http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 10 No 2 2025

RESEARCH ARTICLE

An Integrated Approach to Land Condition Mapping: Combining Terrestrial Surveys, Photogrammetry, and GIS for Data Center Development in Nongsa Special Economic Zone

Sudra Irawan[1]*, Prastiwo Anggoro[2], Rizki Widi Pratama[3], Farouki Dinda Rassarandi[3], Marsanda Nainggolan[3], Muhammad Adi Hasan Basri[3], M. Rajab Al Hakim[3], Fridheani Reshana Sembiring[3], Pernando Simanjuntak[3], Tia Artini[3], Satriya Bayu Aji[3]

[1] *Professional Engineer Program, Department of Mechanical Engineering, Politeknik Negeri Batam, Batam, Riau Islands, Indonesia.*
[2] *PT. Lancang Kuning Sukses, Bintang Industrial Park Lot B-308, Batam, Riau Islands, Indonesia.*
[3] *Geomatics Technology, Department of Informatics Engineering, Politeknik Negeri Batam, Batam, Riau Islands, Indonesia.*

* Corresponding author: sudra@polibatam.ac.id
Received: March 14, 2025; Accepted: May 16, 2025.
DOI: 10.25299/jgeet.2025.10.02.21462

Abstract

Accurate and comprehensive land condition mapping is crucial for infrastructure development planning, particularly for data center construction in Nongsa Special Economic Zone (SEZ). This research integrates terrestrial survey, photogrammetry, and geographic information system (GIS) data to produce optimal land condition maps. The methodology involves field data collection through terrestrial measurements, aerial photography using photogrammetry, and data processing/analysis using GIS tools. This integrated approach enables the creation of comprehensive land condition maps, incorporating topography, land use, and other supporting parameters. The results demonstrate improved mapping accuracy and detailed spatial information, supporting informed location decisions. Eleven thematic maps were created, including topography, longitudinal and transverse profiles, composite volume, DSM/DTM contours, land cover, soil type, slope, water density, and flood hazard maps. Flood hazard analysis reveals that Nongsa has low (1.13 km^2), moderate (61.16 km^2), high (34.32 km^2), and very high (0.0078 km^2) flood risk areas. The majority of Nongsa (61.16 km^2) falls within the moderate flood risk category. This research identifies that a significant portion of Nongsa, specifically 61.16 km^2, is categorized as having a moderate flood risk, highlighting the need for targeted infrastructure planning and risk mitigation strategies in the development of data centers within the SEZ. The results of this study also provide important insights into the impact of land use changes on the local ecosystem, making them valuable for planning more environmentally friendly and sustainable development.

Keywords: Terrestrial Survey, Photogrammetry, GIS, Land Condition Mapping, Flood, Nongsa SEZ

1. Introduction

1.1 Sub Introduction

The construction of a data center building requires in-depth planning and analysis to ensure the sustainability, efficiency, and security of the infrastructure built. Nongsa Special Economic Zone (SEZ), as one of the strategic areas for information technology development in Indonesia, is an ideal location for data center construction. However, the development in the area faces various challenges, such as varied topography, potential environmental risks, and the need for optimal land use.

In this context, mapping land conditions is a critical first step to support the planning and development. Accurate mapping not only helps in understanding the physical characteristics of the land, but also provides important information related to site feasibility, potential risks, and optimal spatial planning. To achieve a high level of accuracy, a comprehensive integration of data and methods is important.

The combination of terrestrial survey, photogrammetry, and geographic information system (GIS) is very relevant for this purpose. Terrestrial surveys provide detailed data on field conditions directly. Photogrammetry enables spatial data collection through aerial photography. GIS plays a role in spatial data processing, analysis, and visualization. By integrating these three methods, accurate and informative land condition maps can be provided.

This research aims to develop the data integration method and survey technique to support the mapping of suitable land conditions for the construction of the data center building in Nongsa SEZ. This approach resulted in a mapping model that is not only efficient but also reliable for data-based development planning needs.

The results of the data processing can be used to assess flooding in Nongsa, where all data center buildings will be constructed. Flooding is a frequent natural disaster in many parts of the world, including Indonesia, which has a geography that is vulnerable to such disasters. Flooding can occur due to a variety of factors, such as heavy rainfall, river overflow, deforestation, land use change, and errors in planning and management of urban and rural areas. Floods often have adverse impacts on society, the environment, and the economy, such as damage to infrastructure, loss of natural resources, and threats to human safety (Sulaiman et al., 2020).

The importance of flood-related research lies not only in understanding its causes and impacts but also in efforts to reduce risks and increase community resilience to this disaster. Flood-related research aims to obtain accurate data on the causative factors, patterns of flood occurrence, and impacts so that more effective policy recommendations and mitigation strategies can be developed. Batam, located in the Riau Islands, Indonesia, is one of the fastest growing industrial and trading cities. As one of the economic centers in southern Sumatra, Batam has a well-developed infrastructure, as well as high tourism and industrial potential. Nevertheless, Batam faces various challenges related to environmental governance and natural disasters, one of which is flooding.

Flooding in Batam has become an increasingly frequent problem in recent years. Climate change, heavy rainfall, and errors in urban planning and management are some of the factors that cause flooding in Batam. In addition, rapid urbanization and deforestation of the surrounