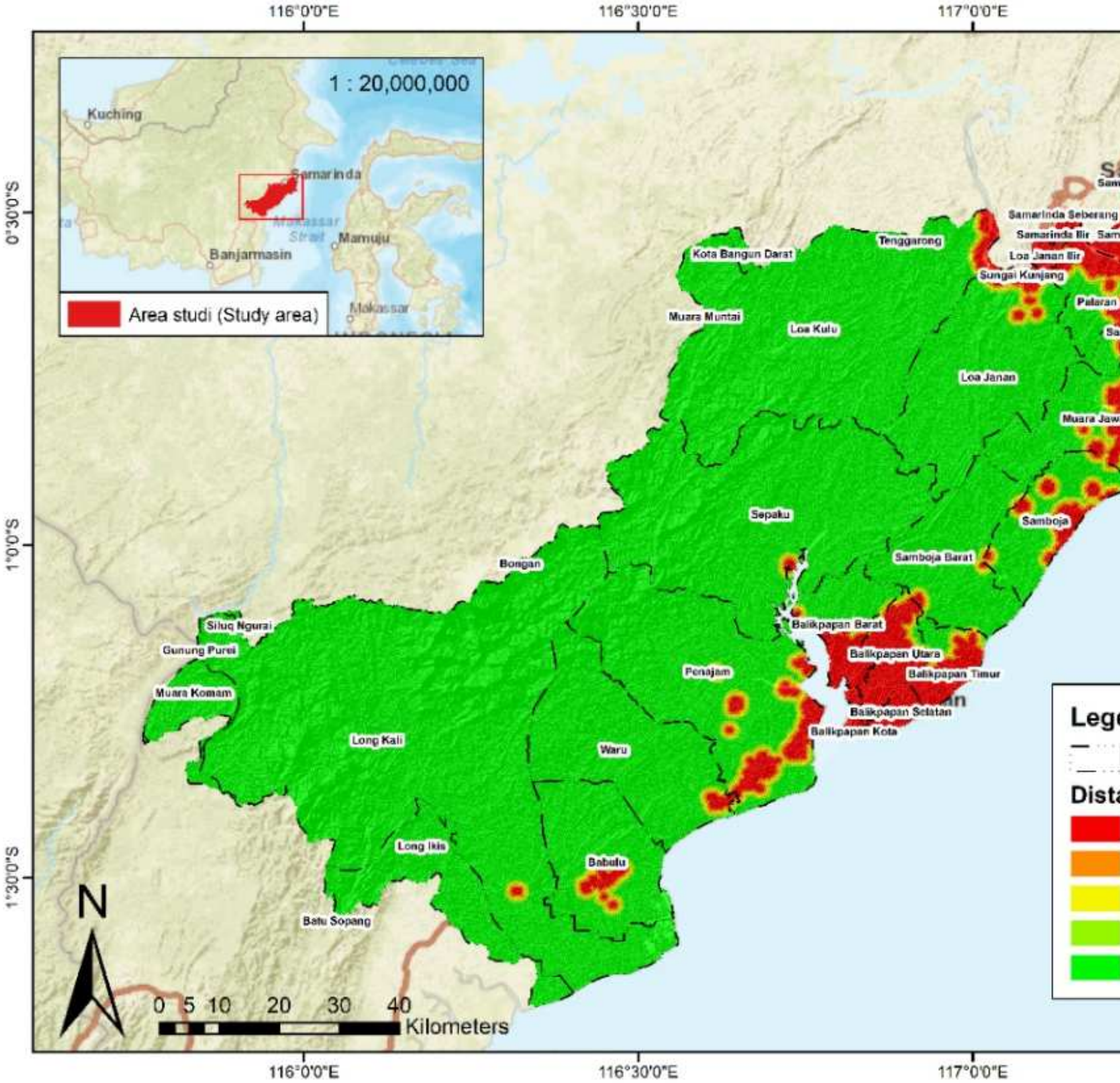


Figure 6. Spatial Distribution of Distance to Populated Area
Source: Spatial analysis, 2025

risk, showing areas that are still quite close to the center of human activity.

- **600 – 1.200 meters** (marked in yellow) is categorized as medium risk.
- **1.200 – 1.600 meters** (marked in light green) shows low risk because the effect of human activity starts to decrease.
- **> 1.600 meters** (marked in dark green), represents a very low level of risk. These areas are relatively far from population centers, and human activities that could potentially cause fire are minimal.

Novita & Vonnisa (2021) reported that the proximity of an area to populated areas significantly increases the risk of fire occurrence, due to the high concentration of human activities that have the potential to trigger fire sources. In addition, the economic and social aspects of an area, such as the level of population density, the dominant type of economic activity, and the presence of infrastructure, also play a role in strengthening the spatial pattern of fire risk (Thoha & Triani, 2021).

Further spatial analysis based on Figure 7 shows that very high levels of risk only covered around 7.9% of the total IKN area and its surrounding watersheds. In contrast, the majority of the area at 85.5%, fell into the very low risk category. The proportion of areas with a high level of risk was 2.3%, while the low and medium categories each covered 2.2% of the total area. The dominance of the very low risk classification can be attributed to the existing condition of the IKN area and its surrounding watersheds, which is characterized by a high proportion of green areas, particularly forests and plantations. These areas have relatively low levels of human intervention, which significantly reduces the potential risk of fire (Miettinen et al., 2011).

The model demonstrates that areas measuring less than 400 meters from population centers are typically urban and districts in East Kalimantan Province. These areas include several districts in Samarinda City, namely Kota, Samarinda Ilir, Samarinda Seberang, Samarinda Ulu, and Samarinda Utara, as well as districts in Balikpapan City, comprising Balikpapan Kota,

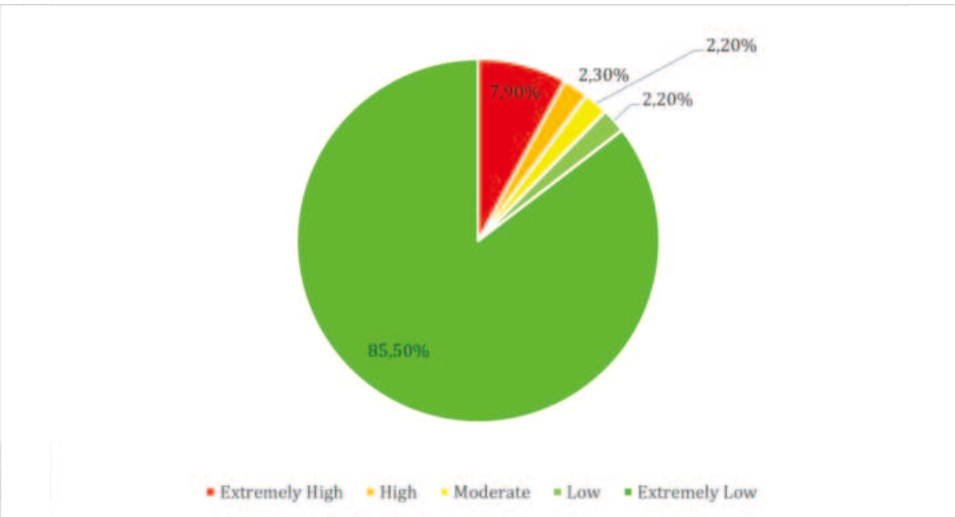


Figure 7. Share of Fire Risk Levels in 2025
Source: Statistical analysis result of fire risk 2025

Balikpapan Timur, Balikpapan Utara, Balikpapan Selatan, and Balikpapan Barat. Samarinda and Balikpapan Cities are the main gateway to East Kalimantan Province and, alongside with Penajam Paser Utara and Kutai Kartanegara Regencies, play a strategic role as partner areas in the development of the IKN to become Indonesia new capital (Bappenas, 2021).

Table 3. Distance to Populated Area by District

District	Regency/City	Spatial Distribution of Distance to Populated Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Anggana	Kutai Kartanegara	9,472	3,453	3,017	2,656	85,901
Babulu	Penajam Paser Utara	1,766	1,364	1,379	1,366	36,691
Balikpapan Barat	Balikpapan	6,382	627	720	797	10,725
Balikpapan Kota	Balikpapan	1,083				
Balikpapan Selatan	Balikpapan	3,827				
Balikpapan Tengah	Balikpapan	1,086				
Balikpapan Timur	Balikpapan	7,372	951	793	632	2,172
Balikpapan Utara	Balikpapan	11,273	937	667	450	426
Batu Sopang	Paser					220
Bongan	Kutai Barat					393
Gunung Purei	Barito Utara					302
Kota Bangun	Kutai Kartanegara					1,686
Loa Janan	Kutai Kartanegara	2,770	1,286	1,440	1,221	62,608
Loa Janan Ilir	Samarinda	2,836	124	6		
Loa Kulu	Kutai Kartanegara	2,419	616	496	468	134,690
Long Ikis	Paser					32,228

District	Regency/City	Spatial Distribution of Distance to Populated Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Long Kali	Paser	189	250	357	452	252,824
Muara Badak	Kutai Kartanegara	5,154	2,184	2,524	2,571	24,484
Muara Jawa	Kutai Kartanegara	6,736	2,938	2,783	2,544	36,637
Muara Komam	Paser					14,403
Muara Muntai	Kutai Kartanegara					47
Palaran	Samarinda	6,941	2,250	1,570	1,149	7,186
Penajam	Penajam Paser Utara	7,538	3,632	3,859	3,911	70,170
Samarinda Ilir	Samarinda	176				
Samarinda Kota	Samarinda	81				
Samarinda Seberang	Samarinda	1,017				
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda	1,352		0		
Samboja	Kutai Kartanegara	3,972	2,335	2,579	2,655	16,452
Sambutan	Samarinda	357	439	689	940	39,033
Sanga-Sanga	Kutai Kartanegara	4,932	487	327	272	324
Sepaku	Penajam Paser Utara	3,281	826	688	649	4,723
Siluq Ngurai	Kutai Barat	268	244	333	440	126,254
Sungai Kunjang	Samarinda					613
Sungai Pinang	Samarinda	112	0			
Tenggarong	Kutai Kartanegara					161
Waru	Penajam Paser Utara	860	467	489	534	58,947

Source: Statistic analysis result on the distribution of distance from populated area, 2025

As shown in Table 3, North Balikpapan district had the largest area in the very high fire risk category, reaching 11,273 hectares. This result reinforces the opinion that urban area or district have a higher level of fire risk than non-urban areas. In general, the IKN area and its surrounding watersheds showed a relatively low level of fire risk in terms of proximity to populated centers. This is because the areas were dominated by forests and plantations, which naturally have a lower intensity of human activity, reducing the potential for fire. However, environmental conditions such as extreme weather and prolonged dry seasons remain critical factors that can elevate fire risk (Gaveau et al., 2014).

Aside from population proximity, the accessibility and response capacity of firefighting teams are also critical factors in fire risk management. Areas near population centers typically benefit from better infrastructure and quicker emergency response, enabling more effective fire control (Tacconi, 2003). Although remote or sparsely populated centers may statistically show a lower possibility of fire ignition, limited access and inadequate infrastructure may significantly worsen the consequences of a fire outbreak.

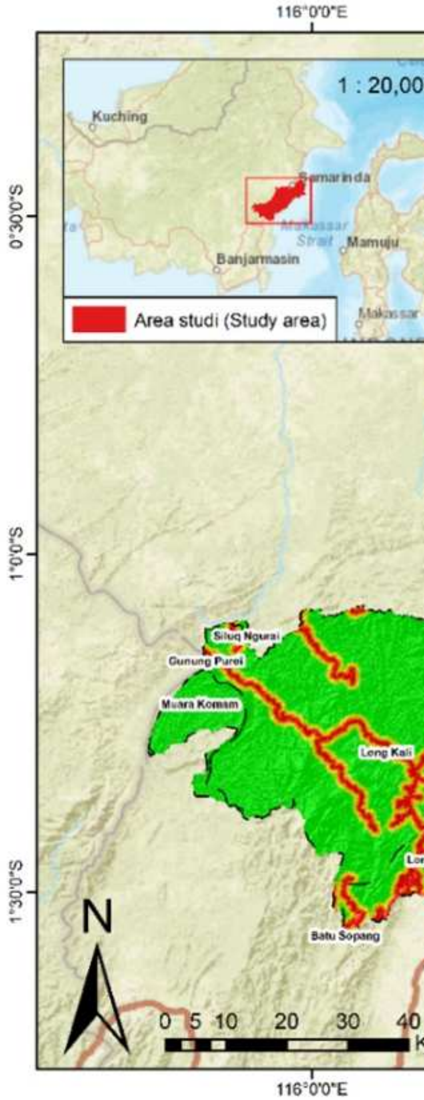
Distance to populated areas serves as a crucial variable in fire risk mapping, both in identifying potential fire triggers due to anthropogenic activities and a basis for developing more comprehensive mitigation and response strategies. Furthermore, very high-risk levels are generally located in urban and district service centers, such as districts in Samarinda Kota, Samarinda Ilir, Samarinda Seberang, Samarinda Ulu, and

Samarinda Utara, as well as Balikpapan Kota, Balikpapan Timur, Balikpapan Utara, Balikpapan Selatan, and Balikpapan Barat. These two cities not only act as centers of economic and administrative activity, but are also an integral part of the buffer zone of IKN and the main gateway to East Kalimantan Province. The results show that although proximity to populated areas does not directly determine the level of hazard, this variable is still relevant as an indicator in the spatial analysis of fire risk.

B. Distance to the main road

Accessibility provided by the road network plays a strategic role in determining the level of human interaction with the surrounding environment. Road serves as the primary infrastructure that enables mobility, resource distribution, and access to certain areas, thereby directly influencing the intensity of human activities. In the context of forest and land fire, the distance of an area to the road network is a critical variable that significantly affects the level of fire risk (Masoudian et al., 2025).

Areas located closer to road networks typically experience higher levels of human



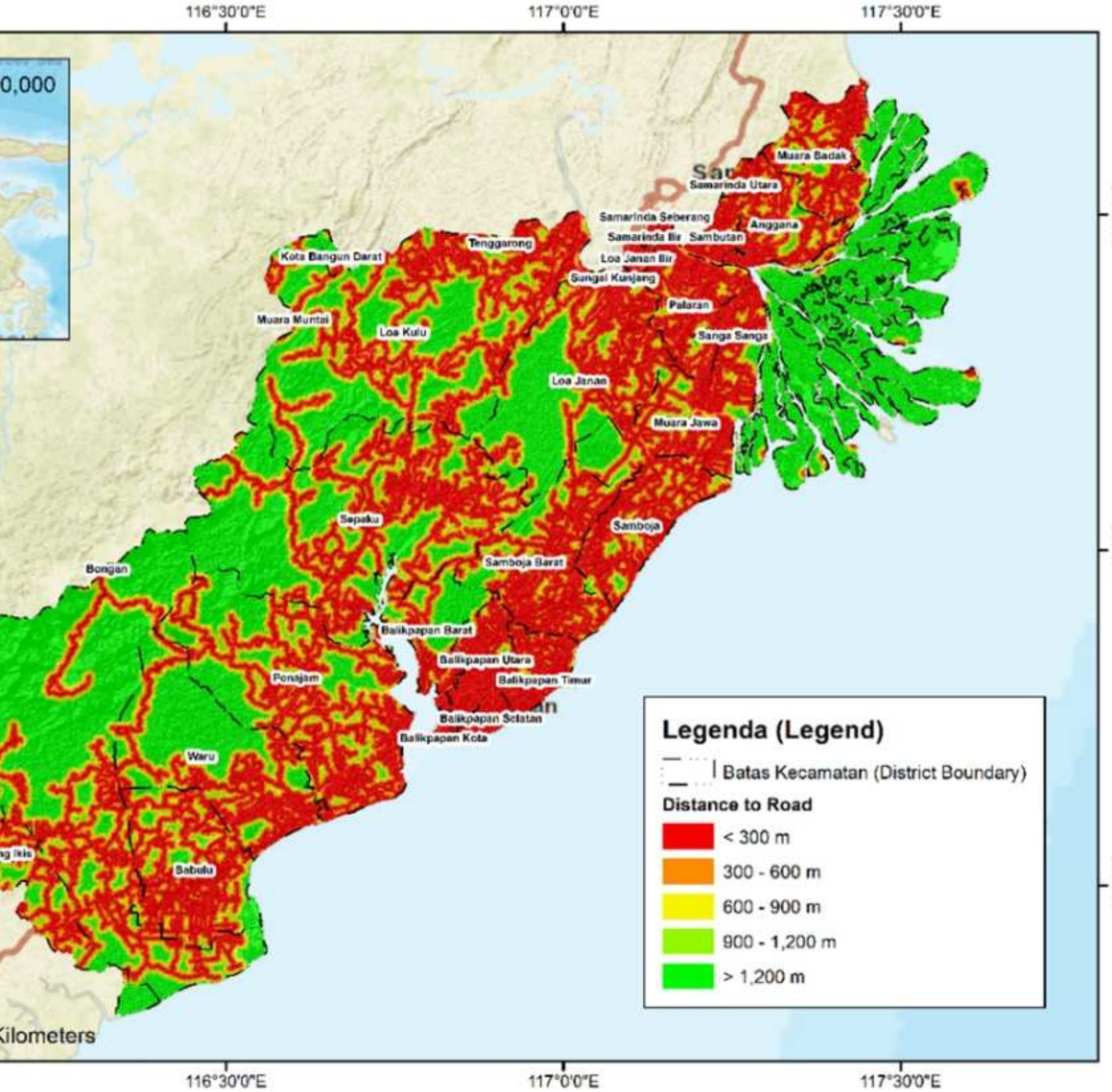


Figure 8. Spatial Distribution of Distance to Road

Source: Spatial analysis, 2025

activity and anthropogenic disturbance, which can increase the tendency of fire-related incidents. Roads provide easier access, making the surrounding landscapes more risk to fire ignition from anthropogenic sources. For example, vehicles travelling along roads, specifically during the dry season or when vegetation is very dry, can trigger fire through various mechanisms. These include sparks from vehicle exhausts, carelessly discarded cigarette butts, and traffic accidents capable of triggering explosions or sparks that ignite nearby vegetation (Bowman et al., 2011; Cochrane, 2003).

Based on the map shown in Figure 8, distance from the road map in the IKN area and its surrounding watersheds is categorized into five classes, as follows:

- **< 300 meters** (marked in red), is an area with a very high level of fire risk due to easy and intense human access.
- **300 – 600 meters** (marked in orange), high fire risk areas are still highly affected by human activities.
- **600 – 900 meters** (marked in yellow), medium risk category.
- **900 – 1.200 meters** (marked in light green), low risk category.
- **> 1.200 meters** (marked in dark green), very low risk category, showing a long distance where human interaction is significantly reduced.

Compared to the current conditions as shown in Figure 6, areas close to the road network have a higher population density. This phenomenon is understandable given that accessibility is a basic need in supporting community daily activities. Road not only serves as a means of mobility, but also the primary corridor that supports the economic, social, and cultural activities of the community (Seto et al., 2012). Therefore, settlements and community activity centers tend to develop linearly following the main road network. This spatial pattern often intersects with the flow of rivers, which historically served as natural transportation routes, and the main source of water for domestic and agricultural needs (Turner et al., 2007). The relationship shows that roads and rivers influence not only where community settle, but also land use, thereby increasing environmental risks, including forest and land fire, as human activities tend to be more concentrated around these accessible areas.

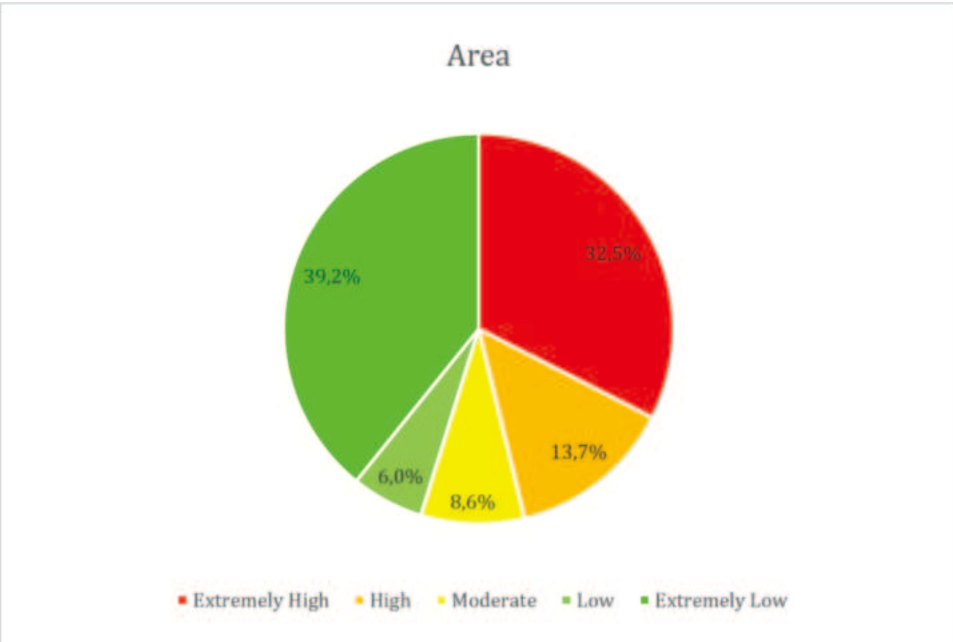


Figure 9. Share of Fire Risk Levels Based on the Distance to Road
Source: Statistical analysis, 2025

Table 4. Distance to Road by District

District	Regency/City	Spatial Distribution of Distance to Road Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Anggana	Kutai Kartanegara	14,332	5,548	3,103	2,013	79,503
Babulu	Penajam Paser Utara	23,131	9,553	4,761	2,374	2,748
Balikpapan Barat	Balikpapan	6,683	2,929	1,892	1,431	6,315
Balikpapan Kota	Balikpapan	1,083				
Balikpapan Selatan	Balikpapan	3,826	1			
Balikpapan Tengah	Balikpapan	1,086				
Balikpapan Timur	Balikpapan	10,476	1,233	202	8	
Balikpapan Utara	Balikpapan	11,440	1,321	464	260	268
Batu Sopang	Paser	18	28	50	52	72
Bongan	Kutai Barat	29	19	17	14	314
Gunung Purei	Barito Utara	37	37	36	30	163
Kota Bangun	Kutai Kartanegara	220	165	160	172	969
Loa Janan	Kutai Kartanegara	25,939	10,446	5,784	3,781	23,374
Loa Janan Ilir	Samarinda	2,714	240	11		
Loa Kulu	Kutai Kartanegara	45,294	24,146	17,023	12,957	39,271
Long Ikis	Paser	10,988	6,239	4,166	2,620	8,215
Long Kali	Paser	35,738	24,252	19,670	16,552	157,860
Muara Badak	Kutai Kartanegara	16,029	5,494	2,648	1,442	11,304
Muara Jawa	Kutai Kartanegara	19,119	7,073	4,191	3,089	18,166
Muara Komam	Paser					14,403
Muara Muntai	Kutai Kartanegara	47				
Palaran	Samarinda	15,019	3,087	862	127	

District	Regency/City	Spatial Distribution of Distance to Road Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Penajam	Penajam Paser Utara	36,245	17,913	11,246	6,673	17,032
Samarinda Ilir	Samarinda	173	3			
Samarinda Kota	Samarinda	76	6			
Samarinda Seberang	Samarinda	1,006	11			
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda	868	342	127	15	
Samboja	Kutai Kartanegara	19,090	5,771	2,171	730	231
Sambutan	Samarinda	25,253	7,851	3,537	1,819	2,998
Sanga-Sanga	Kutai Kartanegara	5,423	886	35		
Sepaku	Penajam Paser Utara	7,777	1,585	582	184	37
Siluq Ngurai	Kutai Barat	39,219	20,978	13,997	10,155	43,190
Sungai Kunjang	Samarinda	15	31	32	68	467
Sungai Pinang	Samarinda	71	41			
Tenggarong	Kutai Kartanegara	110	47	4		
Waru	Penajam Paser Utara	19,349	8,701	5,531	3,999	23,716

Source: Statistical analysis result of distance distribution to road, 2025

Figure 9 shows the spatial distribution of forest fire risk levels based on distance to the road network. Based on the data analysis, about 46.2% of the total IKN area and its surrounding watersheds falls into the high to very high-risk category. This result shows a strong correlation between the level of fire risk and the proximity of an area to the road network.

As shown in Table 4, the spatial distribution of distance to the road network indicates that Loa Kulu and Siluq Ngurai had the largest areas in the category of close distance, covering 45,294 hectares and 39,219 hectares, respectively. In terms of existing conditions, these two sub-districts have spatial characteristics where settlements and community activities tend to be centered along main roads that have historically also followed river flows. This pattern shows a strong relationship between the presence of road infrastructure, settlement patterns, and the intensity of socioeconomic activities (Hansen & DeFries, 2007a).

The concentration of human activity along major road corridors implies fire risk, specifically during the dry seasons. Activities such as agricultural or plantation land clearing through burning, domestic waste burning, and recreational activities in areas around roads are potential sources of fire triggers (Flannigan et al., 2009). Therefore, areas near road networks should be considered as high-priority in forest and land fire mitigation strategies.

Understanding the spatial pattern of fire risk in relation to distance to roads is crucial for effective landscape management planning and disaster mitigation policies. Some risk reduction strategies in areas near roads may include installing fire hazard warning signs along road corridors, enhancing access and preparedness for firefighting teams, particularly in zones with high human activity, and actively educating communities about hazardous practices and the importance of fire prevention.

Mitigation-based land management strategies should be strengthened in addition to socio-infrastructure approaches. These strategies include the creation of firebreaks along roadsides, management and clearance of dry fuels (dead and flammable vegetation), and intensive monitoring with early warning systems, specifically during the dry season or periods of extreme weather (Bowman et al., 2011).

7.1.2 Climate

A. LST

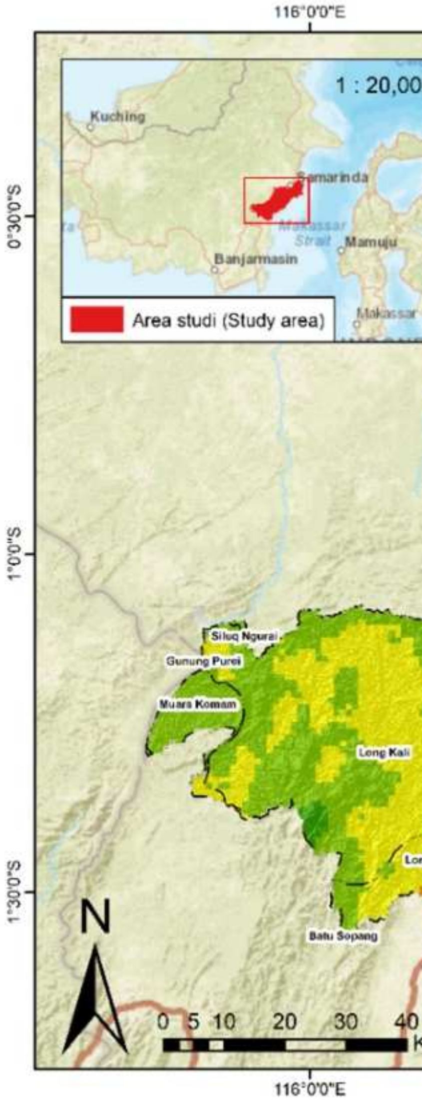
Climate is one of the primary natural factors that significantly contribute to wildfire risk. In general, climate elements, such as temperature, humidity, precipitation, and wind speed, strongly influence the degree of surface fuel dryness, oxygen availability, and rate of fire spread (Flannigan et al., 2009). Among these climate variables, LST is a key indicator in assessing potential fire risk because it directly influences the physical conditions of natural fuels and the surrounding environment that support fire (Jodhani et al., 2024).

Rising LST accelerates the drying process of vegetation, lowers air humidity, and increases the flammability of natural fuels such as dry leaves, twigs, and litter. Under dry and hot air conditions, vegetation becomes more flammable, hence, areas with high LST tend to have a higher fire risk (Rendana et al., 2023). In addition, these temperature increases are often closely related to anthropogenic activities, including deforestation and land use change, as well as the global warming phenomenon, which has cumulatively contributed to the trend of increasing air temperatures in various areas, including East Kalimantan.

LST analysis shows average values ranging from 27°C to 29°C in the IKN area and its surrounding watersheds. Based on this range, the area is classified into five categories of fire risk level. LST map in Figure 10 shows the spatial distribution of temperatures within these categories, providing a comprehensive visualization of areas with higher fire potential.

The moderate temperature category is the dominant class in the LST distribution, accounting for 61.1% of the total area, suggesting more than half of the IKN area and its surrounding watersheds is within the moderate fire risk zone, which still requires attention in the context of disaster mitigation. Rainfall factors strongly influence daily temperature variations, with low rainfall conditions leading to increased surface temperature, as well as decreased air humidity, which synergistically elevate the flammability of natural fuels and ultimately increase the risk of fire occurrence. Conversely, high rainfall contributes to lower LST and increased relative humidity, decreasing the potential for forest and land fire (Rendana et al., 2023).

Based on Table 5, the distribution of LST by district shows that Loa Kulu in Kutai Kartanegara Regency had the largest area in the high category, comprising both the high



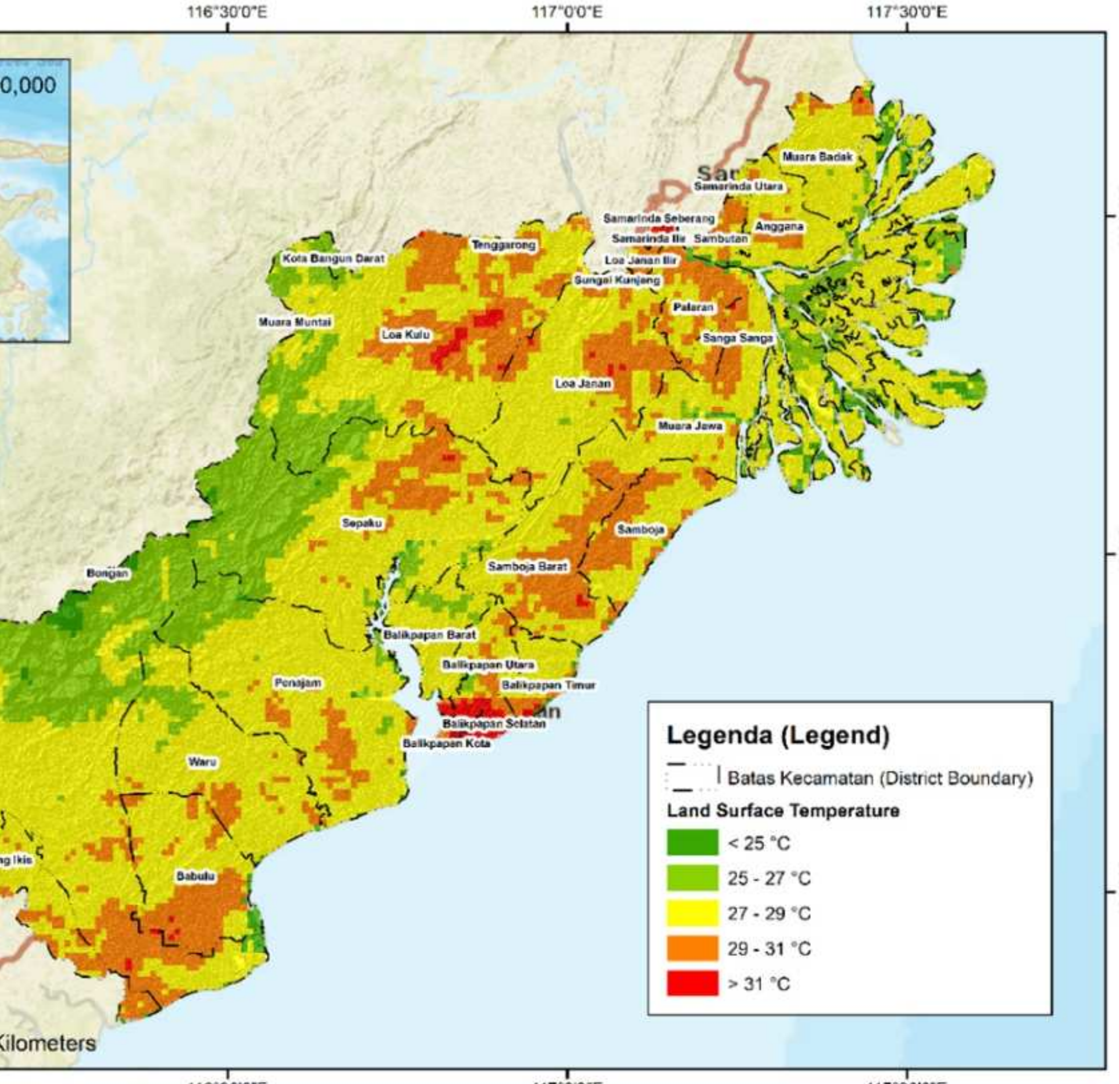


Figure 10. Spatial Distribution of Land Surface Temperature

Source: Spatial analysis, 2025

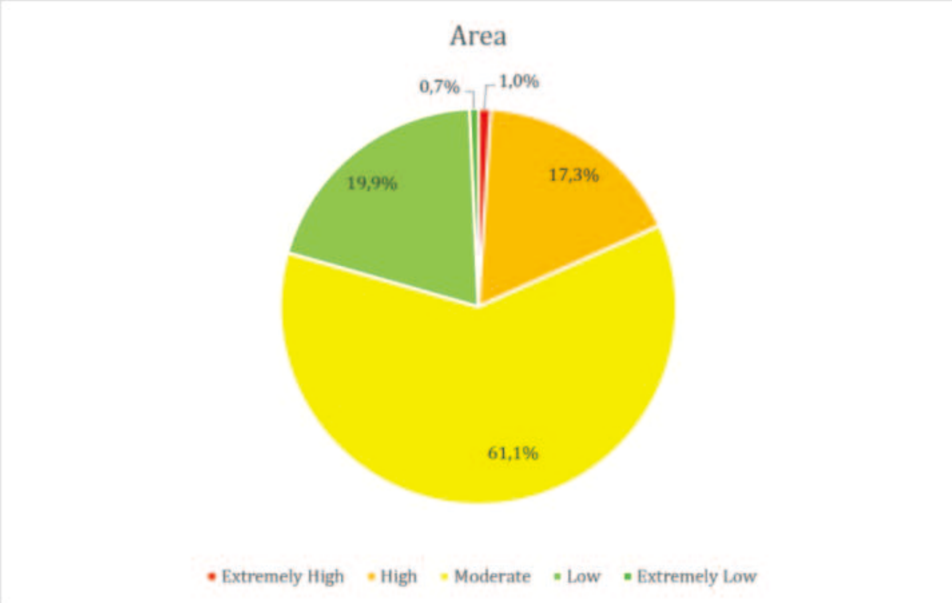


Figure 11. Share of Fire Risk Levels Based on Land Surface Temperature
Source: Statistical analysis, 2025

Table 5. Land Surface Temperature by District

District	Regency/City	Spatial Distribution of Land Surface Temperature Class (ha)				
		Extremely Low	Low	Moderate	High	Extremely High
Anggana	Kutai Kartanegara	11,910	13,046	74,406	4,289	
Babulu	Penajam Paser Utara	1,175	2,846	23,504	17,360	362
Balikpapan Barat	Balikpapan	279		15,442	253	430
Balikpapan Kota	Balikpapan	148		12	363	520
Balikpapan Selatan	Balikpapan	51		63	861	2,786
Balikpapan Tengah	Balikpapan	14		7	151	915
Balikpapan Timur	Balikpapan	495		8,698	2,167	393
Balikpapan Utara	Balikpapan		658	7,987	3,686	1,422
Batu Sopang	Paser		167			

District	Regency/City	Spatial Distribution of Land Surface Temperature Class (ha)				
		Extremely Low	Low	Moderate	High	Extremely High
Bongan	Kutai Barat	161	137			
Gunung Purei	Barito Utara		95	130		
Kota Bangun	Kutai Kartanegara		1,554	51		
Loa Janan	Kutai Kartanegara	31	198	50,542	17,993	537
Loa Janan Ilir	Samarinda	32		488	2,333	56
Loa Kulu	Kutai Kartanegara		25,767	72,004	36,938	3,011
Long Ikis	Paser	154	3,415	20,615	7,080	
Long Kali	Paser	7,735	103,584	123,927	17,162	333
Muara Badak	Kutai Kartanegara	3,306	1,406	29,331	2,299	99
Muara Jawa	Kutai Kartanegara	3,860	1,395	38,599	7,504	
Muara Komam	Paser		11,919	1,464		
Muara Muntai	Kutai Kartanegara		0	12		
Palaran	Samarinda	676		7,537	10,860	22
Penajam	Penajam Paser Utara	803	12,562	66,429	9,236	
Samarinda Ilir	Samarinda	41		1	35	52
Samarinda Kota	Samarinda	33				50
Samarinda Seberang	Samarinda	150		57	499	276
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda		198	1,076	0	
Samboja	Kutai Kartanegara	137		15,651	11,902	
Sambutan	Samarinda	89	254	22,398	18,326	298
Sanga-Sanga	Kutai Kartanegara	590		2,266	3,292	
Sepaku	Penajam Paser Utara	22	39	5,205	4,822	77
Siluq Ngurai	Kutai Barat	1,981	43,368	65,095	16,621	198
Sungai Kunjang	Samarinda		414	96		

Source: Statistical analysis results of land surface temperature, 2025 and extremely high classes. This was followed by Sambutan in Samarinda City and Loa Janan in Kutai Kartanegara Regency. In line with the spatial distribution pattern, high-risk levels for forest and land fire are generally located in areas with high population density, which can also increase fire risk due to human activities (see Figure 10).

7.1.1 Topographic

Topography is one of the environmental factors that significantly influences the level of risk and dynamics of forest and land fire behavior. It reflects the morphological characteristics of the Earth surface, including elements such as elevation, slope, aspect, and TWI. These four elements collectively influence fire spread patterns, movement speed, and intensity in an area. Therefore, topographic analysis is a crucial component of spatially-based fire risk assessment. For example, steep slopes can accelerate the spread of a fire event because heat and fire tend to move upslope more quickly than on flatter terrain.

Elevation determines air temperature and humidity conditions, which indirectly affect the dryness of natural trigger fuel such as

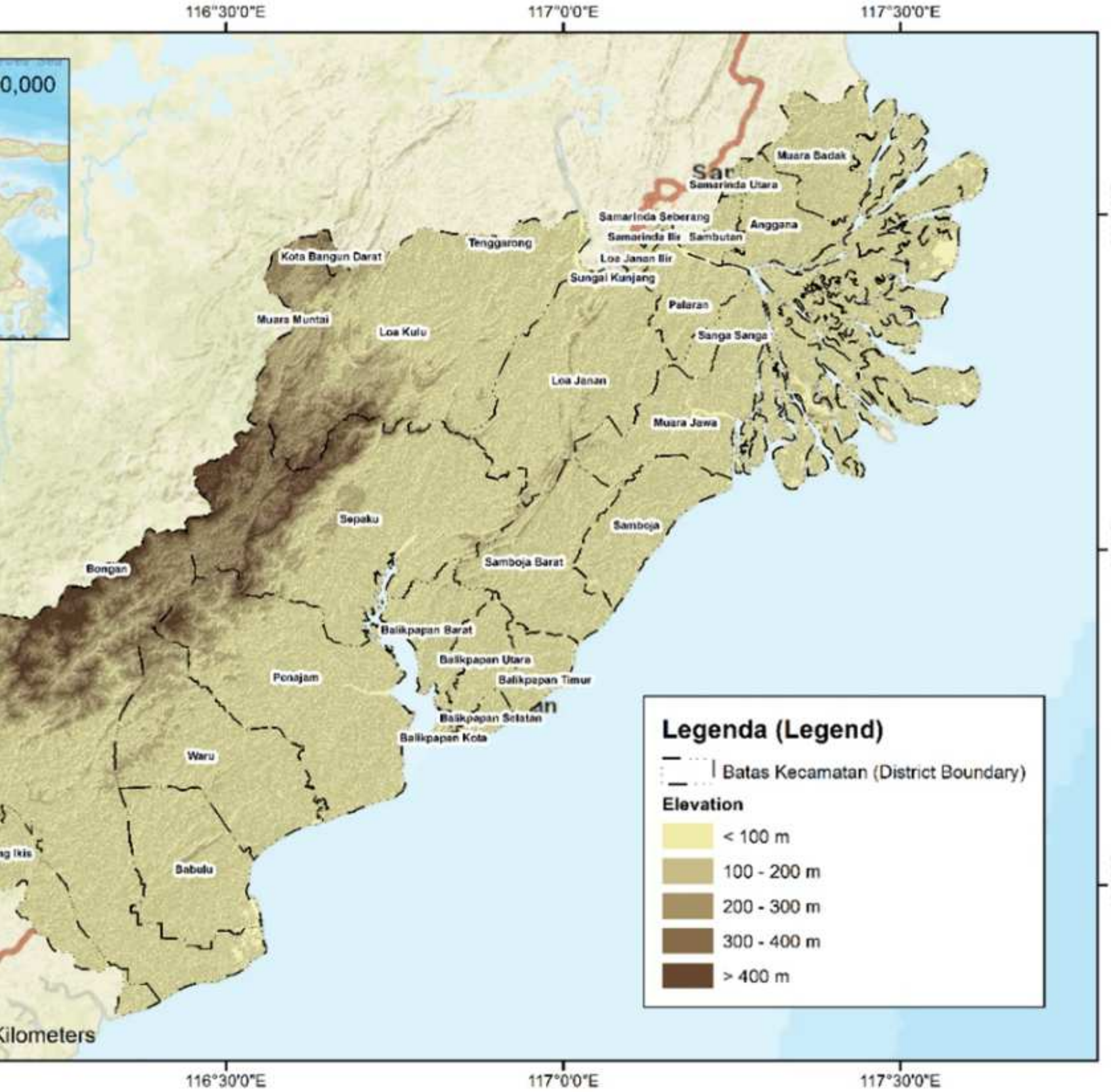


Figure 12. Spatial Distribution of Elevation

Source: Spatial analysis, 2025

litter and understory vegetation. Slope direction is also an important factor as it relates to the level of exposure to solar radiation, which affects the temperature and humidity of the vegetation. However, in tropical areas close to the equator (East Kalimantan), variations in irradiance due to slope direction are relatively small, as sunlight intensity is relatively even throughout the year (Viedma, 2008).

A. Land elevation

Land elevation, which refers to the height of a location above sea level, is a crucial topographic variable in assessing forest fire risk. Low elevation areas generally tend to have higher humidity levels due to increased potential for water accumulation and relatively warmer temperatures. However, these low areas are also prone to the buildup of dry, flammable materials (leaves and twigs), specifically during the dry season, which increases fire

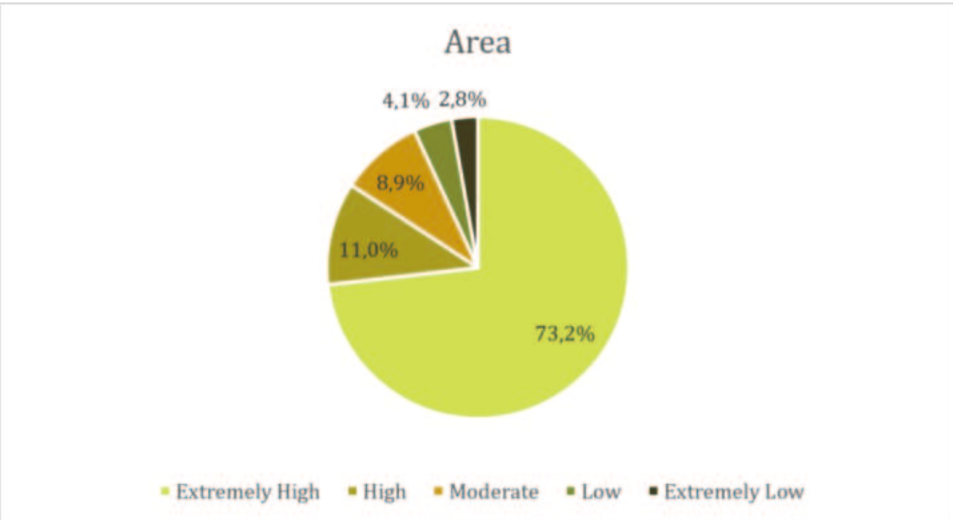


Figure 13. Share of Fire Risk Levels Based on Elevation
Source: Statistical analysis, 2025

risk. High-elevation areas, on the other hand, tend to have lower temperatures and higher relative humidity, reducing fire risk.

The land elevation map was classified into several elevation classes, with different gradation colors. Elevations less than 100 meters above sea level (MASL) were given the light gradation color, while the highest elevations of more than 400 MASL were marked with the dark gradation color. Fire risk level was subsequently classified into five categories based on elevation. These categories are based on the assumption that the lower the elevation, the greater the susceptibility to fire risk, due to higher ambient temperature, lower humidity level, and increased accumulation of combustible surface fuels (Finney, 2005; Keeley, 2009).

Spatial analysis shows that the IKN area and its surrounding watersheds was dominated by lowland areas, with approximately 73.2% of the total area situated at elevations below 100 MASL. This topographic characteristic suggests a high potential for fire risk, particularly when combined with biophysical factors and the typically higher intensity of human activity in lowland zones. Geographically, these lower elevations are commonly found along alluvial plains and river corridors, which historically function as natural transportation routes and hubs of settlement. The convergence of low elevation, easy accessibility, and dense human activity contributes to an increased risk of both natural and human-induced forest and land fire.

Based on Table 6, Long Kali district had the largest expanse of low-elevation land, covering 19,384 hectares. This condition can

Table 6. Elevation by District

District	Regency/City	Spatial Distribution of Elevation Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Anggana	Kutai Kartanegara	104,169	157	77	37	55
Babulu	Penajam Paser Utara	41,992	574			
Balikpapan Barat	Balikpapan	18,925	325			
Balikpapan Kota	Balikpapan	1,082	0			
Balikpapan Selatan	Balikpapan	3,827				
Balikpapan Tengah	Balikpapan	1,086				
Balikpapan Timur	Balikpapan	11,919				
Balikpapan Utara	Balikpapan	13,753				
Batu Sopang	Paser			1	112	108
Bongan	Kutai Barat			12	62	316
Gunung Purei	Barito Utara		6	144	124	27
Kota Bangun	Kutai Kartanegara		201	1,330	154	
Loa Janan	Kutai Kartanegara	64,912	4,379	34		
Loa Janan Ilir	Samarinda	2,918	48			
Loa Kulu	Kutai Kartanegara	84,633	30,825	16,609	4,961	1,664
Long Ikis	Paser	23,654	2,967	2,975	1,777	854
Long Kali	Paser	88,909	64,898	57,470	23,405	19,384
Muara Badak	Kutai Kartanegara	36,765	148			
Muara Jawa	Kutai Kartanegara	51,149	489			
Muara Komam	Paser		935	9,605	3,171	690
Muara Muntai	Kutai Kartanegara		17	30		
Palaran	Samarinda	19,038	57	0		

District	Regency/City	Spatial Distribution of Elevation Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Penajam	Penajam Paser Utara	74,116	7,295	4,754	1,870	1,075
Samarinda Ilir	Samarinda	176	0			
Samarinda Kota	Samarinda	82				
Samarinda Seberang	Samarinda	995	22			
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda	1,346	6			
Samboja	Kutai Kartanegara	27,993	0			
Sambutan	Samarinda	39,500	1,957	1		
Sanga-Sanga	Kutai Kartanegara	6,342				
Sepaku	Penajam Paser Utara	10,165				
Siluq Ngurai	Kutai Barat	76,105	11,974	14,034	14,537	10,888
Sungai Kunjang	Samarinda		2	524	84	2
Sungai Pinang	Samarinda	112				
Tenggarong	Kutai Kartanegara	161	0			
Waru	Penajam Paser Utara	50,844	8,297	1,898	257	

Source: Statistical analysis, 2025

be attributed to the geographical location of the Long Kali district, which is situated in the lowlands and follows the main river course, naturally facilitating the accumulation of surface fuel, such as litter, dry leaves, and twigs. In addition, the position along the river path also makes the district a strategic location for community activities, including settlements, agriculture, and local transportation. The high interaction between humans and the environment in the low-elevation area increases the

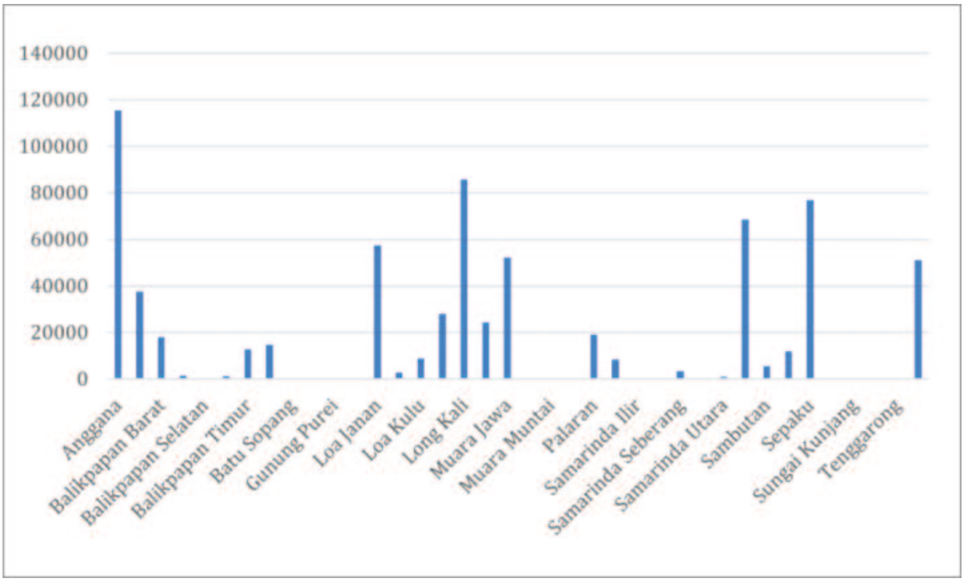


Figure 14. District with High Fire Risk Level
Source: Statistical analysis, 2025

potential for fire, either through land-clearing practices with fire, burning garbage, or other activities that risk creating sources of fire.

Land elevation has a multifaceted influence on forest fire risk, which can be explained by several mechanisms:

1. **Variation of climatic conditions and microclimate**
   Elevation plays a role in determining air temperature and relative humidity. Lowland areas typically experience higher temperatures and lower humidity, which causes vegetation to dry out easily and become susceptible to fire (Bradstock et al., 2010). Conversely, higher elevation areas typically have cooler temperatures and greater relative humidity conditions that help maintain vegetation moisture, reducing the likelihood of fire occurrence (Agee, 1993).

2. **The influence of species and vegetation condition**
   Vegetation type and fuel conditions are closely influenced by elevation. Lowland areas are often dominated by fire-prone fuels such as dry grasses, shrubs, and accumulated leaf litter. In contrast, highland areas typically support denser and more moisture-rich vegetation, which lowers the probability of fire ignition and spread (Gill et al., 2013).
3. **The influence of wind patterns and fire spread**
   Elevation affects wind movement patterns, which determines the direction and speed of fire spread. Winds moving downhill from a mountainside can accelerate fire spread, while uphill winds from a mountainside can slow or even help the firefighting process (Sharples et al., 2012).

The IKN area and its surrounding watersheds topographic condition, which is mostly at an elevation below 100 MASL, poses a very high risk of forest and land fire. This requires special treatment in area management and fire mitigation planning, specifically in lowland areas with higher fire risk. Priority efforts such as early monitoring, dry fuel load management, and regulation of human activities should focus on areas with similar elevation characteristics.

B. Land Moisture

Land moisture is one critical parameter that influences an area risk of forest and land fire. It is related to elevation, with higher elevations retaining more land moisture, while lowland areas typically have lower moisture levels. This pattern is influenced by hydrological processes, including surface runoff,

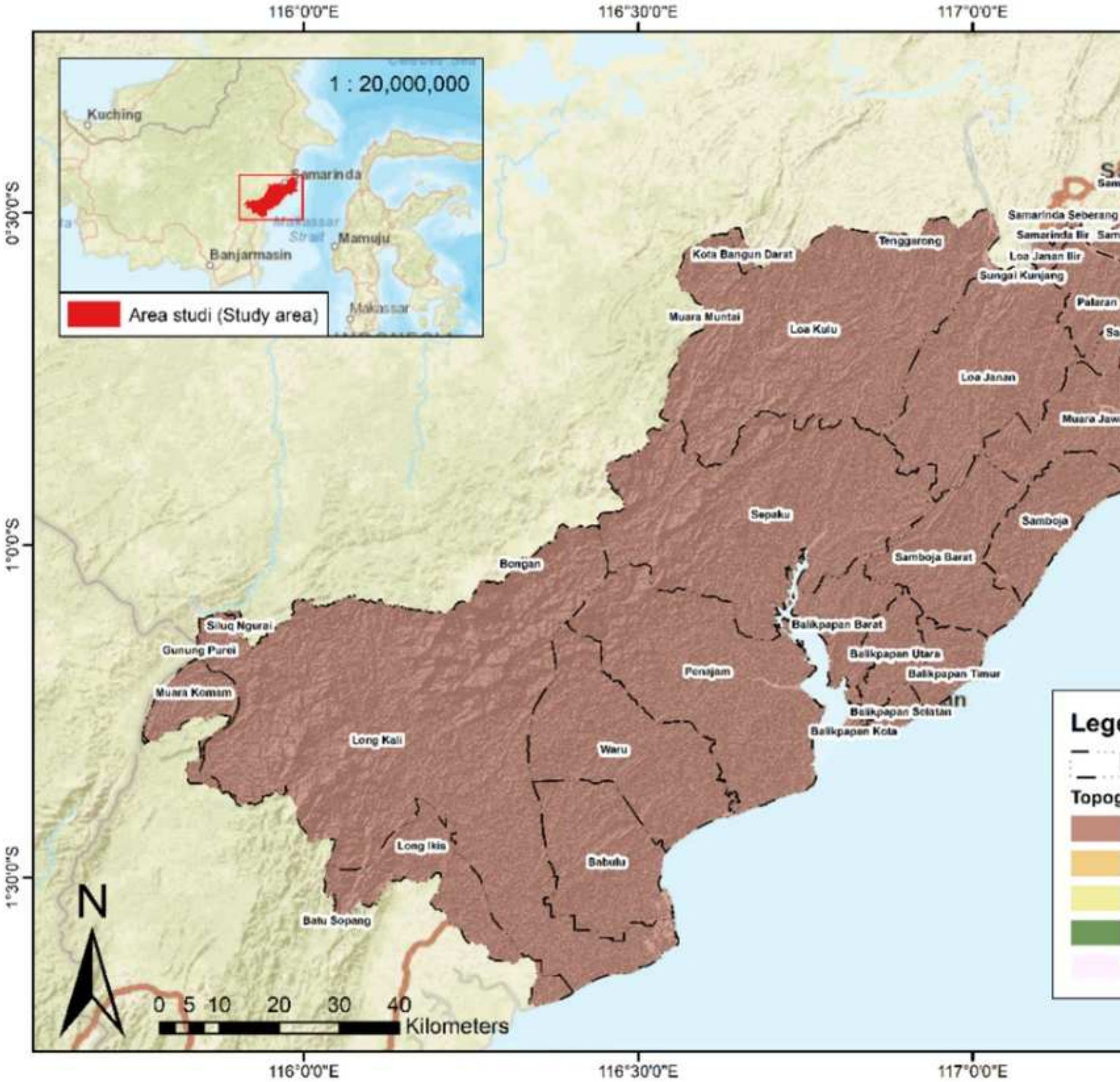


Figure 15. Spatial Distribution of Land Moisture
Source: Spatial analysis, 2025

infiltration, and evaporation, all of which are shaped by the area topographic characteristics (Sidle & Ziegler, 2012).

Although the IKN area and its surrounding watersheds showed significant variations in land elevation, the overall land moisture characteristics were relatively uniform, with a predominance of low-moisture conditions. TWI was used as a key indicator of soil moisture and fire risk. TWI provides an estimate of groundwater accumulation potential based on topographic features (Beven & Kirkby, 1979). By incorporating both catchment area and slope, the index offers a more accurate representation of moisture distribution across the landscape.

Based on the analysis result, the IKN area and its surrounding watersheds showed a very high dominance in the TWI category < 7, covering about 99.91% of the total area. This condition shows that nearly the entire area has very low land moisture levels and limited potential for water accumulation. Land with low moisture has a minimal water storage capacity, making it highly susceptible to ignition and fire spread, specifically during the long dry season or rapid transition to a wet season (van der Werf et al., 2009).

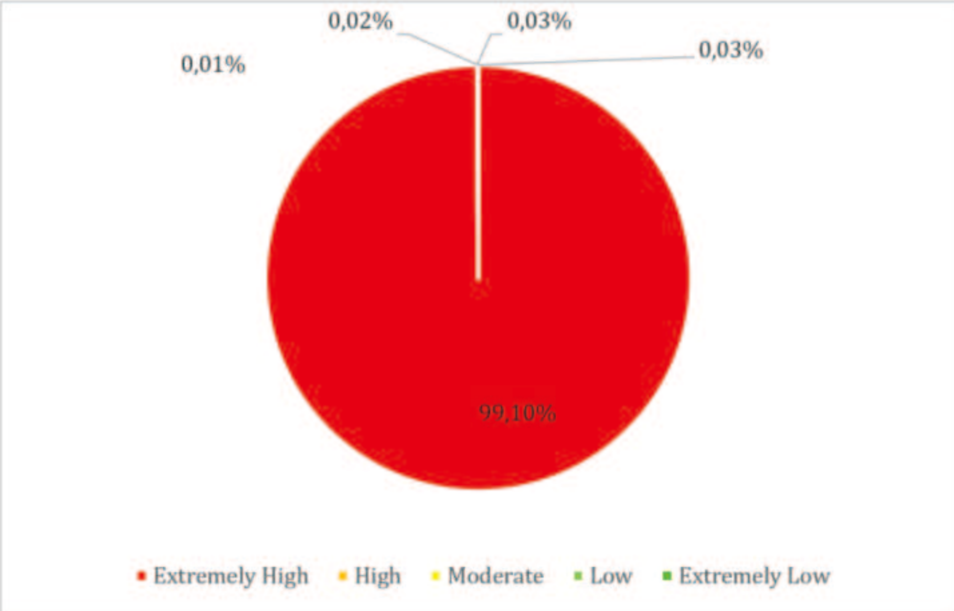


Figure 16. Share of Fire Risk Levels Based on Land Moisture
Source: Statistical analysis, 2025

TWI is a crucial variable in determining the distribution of land moisture and vegetation conditions within a given area. Areas with high TWI values show a higher possibility for surface water accumulation, resulting in a high level of land moisture. This condition has a positive impact on the lifespan of vegetation because trees become more resistant to drought, and the potential for fire decreases due to the high-water content in the soil, which prevents fire from starting and spreading (Keeley, 2009). In contrast, areas with low TWI values are characterized by low water accumulation capacity and soil moisture. Vegetation in these areas is more prone to water stress, which can lead to highly flammable surface fuels during the dry season or extreme weather conditions. Consequently, areas with low TWI tend to be hotspots of fire risk, particularly when combined with intensive human activities (Dingman, 2015).

In the IKN area and its surrounding watersheds, soil moisture was mostly characterized by TWI <7, suggesting a dry land condition with low resistance to fire spread. The low land moisture levels also correlated with intense anthropogenic activities, such as the presence of settlements, community activity centers, and open land. According to Bowman et al. (2011), the ecological carrying capacity for water storage is generally very limited due to the disruption of soil structure and the loss of cover vegetation, which functions to maintain moisture, specifically in former mining areas. Under these conditions, the surface organic material, such as dry leaves, twigs, and dead vegetation, dries faster, producing a significant volume of flammable fuel. The situation is worse in areas with poor land cover, where maintaining soil moisture is challenging and surface fuel accumulation is also uncontrolled, thereby significantly increasing the fire risk (Certini et al., 2021).

The results showed that ecologically, the IKN area and its surrounding watersheds had a very high level of fire risk, specifically because the coverage included settlements, community activity areas, and ex-mining land, all characterized by low capacity in maintaining soil moisture. Therefore, in the framework of forest and land fire management and mitigation, the level of soil moisture, represented by the TWI value, should be used as one of the primary parameters. The integration of land moisture information into risk modeling and early warning systems can help design more targeted strategies, including prioritizing dry land rehabilitation, providing outreach to the community, and installing fire control infrastructure.

Table 7. Land Moisture by District

District	Regency/City	Spatial Distribution of Topographic Wetness Index Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Anggana	Kutai Kartanegara	104,441	35	12	4	6
Babulu	Penajam Paser Utara	42,560	4	1	1	2
Balikpapan Barat	Balikpapan	19,245	0	2	2	2
Balikpapan Kota	Balikpapan	1,082	0	0		
Balikpapan Selatan	Balikpapan	3,827	0	0		
Balikpapan Tengah	Balikpapan	1,086	0			
Balikpapan Timur	Balikpapan	11,914	1	1	0	3
Balikpapan Utara	Balikpapan	13,748	0	2	2	
Batu Sopang	Paser	220				
Bongan	Kutai Barat	392				
Gunung Purei	Barito Utara	300				
Kota Bangun	Kutai Kartanegara	1,687				
Loa Janan	Kutai Kartanegara	69,309	3	7	1	5
Loa Janan Ilir	Samarinda	2,965		0	1	18
Loa Kulu	Kutai Kartanegara	138,672	5	2		
Long Ikis	Paser	32,223	1		0	
Long Kali	Paser	254,048	8	1	2	10
Muara Badak	Kutai Kartanegara	36,900	7	2	5	
Muara Jawa	Kutai Kartanegara	51,594	9	9	8	17
Muara Komam	Paser	14,402				
Muara Muntai	Kutai Kartanegara	46				
Palaran	Samarinda	19,071	4	8	1	12

District	Regency/City	Spatial Distribution of Topographic Wetness Index Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Penajam	Penajam Paser Utara	89,068	3	2	5	30
Samarinda Ilir	Samarinda	176				0
Samarinda Kota	Samarinda	80				1
Samarinda Seberang	Samarinda	1,008	0	0		9
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda	1,351	0	0		
Samboja	Kutai Kartanegara	27,985	3	2	1	1
Sambutan	Samarinda	41,453	1	1	1	1
Sanga-Sanga	Kutai Kartanegara	6,331	4	0	1	5
Sepaku	Penajam Paser Utara	10,165	0	0		
Siluq Ngurai	Kutai Barat	127,514	4	4	7	9
Sungai Kunjang	Samarinda	613				
Sungai Pinang	Samarinda	110	1			2
Tenggarong	Kutai Kartanegara	161				
Waru	Penajam Paser Utara	61,290	2	0	1	3

Source: Statistical analysis, 2025

C. Slope

Slope is among the key factors affecting surface hydrology and land moisture distribution in an area. It also plays an important role in determining the pattern of vegetation distribution, which directly impacts the potential risk of land and forest fire. In areas with steep slopes, rainwater surface flow occurs at a higher speed. Consequently, rainwater tends to flow rapidly across the surface, reducing the opportunity for infiltration and leading to lower soil moisture levels (Dingman, 2015). The quick drying of soil under such conditions increases the risk of fire, particularly during dry seasons when rainfall is scarce.

Based on the spatial analysis data of slope in the IKN area and its surrounding watersheds (Figure 17), slope was categorized with a color gradation ranging from green (low slope) to red (high slope). This slope classifi-cation, which is associated with the level of fire risk, includes:

- **Slope < 5°**: The risk of fire is very low, because rainwater is more easily retained on the ground surface and humidity is better maintained.
- **Slope 5° – 10° and 10° – 20°**: Medium fire risk, requiring more intensive vegetation and soil moisture management.
- **Slope > 30°**: The fire risk is very high, as water flows quickly and the soil dries out quickly, resulting in vegetation being flammable.

Figure 18 and Table 8 show that the IKN area and its surrounding watersheds had quite significant slope variations. The results from the analysis include:

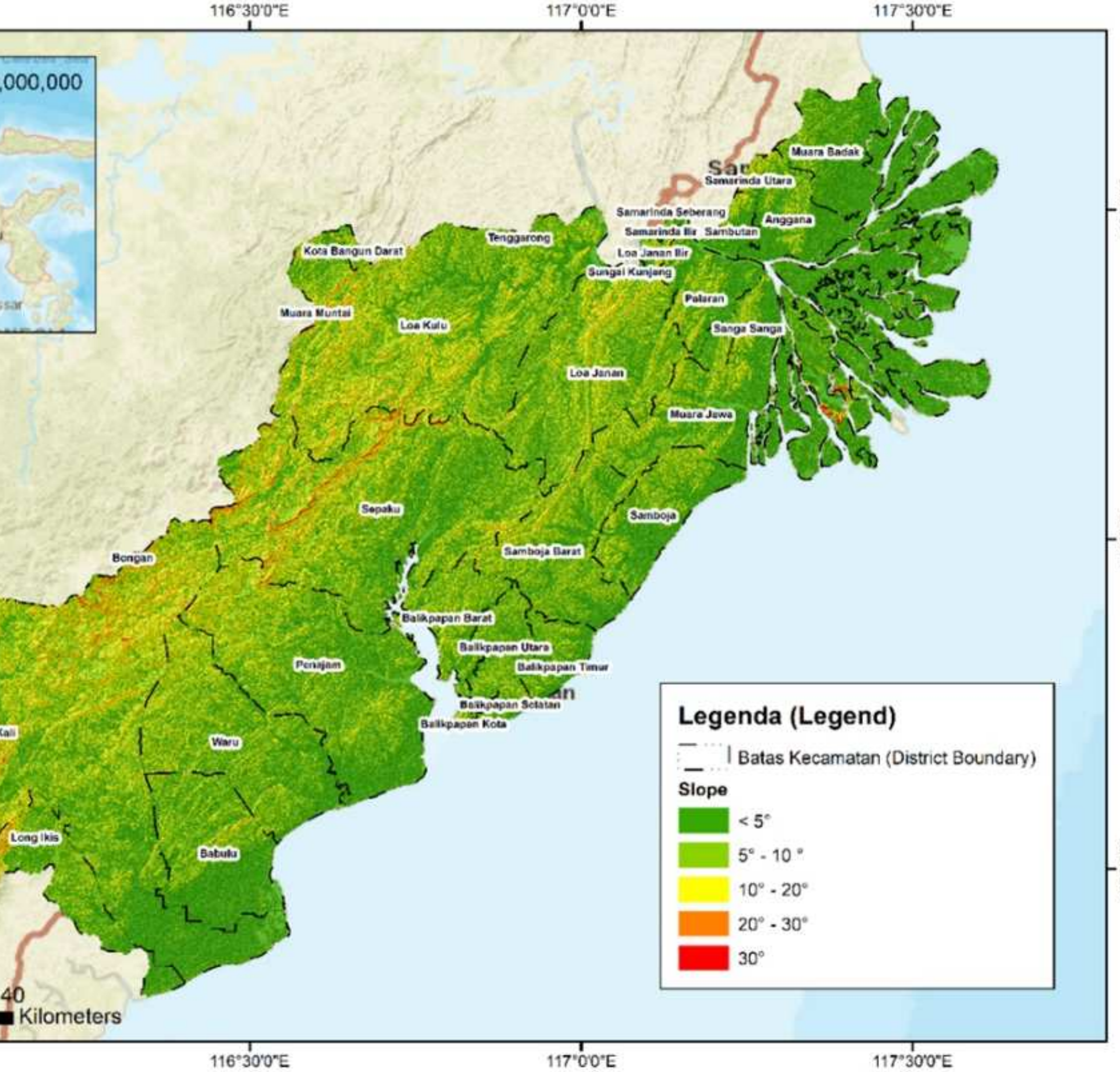


Figure 17. Spatial Distribution of Slope

Source: Spatial analysis, 2025

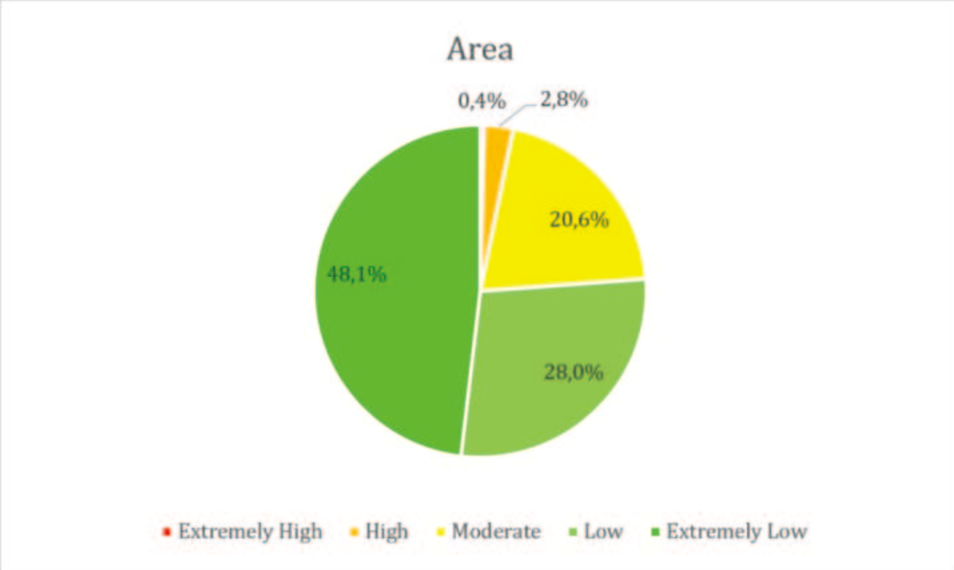


Figure 18. Share of Fire Risk Levels by Slope
Source: Statistical analysis, 2025

- Approximately 48% of the total area was in the very low slope category (<5°). This area is relatively morphologically stable and has a lower fire risk because fire spreads more slowly on flat land.
- About 20.6% of the area was classified as a moderate slope (between 5° and 20°). In this area, adaptive vegetation and soil moisture management strategies are required because moderate slopes can accelerate fire propagation when not managed properly.
- Only about 0.4% of the area was classified in the very high slope category (>30°). Despite the small coverage, this area has a high level of risk, not only to fire, but also land degradation, erosion, and landslides, which can synergistically worsen the impacts of forest and land fire.

Table 8. Slope by District

District	Regency/City	Spatial Distribution of Slope Class (ha)				
		Extremely Low	Low	Moderate	High	Extremely High
Anggana	Kutai Kartanegara	87,414	12,989	3,436	262	393
Babulu	Penajam Paser Utara	28,165	10,326	3,810	247	18
Balikpapan Barat	Balikpapan	8,311	7,256	3,627	57	
Balikpapan Kota	Balikpapan	522	332	208	21	0
Balikpapan Selatan	Balikpapan	2,023	1,368	435	0	
Balikpapan Tengah	Balikpapan	512	375	195	4	0
Balikpapan Timur	Balikpapan	7,273	3,753	892	0	
Balikpapan Utara	Balikpapan	6,738	5,651	1,361	3	
Batu Sopang	Paser	22	46	92	45	16
Bongan	Kutai Barat	62	112	147	57	11
Gunung Purei	Barito Utara	66	114	106	14	1
Kota Bangun	Kutai Kartanegara	530	614	485	55	2
Loa Janan	Kutai Kartanegara	25,592	26,216	16,580	920	17
Loa Janan Ilir	Samarinda	1,325	736	817	85	2
Loa Kulu	Kutai Kartanegara	45,411	48,083	40,780	4,251	166
Long Ikis	Paser	14,343	9,375	6,308	1,920	280
Long Kali	Paser	75,044	72,483	85,922	17,842	2,776
Muara Badak	Kutai Kartanegara	30,029	5,867	1,009	8	
Muara Jawa	Kutai Kartanegara	35,250	10,456	5,762	169	1
Muara Komam	Paser	2,884	4,373	5,469	1,416	259
Muara Muntai	Kutai Kartanegara	8	15	22	3	
Palaran	Samarinda	11,620	4,270	3,038	165	3

District	Regency/City	Spatial Distribution of Slope Class (ha)				
		Extremely Low	Low	Moderate	High	Extremely High
Penajam	Penajam Paser Utara	45,825	27,594	14,847	810	33
Samarinda Ilir	Samarinda	107	23	38	8	
Samarinda Kota	Samarinda	78	4			
Samarinda Seberang	Samarinda	629	205	169	13	1
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda	342	416	560	34	0
Samboja	Kutai Kartanegara	16,813	7,872	3,290	18	
Sambutan	Samarinda	19,131	14,885	7,185	252	5
Sanga-Sanga	Kutai Kartanegara	4,659	974	687	23	
Sepaku	Penajam Paser Utara	6,190	2,390	1,541	43	1
Siluq Ngurai	Kutai Barat	46,001	42,201	33,218	5,452	666
Sungai Kunjang	Samarinda	137	233	222	18	
Sungai Pinang	Samarinda	106	5	1		
Tenggarong	Kutai Kartanegara	52	77	32		
Waru	Penajam Paser Utara	27,392	21,905	11,520	471	7

Source: Statistical analysis, 2025

Long Kali District in Paser Regency is one example of a high-slope area, covering around 2,776 hectares with a slope area of more than 30°. Therefore, to reduce the risk of vertical and quick fire spread, this area requires the implementation of integrated soil conservation and land management strategies, such as terracing, slope-retaining vegetation, and soil moisture monitoring.

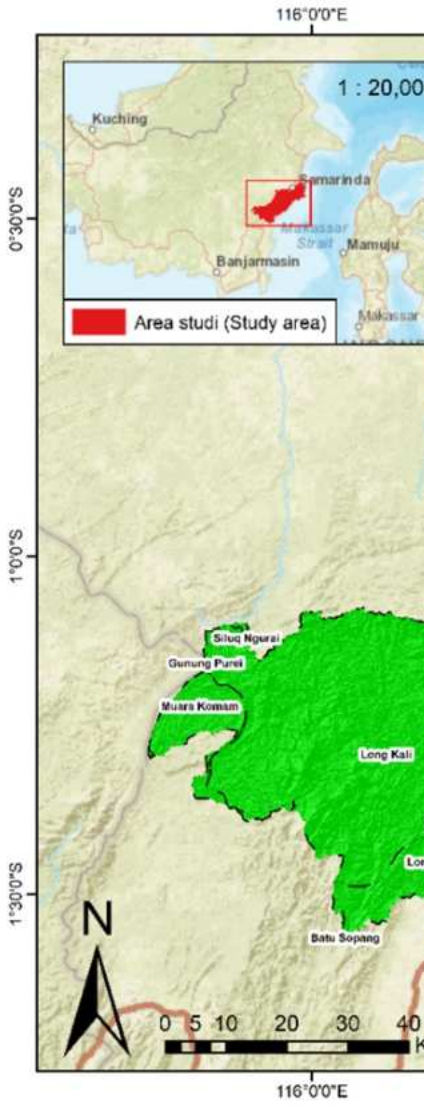
Areas with steep slopes tend to experience faster soil drying processes caused by intense surface runoff. This condition decreases soil moisture and increases vegetation risk to fire. In addition, steep slopes increase the risk of soil erosion and landslides, which not only damage the structure of the land cover but also expand the potential risk of the area to fire spread due to the loss of vegetative cover. Considering these characteristics, land management in areas with high slopes needs to implement an integrated conservation approach, such as planting erosion-resistant vegetation, terracing construction, and surface flow management aimed at slowing runoff and increasing water infiltration. On the other hand, for areas with low to moderate slopes, management strategies should focus on efforts to maintain soil moisture. This can be achieved through organic matter management and micro-irrigation systems, as well as strengthening vegetation resistance to fire, as part of landscape-based fire risk mitigation.

7.1.4 Vegetation

Vegetation density is an important indicator for understanding the hydrological dynamics and the risk of hydrometeorological disaster in an area, specifically for flood and forest/land fire. In general, vegetation density is expressed as an index, the NDVI, which reflects the level of greenery and biomass cover of an area (Huete, 1997). Vegetation plays an important role in reducing the risk of forest and land fire through the ability to maintain biomass moisture and reduce the accumulation of dry fuel. Healthy and dense vegetation, specifically in tropical forest areas, tends to retain high moisture levels, making it more resistant to fire ignition. In contrast, degradation caused by activities such as land clearing, mining, and plantation expansion leads to an increase in flammable materials and the possibility of fire spreading (Field et al., 2009; Syaufina, 2018).

Most of the IKN area and its surrounding watersheds showed a dominant dark green color (NDVI > 0.45), indicating that the area still had relatively good vegetation cover, capable of protecting against potential fire. Figure 19 shows the detailed vegetation density distribution in the IKN area and its surrounding watersheds based on NVDI values:

- **Red (NDVI < 0)**: Almost no vegetation, such as grassland or water bodies, and is highly susceptible to fire spread.
- **Orange (NDVI 0 – 0,15)**: Sparse or damaged vegetation cover, high risk of forest and land fire
- **Light green (NDVI 0,15 – 0,3)**: Moderate vegetation with modest forest and medium fire potential.
- **Dark green (NDVI > 0,45)**: Dense and healthy vegetation, with a high ability to prevent the fire spread.



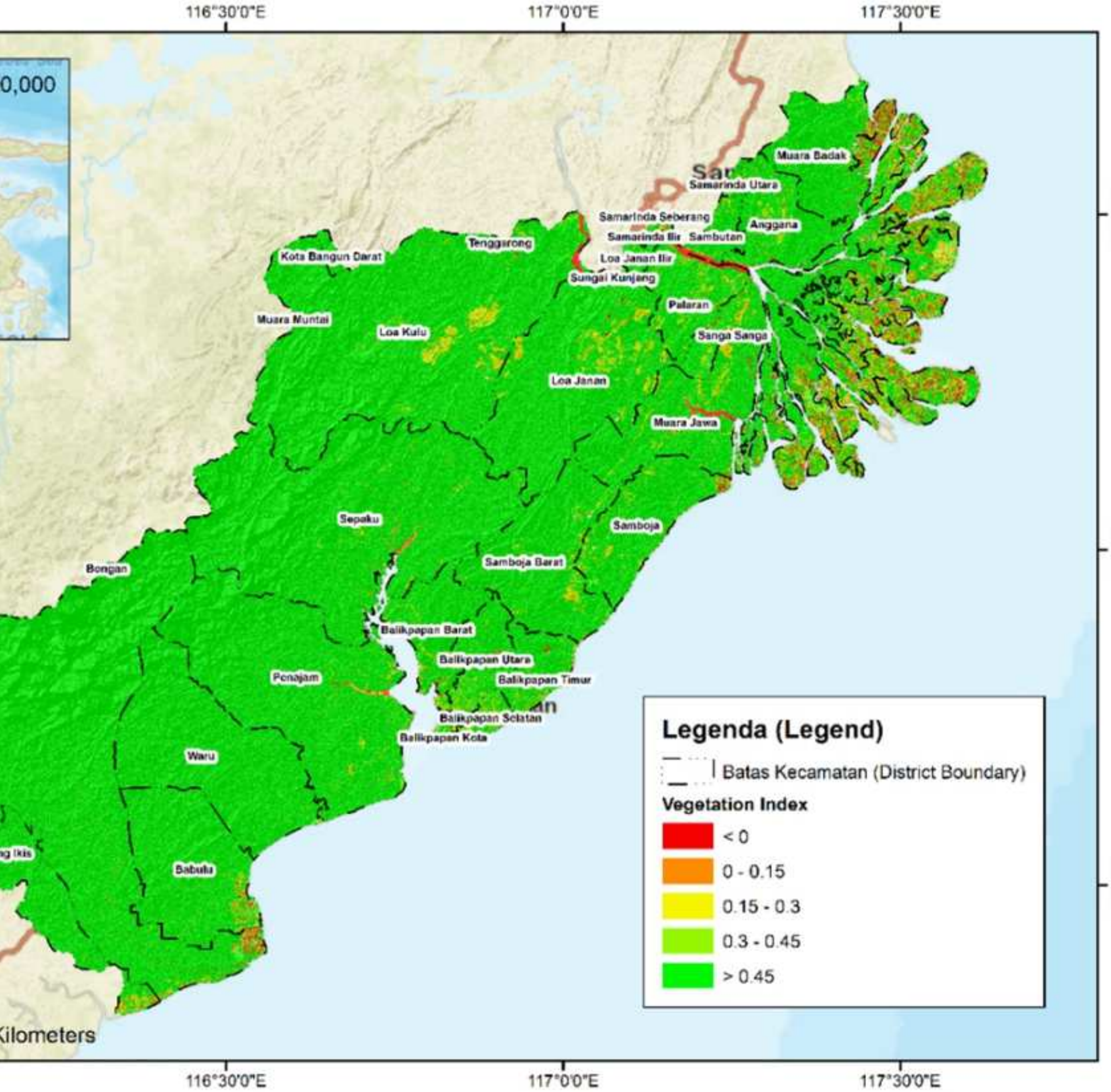


Figure 19. Spatial Distribution of Vegetation Density
Source: Spatial analysis, 2025

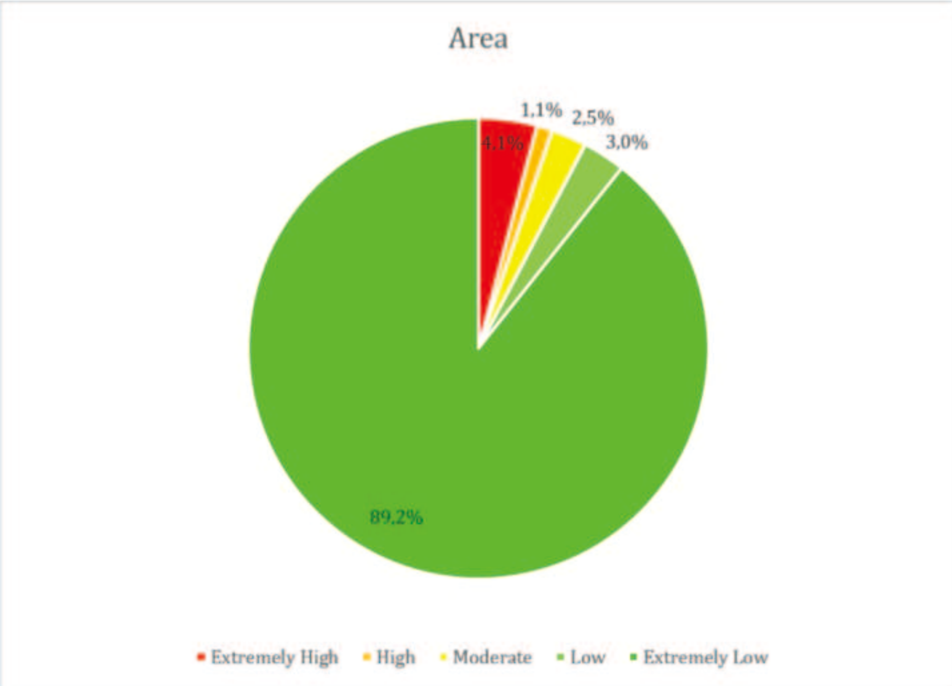


Figure 20. Share of Fire Risk Levels by Vegetation Density
Source: Statistical analysis, 2025

Based on Figure 20, the majority of the IKN area and its surrounding watersheds was characterized by an extremely low level of fire risk, accounting for 89.2%. This result shows a lower potential for fire occurrence, as higher NDVI values generally correlate with dense, healthy vegetation that retains higher moisture levels, thereby reducing flammability. In contrast, areas with low NDVI values, often associated with sparse or stressed vegetation, are more susceptible to fire ignition due to reduced moisture content and an abundance of dry, combustible material. NDVI is a satellite image-based vegetation indicator that is effective in detecting land cover conditions and vegetation health, making it highly relevant for early identification of fire-prone areas, specifically during the dry season period when vegetation moisture decreases drastically (Chuvieco et al., 2010).

Although vegetation cover with high index still dominated most of the IKN area and its surrounding watersheds, several districts showed indications of vegetation degradation, specifically in areas with high pressure due to anthropogenic activities, such as land conversion, extractive industry activities, and settlement expansion. According to Tacconi (2003), forest fragmentation and degradation are key factors that increase the

Table 9. Vegetation Density by District

District	Regency/City	Spatial Distribution of Vegetation Index Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Anggana	Kutai Kartanegara	5,903	6,728	10,682	10,964	70,190
Babulu	Penajam Paser Utara	232	280	456	1,078	40,520
Balikpapan Barat	Balikpapan	97	147	663	681	17,662
Balikpapan Kota	Balikpapan	0	40	236	272	535
Balikpapan Selatan	Balikpapan	2	41	477	842	2,465
Balikpapan Tengah	Balikpapan	0	70	280	330	407
Balikpapan Timur	Balikpapan	81	86	305	680	10,764
Balikpapan Utara	Balikpapan	79	61	413	1,067	12,109
Batu Sopang	Paser					221
Bongan	Kutai Barat					390
Gunung Purei	Barito Utara					301
Kota Bangun	Kutai Kartanegara					1,686
Loa Janan	Kutai Kartanegara	353	128	2,630	2,726	63,438
Loa Janan Ilir	Samarinda	65	11	140	319	2,430

District	Regency/City	Spatial Distribution of Vegetation Index Class (ha)				
		Extremely High	High	Moderate	Low	Extremely Low
Loa Kulu	Kutai Kartanegara	739	173	2,783	2,609	132,340
Long Ikis	Paser	54	159	394	539	31,080
Long Kali	Paser	632	504	645	950	251,329
Muara Badak	Kutai Kartanegara	1,436	1,180	1,746	2,212	30,335
Muara Jawa	Kutai Kartanegara	1,621	979	2,462	2,759	43,813
Muara Komam	Paser		0	0	0	14,401
Muara Muntai	Kutai Kartanegara					47
Palaran	Samarinda	921	132	991	1,423	15,609
Penajam	Penajam Paser Utara	245	295	663	1,229	86,677
Samarinda Ilir	Samarinda	38	9	23	27	75
Samarinda Kota	Samarinda	45	5	14	8	4
Samarinda Seberang	Samarinda	149	17	130	191	527
Samarinda Ulu	Samarinda	1				
Samarinda Utara	Samarinda	1	1	72	93	1,184
Samboja	Kutai Kartanegara	161	144	796	1,332	25,541
Sambutan	Samarinda	28	85	864	1,179	39,230
Sanga-Sanga	Kutai Kartanegara	454	27	194	331	5,331
Sepaku	Penajam Paser Utara	81	92	923	784	8,261
Siluq Ngurai	Kutai Barat	213	237	546	1,522	125,021
Sungai Kunjang	Samarinda					611
Sungai Pinang	Samarinda	91	1	0	0	20
Tenggarong	Kutai Kartanegara					161
Waru	Penajam Paser Utara	7	16	52	174	61,045

Source: Spatial analysis, 2025

risk of forest and land fire, specifically in tropical areas such as Kalimantan.

In this context, adaptive vegetation and landscape management approaches are very important to reduce the risk of forest and land fire. The approach includes:

- Protection of natural forest areas from deforestation and land conversion activities.
- Rehabilitation of degraded land using local vegetation species that are resistant to fire.
- Controlling the expansion of extractive industries, such as mining and large-scale plantations, through a fire risk-based spatial planning approach.
- Regular vegetation monitoring using satellite imagery and vegetation indices such as NDVI.

7.2 Variables Contributing to Flooding Disaster

7.2.1 Topographic

Topography is critical in determining the risk of an area to flooding. It determines surface water flow patterns, runoff velocity, and water accumulation locations. The two main components of topography that play a significant role in hydrological and flood processes are elevation and slope.

- **Elevation**: In general, areas with low elevation are more at risk of flooding as water tends to flow and collect in lower areas. Choubin et al. (2019) showed a negative correlation between elevation and flood occurrence, where flood frequency increases as elevation decreases. Watersheds and floodplains are usually associated with low elevations that increase the risk of inundation and flooding.

- **Slope**: This factor significantly influences surface runoff velocity and volume. Steeper slopes facilitate rapid water movement, reducing infiltration time and increasing the potential for soil erosion and downstream flooding (Meraj et al., 2018). In contrast, gentle or flat slopes tend to slow down water flow, enhancing water infiltration and absorption but also causing runoff accumulation that can trigger local flooding (Tehrany et al., 2014).

The watersheds around the IKN area were dominated by low elevation and gentle slopes, showing a high level of risk to flooding and surface water inundation. This risk increases when there is a decrease in the quality and extent of vegetation cover, which functions as a water flow barrier, infiltration regulator, and surface runoff inhibitor. Furthermore, topographic characteristics play a crucial role in determining flood-prone locations, specifically through the influence on the direction and speed of surface water flow. Basin and valley areas with low topographic contours tend to be runoff accumulation points (basin outlets), which hydrologically have the potential to experience flooding when the natural capacity is exceeded (Kundzewicz & Takeuchi, 1999).

7.2.2 Precipitation

Precipitation is one of the primary drivers of flood, particularly when the volume of water surpasses the capacity of natural and artificial drainage systems such as rivers, channels, or reservoirs. High precipitation potentially increases the risk of flooding due to the high potential for excess water flow capacity relative to the real capacity. Based on historical data from the National Disaster Management Agency (BNPB), the IKN area and its surrounding watersheds has been experiencing annual flooding for the past decade, showing a high level of hydrometeorological disaster. This information is supported by data from the Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS), showing that the IKN area has an average annual rainfall of more than 2,500 mm/year in the last 10 years (Figure 22). Consequently, the area is classified as high rainfall, which directly increases the potential for flooding due to precipitation intensity above the capacity of natural and artificial drainage systems. Tabari (2020) also mentioned that global climate change could potentially intensify the hydrological cycle, leading to an increase in the frequency and intensity of extreme precipitation events. This phenomenon elevates the risk of flooding in tropical areas with limited drainage systems, specifically in urban areas that experience increased land conversion and decreased water absorption capacity.

Based on Figure 21, the daily precipitation rate shows quite significant variability, with the lowest and highest values of 31.87 mm/day and 71.79 mm/day, respectively. This variation reflects the dynamics of the local climate influenced by many factors, including global climate change that increases the intensity of extreme precipitation, changes in land cover disrupting micro air circulation patterns, and decreased soil infiltration capacity due to land conversion, specifically from forests or grassland to settlement areas. Fluctuations in daily precipitation patterns contribute directly to the instability of hydrological dynamics,

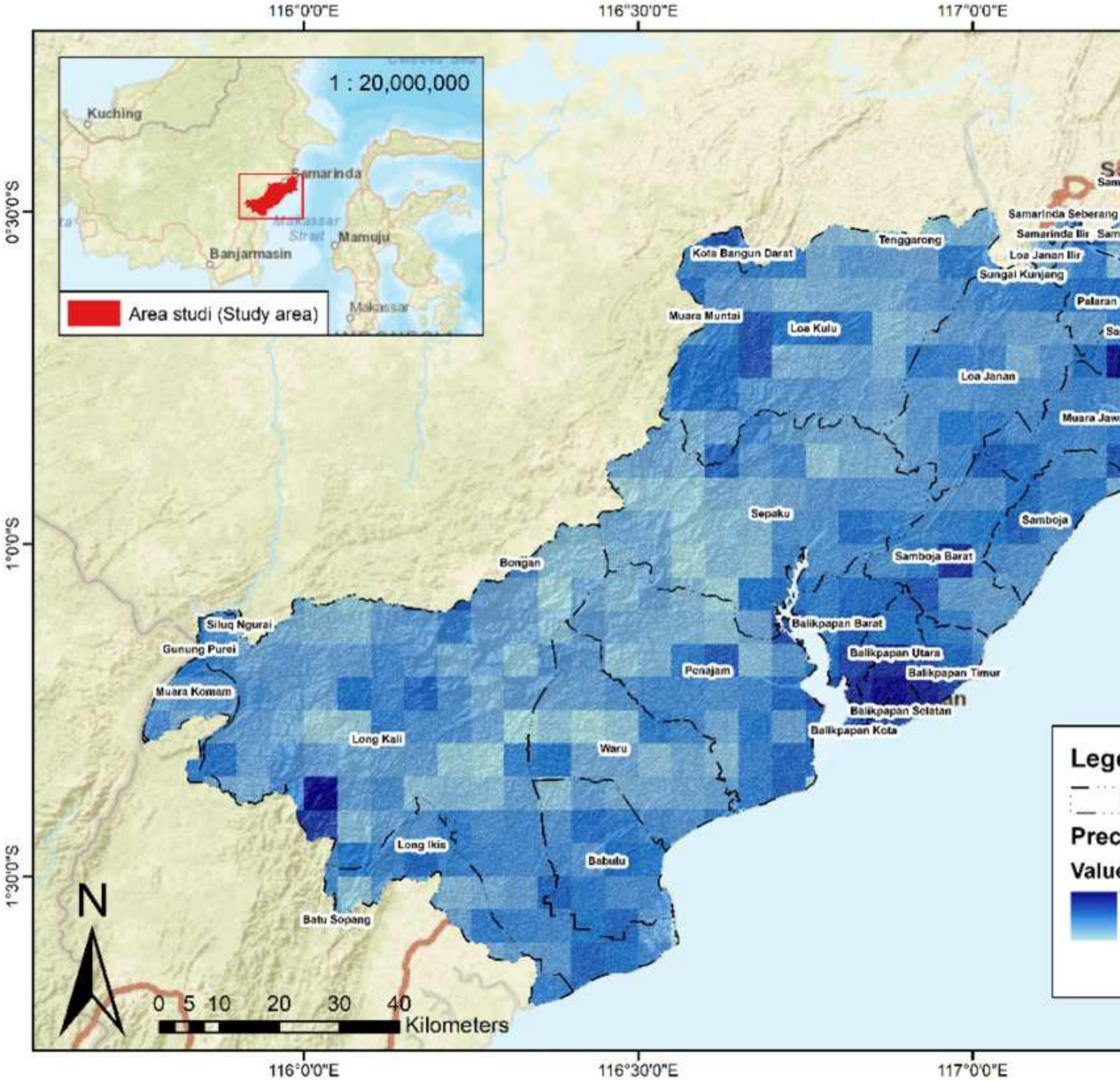
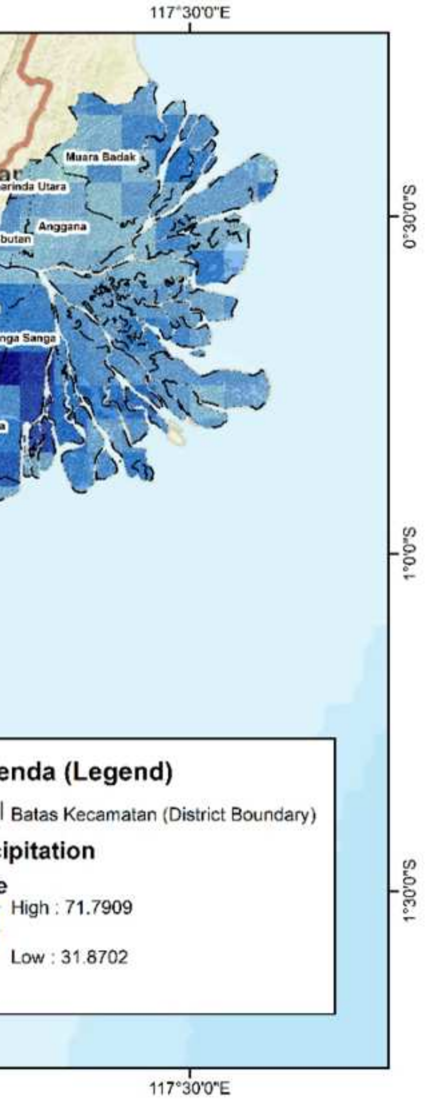


Figure 21. Spatial Distribution of Precipitation Levels
Source: Spatial analysis, 2025



which ultimately becomes one of the main factors triggering annual flooding.

Figure 22 shows a declining trend in annual precipitation in the IKN area and its surrounding watersheds from 2022 to 2023. In 2022, the area experienced relatively high rainfall exceeding 3,000 mm/year, but by 2023, there was a drastic decline to below 2,500 mm/year. In the previous year, a declining pattern was observed from 2017 to 2019. This decreasing trend can be attributed to climatic factors such as El Niño, which creates drier conditions. Additionally, land degradation also contributes to changing precipitation patterns by indirectly affecting the water and energy cycle. Changes in vegetation cover impact processes such as evapotranspiration, cloud formation, and the atmospheric cycle, all of which play a role in determining rainfall patterns and distribution.

The graph in Figure 22 shows a significant decrease in water holding capacity from 2022 to 2023. In 2022, the area had a relatively high water holding capacity, which was more than 3,000 mm/year, but in 2023, there was a drastic decline to less than 2,500 mm/year. This decline in capacity reflects the degradation of hydrological function, which

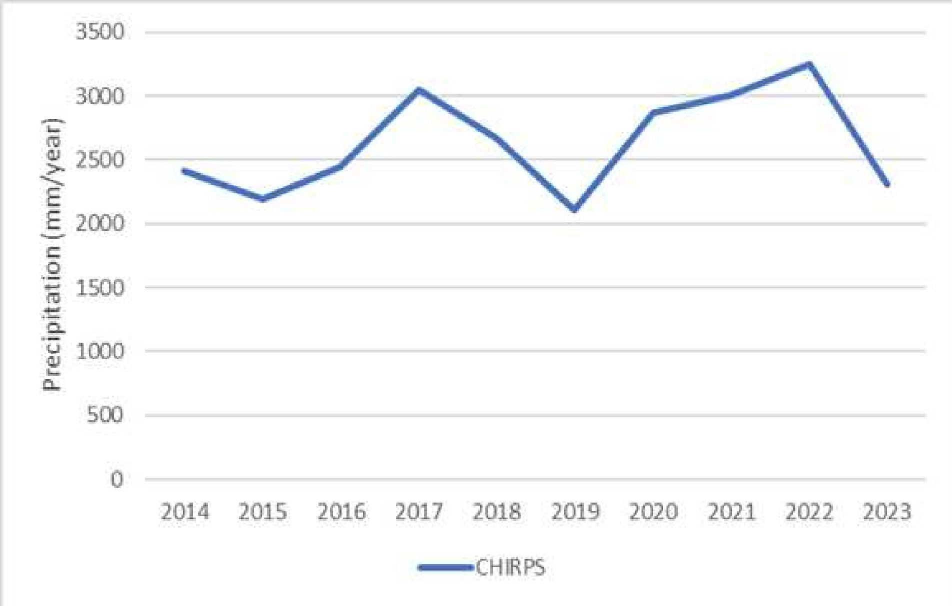


Figure 22. Annual Precipitation Between 2015 and 2023
Source: Statistical analysis, 2025

indirectly shows a reduction in the ability to absorb and store rainwater. This phenomenon is closely related to various environmental factors, including land degradation due to the conversion of vegetation cover, the influence of climate change, which causes an increase in the intensity of extreme rainfall and temperature variability, as well as suboptimal water resource management.

Based on Table 10, the distribution of precipitation levels per district was relatively uniform, with an average of between 50 and 60 mm per day. However, there were striking differences in several areas, such as in Long Ikis and Long Kali districts, which recorded the highest precipitation levels of up to 71.8 mm per day. In comparison, Samarinda Kota district had the lowest value

Table 10. Maximum Precipitation by District

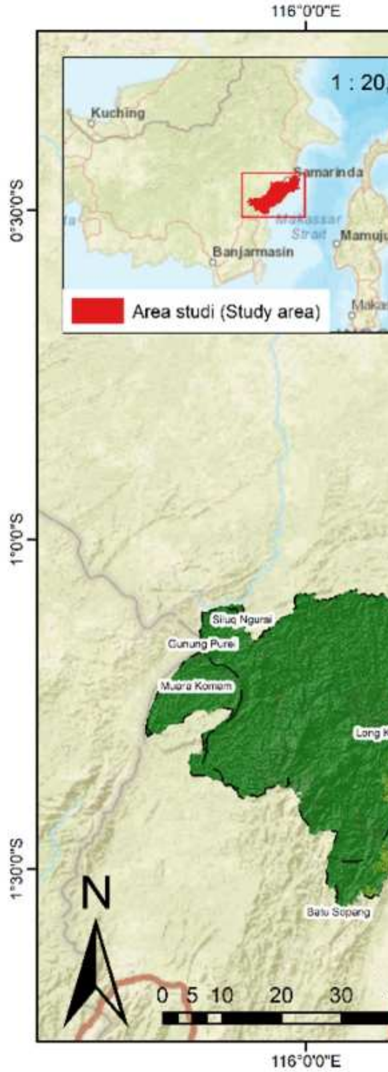
District	Regency/City	Max Precipitation (mm/day)
Anggana	Kutai Kartanegara	55.6
Babulu	Penajam Paser Utara	55.6
Balikpapan Barat	Balikpapan	65.2
Balikpapan Kota	Balikpapan	70.8
Balikpapan Selatan	Balikpapan	70.8
Balikpapan Tengah	Balikpapan	70.8
Balikpapan Timur	Balikpapan	67.2
Balikpapan Utara	Balikpapan	70.8
Batu Sopang	Paser	63.7
Bongan	Kutai Barat	59.4
Gunung Purei	Barito Utara	52.3
Kota Bangun	Kutai Kartanegara	57.3
Loa Janan	Kutai Kartanegara	56.1
Loa Janan Ilir	Samarinda	51.2
Loa Kulu	Kutai Kartanegara	58.2
Long Ikis	Paser	71.8
Long Kali	Paser	71.8
Muara Badak	Kutai Kartanegara	52.6
Muara Jawa	Kutai Kartanegara	70.7
Muara Komam	Paser	63.7
Muara Muntai	Kutai Kartanegara	53.7
Palaran	Samarinda	59.2
Penajam	Penajam Paser Utara	59.7
Samarinda Ilir	Samarinda	59.2
Samarinda Kota	Samarinda	43.4
Samarinda Seberang	Samarinda	45.6
Samarinda Ulu	Samarinda	59.2
Samarinda Utara	Samarinda	59.2
Samboja	Kutai Kartanegara	65.1
Sambutan	Samarinda	59.2
Sanga-Sanga	Kutai Kartanegara	70.7
Sepaku	Penajam Paser Utara	59.6
Siluq Ngurai	Kutai Barat	47.6
Sungai Kunjang	Samarinda	43.4
Sungai Pinang	Samarinda	45.6

Source: Statistical analysis, 2025

of 43.4 mm per day. The difference can be attributed to geographical factors, local topography, and microclimate variations influenced by wind patterns, air humidity, and local land cover (Dinku et al., 2018). This condition shows that although the rainfall pattern is quite uniform, local variations may cause different levels of flood risk between areas.

7.2.3 Land cover

Land cover is one of the main factors influencing flooding due to the close relationship with surface flow and soil permeability. Different land cover types directly affect the speed and volume of water flowing towards drainage channels or rivers, as well as the volume of rainwater absorbed by the soil and stored in the ecosystem. Nie et al. (2011) stated that watersheds provide different hydrological responses depending on the land cover. Land with natural cover or dominated by vegetation, such as secondary forests and industrial plantations, tends to have higher permeability. This enables more optimal absorption of rainwater, slows down surface flow, and reduces the risk of flooding. In contrast, urban land dominated by imper-



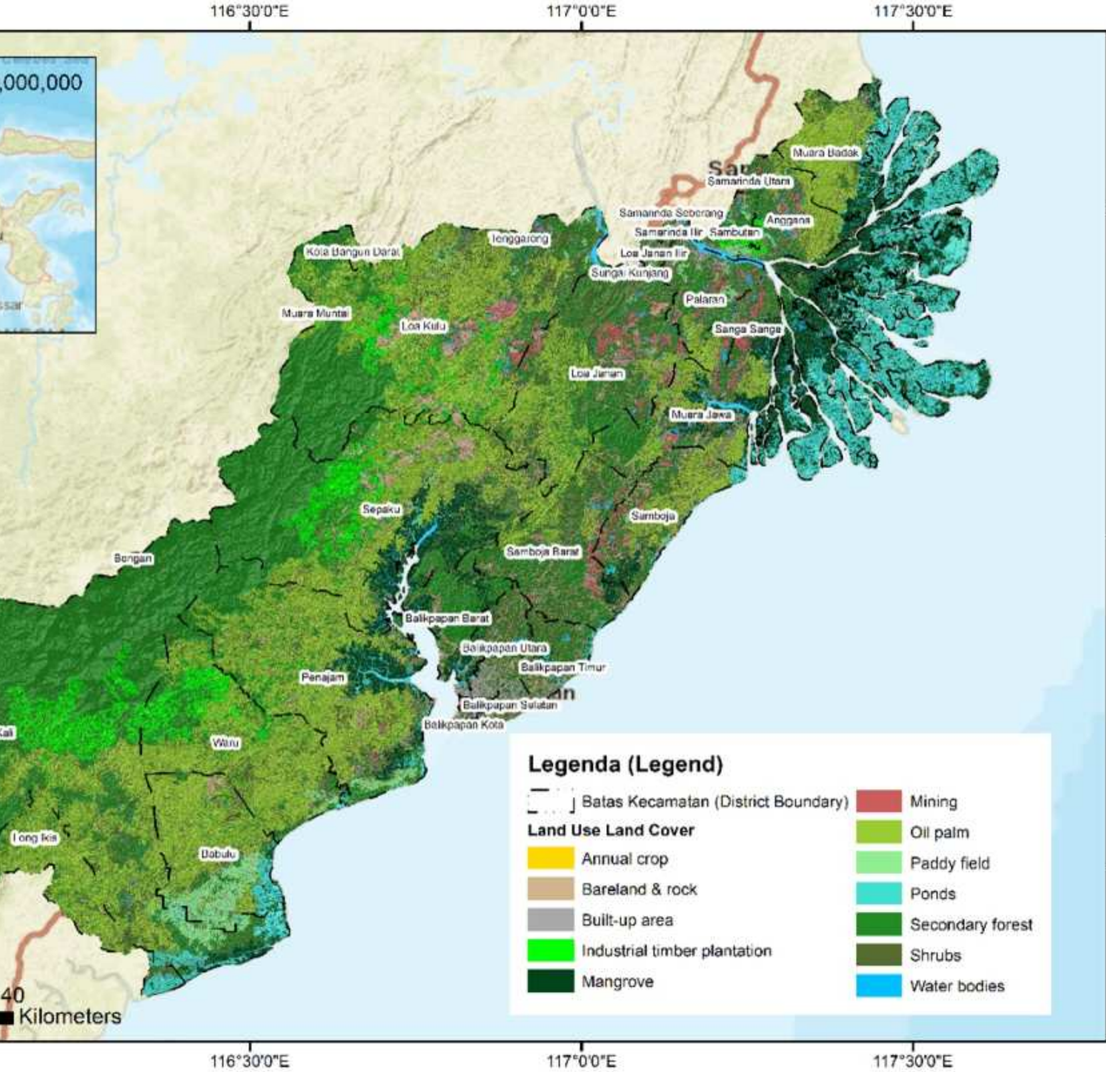


Figure 23. Spatial Distribution of Land Use/ Land Cover
Source: Spatial analysis, 2025

meable surfaces such as concrete and asphalt has a large surface flow coefficient.

Consequently, rainwater quickly flows into the drainage system, significantly increasing the risk of flooding (Suriya & Mudgal, 2012).

The development of the new Indonesian capital city will directly impact the increase in urbanization, specifically in the Central Government Core Area (KIPP). Based on assessment using Landsat 8 imagery in 2023, land cover in the river basin around the KIPP area is dominated by vegetation cover such as industrial plantation forests and secondary forests, which have an important role in regulating water flow and maintaining hydrological balance.

Figure 23 shows that the land cover conditions area is very diverse, reflecting the complexity of spatial use influenced by various ecological and socio-economic functions. The main types of land cover identified include annual crops, bareland and rock, build-up area, industrial timber plantation, mangrove, mining, oil palm, paddy field, ponds, secondary forest, shrubs, and water bodies. The diversity of land cover shows a combination of conservation, production, and settlement functions, which directly affect surface water flow patterns, infiltration capacity, and potential flood risks in each area. Differences in land cover characteristics between districts also show that each area has a unique spatial utilization pattern consistent with geographical conditions and spatial functions.

Table 11 shows that several types of land cover contribute significantly to increasing flood potential, including:

Table 11. Land Cover by District

District	Regency/City	Spatial Distribution of Land Use Land Cover Class (ha)											
		Annual crop	Bare-land & rock	Built-up area	Industrial timber plantation	Mangrove	Mining	Oil palm	Paddy field	Ponds	Secon-dary forest	Shrubs	Water bodies
Anggana	Kutai Kartanegara	45	428	859	719	35,078	1,734	5,551	317	40,106	6,727	7,450	5,496
Babulu	Penajam Paser Utara	85	1,018	876	11	765	127	18,906	7,304	2,225	6,337	4,600	316
Balikpapan Barat	Balikpapan	15	706	905		4,266	372			231	9,973	2,393	390
Balikpapan Kota	Balikpapan		3	543			56				124	349	2
Balikpapan Selatan	Balikpapan	6	75	1,667			65				710	1,280	19
Balikpapan Tengah	Balikpapan		6	609			133				84	250	3
Balikpapan Timur	Balikpapan	59	662	1,319		963	135		2	542	3,857	4,221	157
Balikpapan Utara	Balikpapan	62	968	2,059		1,252	281			19	3,676	5,022	414
Batu Sopang	Paser										207	17	
Bongan	Kutai Barat										344	56	7
Gunung Purei	Barito Utara			0							299	8	
Kota Bangun	Kutai Kartanegara		0	9			0	802			707	155	15
Loa Janan	Kutai Kartanegara	138	2,275	2,162	3		4,510	15,281	232		22,459	21,188	1,080
Loa Janan Ilir	Samarinda	7	65	640			89		155		773	1,146	91
Loa Kulu	Kutai Kartanegara	25	4,710	2,681	6,971		2,723	42,057	1,220		51,033	25,602	1,704
Long Ikis	Paser	24	89	146		224	38	15,600		1,575	9,788	4,684	67
Long Kali	Paser	88	352	413	11,728	2,727	114	25,652	3,248	3,706	179,325	25,311	1,374
Muara Badak	Kutai Kartanegara	83	403	745	7	6,347	184	14,411		8,404	1,870	3,635	838

District	Regency/City	Spatial Distribution of Land Use Land Cover Class (ha)											
		Annual crop	Bare-land & rock	Built-up area	Industrial timber plantation	Mangrove	Mining	Oil palm	Paddy field	Ponds	Secon-dary forest	Shrubs	Water bodies
Muara Jawa	Kutai Kartanegara	9	1,198	1,517		14,961	2,304	7,976		5,116	8,272	7,668	2,623
Muara Komam	Paser		0	4			0				13,235	1,164	22
Muara Muntai	Kutai Kartanegara		0		5			29			6	8	
Palaran	Samarinda	95	315	1,384		0	1,900	1,026	864		6,584	5,423	1,506
Penajam	Penajam Paser Utara	216	1,755	1,815	655	8,644	697	37,174	1,397	1,793	21,896	12,162	907
Samarinda Ilir	Samarinda			44			1				33	38	56
Samarinda Kota	Samarinda			21			1					3	56
Samarinda Seberang	Samarinda	0	4	389			5				185	267	168
Samarinda Ulu	Samarinda											1	
Samarinda Utara	Samarinda		76	95			85	0			710	388	
Samboja	Kutai Kartanegara	78	1,678	1,549		1,744	1,712	7,568	48	869	4,654	7,769	330
Sambutan	Samarinda	171	2,340	1,561		1,299	1,972	4,551	11	112	15,026	13,930	486
Sanga-Sanga	Kutai Kartanegara	4	248	329	1,150		171		606		1,875	1,300	664
Sepaku	Penajam Paser Utara	7	55	401		624	1,471	1,780			2,215	3,002	610
Siluq Ngurai	Kutai Barat	110	5,371	1,838	10,415	14,396	657	27,746	311	351	47,522	17,434	1,397
Sungai Kunjang	Samarinda										583	37	0
Sungai Pinang	Samarinda			0							8	12	93
Tenggarong	Kutai Kartanegara						6	36			62	55	3
Waru	Penajam Paser Utara	72	341	370	7,090	118	25	28,905	633	179	16,104	7,385	74

Source: Statistical analysis, 2025

(a) **Bareland and rocks**, which usually have low soil moisture and water absorption capacity, as well as trigger high surface runoff when it rains. This condition is common on hard and less vegetated land surfaces, which cannot absorb water optimally.
(b) **Build-up area**, include residential areas, roads, and buildings, whose surfaces are impermeable, thereby inhibiting water infiltration into the soil and causing increased surface flow.
(c) **Mining areas,** naturally have degraded soil, often lose a covering vegetation layer, and have dense or damaged soil structures, which reduces water absorption capacity.
(d) **Water bodies**, although this area does not directly absorb water, the existence of lakes, swamps, or rivers influences the flow patterns and acts as a place to collect surface water runoff.

In general, bare land and rocks, developed land, and mining areas have dry soil characteristics and low water absorption, specifically during the dry season. The dry soil often results in increased surface runoff, due to the reduced capacity of the soil to absorb water, thereby elevating the risk of flooding (J. Zhao et al., 2022). This phenomenon is particularly prevalent in urban and semi-urban areas, where land use change is rapid and massive, worsening the risk of flooding (Nie et al., 2011; Zhou et al., 2019). Therefore, land cover management and increasing the cover of water-absorbing vegetation are critical to reduce flood risk in the IKN area and beyond.

8 Alternative Risk Management Strategies

Degraded Forest in Sepaku
Photo credit: Relissiana

East Kalimantan is a province with a high level of risk of hydrometeorological disaster, specifically forest fire and flood. Factors such as changes in land use, ecosystem degradation, and global climate change are deteriorating the intensity and frequency of disaster. Therefore, a science-based approach is needed in designing effective mitigation and adaptation. Risk management-based alternatives are crucial in spatial planning and environmental policies by considering various approaches that have been implemented at the national and international levels. Several alternatives can be used to mitigate the risk of natural disaster in the form of forest fire and flood, which are explained as follows.

8.1 Nusantara Net Zero Strategy 2045

The strategy document "Nusantara Net Zero Strategy 2045", published by the Deputy for Environment and Natural Resources of the Indonesian Capital City Authority in 2023, outlines a comprehensive framework for achieving net-zero emissions in the new capital city. One of the strategies discussed is fire and flood risk management designed to strengthen climate resilience in IKN through a policy-based approach, technology, and stakeholder participation. In relation to the location of the IKN in East Kalimantan, this strategy is very relevant considering the ecological characteristics, which include extensive forest cover, potential for forest and land fire, and the threat of flooding due to high rainfall and changes in land use. Developing IKN as a forest-based city requires an effective mitigation and adaptation system to ensure the environment is maintained and disaster risks are minimized.

In terms of fire risk management, the Nusantara Net Zero Strategy 2045 identifies various preventive and responsive approaches in line with the ecological conditions of East Kalimantan. Historically, the province is prone to forest fire, specifically in the dry season, due to natural factors and human activities such as land clearing for agriculture and plantations. Therefore, the strategies implemented include local regulations and policies specifically for fire prevention, developing technical guidelines and mitigation protocols, as well as increasing public awareness through education and training. Fire risk monitoring can be implemented using technology-based indicators connected to a digital platform for early detection and rapid response. In addition, procurement of firefighting equipment, establishment of firefighting units, as well as sufficient budget allocation, are part of the strategy to ensure operational readiness in dealing with the threat of forest fire.

Flood risk management within the strategy places a strong emphasis on nature-based solutions, which are particularly appropriate given East Kalimantan ecological context, characterized by a vast swamp ecosystem, tropical rainforest, and river basin. Key strategies include reforestation and preservation of green areas as well as wetlands, to increase rainwater infiltration capacity and reduce the risk of flooding due to land conversion in the development of the IKN. Developing an early warning system that includes monitoring water discharge, detecting signs of risk, and preparing emergency action plans is an integral part of the smart city concept. These strategies also underscore the importance of integrating climate change issues into spatial planning to ensure urban expansion remains consistent with environmental carrying capacity. Moreover, community capacity in disaster preparedness can be increased through an inclusive approach that comprises local communities and related stakeholders. This approach includes efforts to mitigate drought risk with the development of an integrated and sustainable water supply system.

All of these strategies are consistent with the vision of developing IKN as a modern city resilient to climate change. Considering the ecological conditions of East Kalimantan, the proposed fire and flood mitigation strategies focus not only on protecting urban infrastructure but also on environmental sustainability and the welfare of local communities. The successful implementation of this strategy will depend greatly on the effectiveness of coordination between institutions, the readiness of supporting infrastructure, and the commitment to adequate funding allocation.

8.2 Zero Burning

Zero-burning is a land management method that does not use open-burning to clear the remaining logging results (Nugroho, 2012). This concept is implemented as part of the forest and land fire control policy (Rahmat & Fadli, 2016), specifically in the Zero Burning Policy, which prohibits land clearing by burning. This policy has been adopted in the ASEAN Agreement on Transboundary Haze Pollution (AATHP), a regional agreement to prevent transboundary haze pollution due to forest fire. Although the agreement became official on November 25, 2003, Indonesia did not ratify and implement it until 2014, through Law No. 26 of 2014. Before the agreement, Indonesia had already enforced a prohibition on open burning under Article 69, paragraph (1), point (h), and paragraph (2) of Law No. 32 of 2009 on Environmental Protection and Management (UU PPLH).

East Kalimantan is one of the areas with the highest risk of forest and land fire due to a combination of many factors. Although many forest and land fire are triggered by land clearing through burning, other factors, such as dry climate patterns due to the El Niño phenomenon, flammable peat soil conditions, and strong winds that accelerate the spread of fire, all exacerbate the frequency and intensity of these events. Human negligence, such as the uncontrolled use of fire in open land, also deteriorates the situation. In this case, the application of the zero burning method is important to reduce the risk of fire and the impact on the environment and economic aspect (Hanafi, 2023). The development of IKN in East Kalimantan is also a factor that must be considered when implementing the zero-burning method. As a large-scale project that requires infrastructure development, significant land clearing cannot be avoided. Therefore, implementing the zero-burning method is crucial to prevent potential fire that can disrupt the development process and damage the surrounding ecosystem. Given that IKN is designed as a green and sustainable city, environmentally friendly land management policies must be a top priority to ensure the vision of this future city can be realized without sacrificing ecological balance.

The main advantage of the zero-burning method is the potential to reduce greenhouse gas emissions resulting from biomass burning (Dwijanarko et al., 2020). In addition, this method also helps to preserve ecosystem balance by maintaining carbon content in the soil and nutrients usually lost due to land burning (Juo & Manu, 1996; Nugroho, 2019). Ecologically, zero burning can increase the capacity of the soil to absorb and retain water, minimizing land degradation that often occurs in areas with frequent fire (Pantami et al., 2010; Putra, 2021). Another benefit is maintaining the population of microorganisms in the soil, which play an important role in preserving land fertility and supporting tree growth (Adeniyi, 2010). Despite the several environmental benefits, the implementation faces some challenges, particularly in East Kalimantan. One of the most significant challenges is the increased risk of disease attacks on plants, such as White Root Fungus (*Rigidoporus microporus*), which can attack plantation commodities such as rubber and oil palm when the remaining biomass is not decomposed immediately (Nugroho, 2019).

Moreover, this method takes a longer time to decompose the falling residues. Land preparation also becomes more difficult due to the pile of remaining biomass, making it less practical and requiring higher operational costs (Dwijanarko et al., 2020).

8.3 Blue Green Infrastructure (BGI)

The article "Blue-Green Infrastructure: An Eco-Friendly Route to Development" published by The Constructor (2024), describes Blue-Green Infrastructure (BGI) as a nature-based approach in urban planning that integrates water aspects (blue), including rainwater management, sustainable drainage systems, and water resource conservation, with vegetation aspects (green), comprising green infrastructure. The objective is to increase resilience toward environmental risks, namely flooding and climate change. This concept includes various elements, such as rain gardens, green roofs, retention ponds, and natural drainage systems designed to manage water more sustainably and reduce surface runoff (O'Donnell et al., 2017). BGI is recognized as an effective method in flood mitigation in urban areas. Several cities, such as Samarinda, Balikpapan, Bandung, and Semarang, have started to adopt this method. However, optimizing the implementation remains a challenge, specifically due to the lack of integration in spatial planning (Ariyaningsih et al., 2024). One of the main challenges is the limited resources and knowledge at the community level. When implementing this strategy, the role of the government is very crucial in ensuring the effectiveness of flood management. The government needs to increase capacity in strategic planning, preparedness, operational management, and collaboration with various parties to support the sustainability of BGI.

Aside from regulatory and spatial planning challenges, rapid urbanization in Indonesia adds to the complexity of BGI implementation. Case studies from cities show that rapid urbanization often hinders the effectiveness of BGI, both in terms of design, implementation, as well as maintenance of green and blue infrastructure. However, this condition also provides opportunities for the development of new strategies and program adjustments that are more appropriate to the various areas in Indonesia (Ariyaningsih et al., 2024). As an alternative strategy in risk management, BGI contributes to reducing waterlogging by increasing natural infiltration capacity while reducing dependence on “grey” infrastructure that often requires high maintenance costs. The use of this strategy is gaining more attention worldwide, specifically regarding the efforts to create cities that are more resilient to climate change. In addition to helping manage rainwater, BGI also has ecological and social benefits, such as improving air quality, reducing the urban heat island effect, improving aesthetics, and community well-being (Thorne et al., 2018).

One example of BGI application in urban areas is showed in a study by Nurhidayati, (2022), which emphasized the effectiveness of permeable pavements as flood mitigation measure. This type of pavement facilitates the direct infiltration of rainwater into the soil, reducing surface runoff and enhancing urban water management. The strategy is consistent with the BGI principle because it reduces waterlogging and also supports improving groundwater quality and maintaining the balance of urban ecosystems. In addition, systems such as Rain Water Harvesting (RWH) can be combined to maximize rainwater use and reduce pressure on conventional water resources (Kaur & Gupta, 2022; Mamangkey et al., 2021). The implementation of the BGI concept, including the use of permeable pavements, is very relevant for the East Kalimantan area, specifically with the presence of the IKN. Increasing infrastructure development and rapid urbanization can potentially increase the risk of flooding due to reduced water catchment areas. Therefore, the BGI concept is a strategic solution in supporting environmental sustainability in East Kalimantan. The success of implementing this strategy relies on an understanding of local environmental conditions, including soil characteristics and rainfall patterns, as well as collaboration between local governments, communities, and the private sector.

Globally, there is a growing shift from traditional grey infrastructure toward more adaptive and sustainable approaches, such as Water-Sensitive Urban Design (WSUD). Cities around the world are starting to implement a combination of green roofs, swales, retention ponds, and permeable surfaces to build more sustainable water management systems. This strategy not only addresses urban flooding but also offers co-benefits, including enhanced biodiversity, improved water conservation, and reduced carbon emissions (Fawzy et al., 2020). With increasing awareness about the impacts of climate change, governments and communities should adopt the BGI strategy as a long-term solution to building more resilient cities. In addition to stronger regulations, education and increased public awareness of BGI technology and sustainable urban planning practices are also key factors in the successful implementation of this concept in Indonesia (Ariyaningsih et al., 2024).

8.4 Ecohydrology and Eco-hydraulics Concept

A combination of natural and anthropogenic factors causes flood problems in East Kalimantan. Naturally, topographic conditions that vary from lowlands to hills and the presence of the Mahakam watershed make the area riskier for water accumulation from rain runoff. High rainfall throughout the year and tides along the coast also worsen the potential for flooding. On the other hand, human activities, including changes in the function of catchment areas, land clearing for plantations and industry, as well as deforestation in upstream areas, also negatively affect the hydrological cycle. The decline in forest area due to the expansion of oil palm plantations and coal mining activities deteriorates the land capacity to absorb rainwater, increasing the frequency and intensity of flooding (Ramadhany, 2023). Poorly managed drainage systems in major cities such as Samarinda, Balikpapan, and Bontang further contribute to severe flooding during intense rainfall (Mauliannur, 2013; Mot, 2016; Pratiwi & Ndraha, 2018).

Conventional flood management strategies generally focus on building drainage and embankment infrastructure, which are often temporary and tend to overlook ecological balance. Therefore, there is a growing need for more sustainable strategies, including the application of ecohydrology and ecohydraulics concepts as an innovative approach to water resource management. Ecohydrology is an innovative approach that combines ecological and hydrological aspects to manage water resources sustainably. This concept was first introduced at the International Conference on Water and Environment in Dublin in 1992 and was further developed by UNESCO in the mid-1990s. The main principle is to ensure a balance between the dynamics of biota and hydrology in the catchment area to address various environmental problems.

One concrete strategy in water resource management is to increase soil absorption capacity, ensuring that the availability and quality of groundwater are maintained. Suboptimal water absorption process leads to an increase in the risk of flooding. Theoretically, green areas should cover 30-40% of the total area to support water absorption, but with the application of wind-based ecohydrology, it can be reduced to 10% (Soeprobowati, 2010). The ecohydrology approach has been applied in various areas, such as Semayan-Malintang, East Kalimantan, and in Lake Limboto, Gorontalo, which covers 562 hectares. Studies in these locations show that the concept can effectively overcome the problems of sedimentation, flooding, and increase fisheries productivity (Pawitan, 2011). Since the 1980s, this concept has been developed by Zalewski et al. (1997) in Poland for agricultural areas and then adapted into sustainable urban planning.

8.5 Education and Community Engagement

In the context of disaster events, the most critical element assessed is not solely the functionality of early warning systems or the robustness of physical infrastructure, but human preparedness. This refers to the capacity of individuals and communities to comprehend risks, respond appropriately, and support collective safety. Effective disaster mitigation is fundamentally dependent on sustained educational efforts that transcend generations. In this regard, Disaster Risk Reduction (DRR) education should be recognized not merely as a supplementary component of formal education but a foundational pillar that contributes to long-term sustainable development and enhances societal resilience (Husniawati et al., 2023).

Disaster have become an almost routine aspect of life in Indonesian society. Although many community members possess adequate knowledge regarding disaster risks and mitigation strategies, particularly in the context of flooding, active participation during actual events often remains limited or unclear (Husniawati et al., 2023). Fostering community participation is crucial, not merely to position communities as passive recipients of protection, but proactive agents in disaster preparedness. Community participation is both irreplaceable and urgent. In every disaster scenario, the community is primarily impacted, and concurrently, the first to respond and assist others. Therefore, integrating the community into preparedness activities, from disaster simulations and evacuation training to community-based educational forums, is not only necessary but also absolute (Irwan & Nakoe, 2021).

Indonesia still faces major challenges in strengthening the culture of disaster preparedness. The weak integration of disaster education into the formal education system, low institutional attention to mitigation, and minimal disaster management performance in many areas are significant challenges (S. P. Astuti et al., 2023). Well-designed schools can be the starting point for major changes, serving not only as a learning space but also for forming collective awareness and transforming behavior. As a country that has ratified the Hyogo Framework, Indonesia is committed to instilling a safety culture from an early age. In this regard, educational institutions play a strategic role. Schools, with broad reach and educational functions, are the ideal medium for nurturing values, attitudes, and skills in addressing disaster (Rahma, 2018).

Effective disaster education must be able to bridge knowledge and action between individual learning and social engagement. The focus is not only on information, but also forming life skills, psychosocial resilience, and community solidarity. This has become the core of comprehensive DRR education, producing citizens who are knowledgeable, responsive, and motivated (Tahmidaten & Krismanto, 2019). Education and community engagement ultimately support each other, forming a social ecosystem prepared to face risks, learn from the past, and together build a safer future.

Mahakam River, credit
Photo credit: Wisnu Hasan

9 Conclusion

In conclusion, this book presents conceptual and applied foundations related to the importance of risk information in area development. Risk information serves as a collection of technical data on potential disaster and a strategic instrument that forms the basis for decision-making in disaster management and sustainable development planning. From a terminology and philosophical point of view, information is obtained from the process of interpreting data. In the context of disaster, information is interpreted as a tool to form collective awareness, guide mitigation strategies, and strengthen the adaptive capacity of the community. By understanding these conceptual roots, development actors can position risk information as an important pillar in resilient city design. Through the evolution of the global DRR paradigm, information has witnessed a transformation from a technocratic to a systemic and participatory approach. In this context, developing the IKN as a national strategic project suggests that risk information needs to be a dynamic and active planning tool,

Rainforest Serenity at Bukit Bangkirai
Photo credit: Stevie Nissauqodry

rather than simply a formal administrative document.

The relocation of capital city to East Kalimantan is an ambitious step for Indonesia in building an environmentally friendly and sustainable city of the future. However, one of the major challenges faced is the risk of natural disaster, specifically forest fire and flood. This book found that from a physical perspective, the level of risk of forest fire was influenced by anthropogenic, climatological, and topographic factors. Meanwhile, the level of flood risk was influenced by aspects of rainfall, topography, and land cover. These aspects must be considered in planning the development of the IKN and surrounding areas.

This book presents various alternative risk management strategies, including low-carbon development through Net Zero Nusantara 2045, and the elimination of land burning practices (Zero Burning) to reduce the number of forest fire. In addition, the application of blue-green infrastructure incorporating natural elements, along with an ecohydrology approach that considers ecosystem balance, is necessary. This approach focuses on watershed management and the conservation of buffer vegetation to mitigate flooding. Strengthening institutional capacity and disaster education within the community is also crucial. The risk management-based alternatives are crucial in spatial planning and environmental policy.

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Erlis Saputra was born on 1 October 1980 in Pekanbaru, Riau province, Indonesia. He completed his doctoral degree from the Department of Human Geography and Spatial Planning at Utrecht University, the Netherlands. Since 2007, he has been a lecturer in the Department of Development Geography, Faculty of Geography, Universitas Gadjah Mada, Indonesia, where he focuses on and teaches urban geography, spatial theory, small city and archipelago development, and spatial and regional planning.

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Femke van Noorloos

Femke van Noorloos is associate professor of International Development Studies and Human Geography & Planning (Faculty of Geosciences, Utrecht University).

Femke is engaged in co-creating research, teaching and impact around urban housing, new cities and megaprojects, focusing on large-scale urban projects such as new cities in relation to land and housing; as well as innovations and policies in incremental housing and citizen-led urban development. She has worked across Latin America, Asia, Africa, and Europe, co-creating knowledge across the global North / South divide. She is also interested in dimensions of migration/mobility, tourism, and intersectional gendered inequalities within these urban dynamics. She has supervised a variety of PhD students and postdocs related to these projects and interests.

Femke is co-director of the International Development Studies Master's programme and teaches in the Human Geography and Planning Bachelor's programme and in the Master's programmes International Development Studies and Global Urban Transformations. She has also taught for a variety of other programmes and audiences e.g. UCU and Summer Schools for professionals. She is also engaged in Shared Value Foundation.

Kei Otsuki

Kei Otsuki is Professor of International Development Studies at Utrecht University. Her research interests center on social equity and justice for sustainable development. She critically explores often contested relationships between the global agenda for sustainability transitions and local environment and well-being. She has conducted field research on the relationship between forest conservation and spontaneous human settlements in the Brazilian Amazon, and between nature conservation and forced displacement and resettlement in Mozambique. She also has a wide range of research experience on the nexus between climate change, gender, and various forms of human mobility in Ghana; alternative (mainly agroecological) forms of solidarity green economy in Brazil, and inclusive urban and infrastructure development in Kanya, Tanzania and Mozambique. Currently, she works on 'green' mineral and natural gas extraction and displacement and resettlement in northern Mozambique, and her latest international research project is on impacts of the new capital city Nusantara on surrounding extraction frontiers in East Kalimantan of Indonesia.

Kei is a core team member of the Critical Pathways community and a board member of the Pathways to Sustainability Strategic Theme of Utrecht University. She actively teaches in Master International Development Studies and Research Master Global Urban Transformations of the

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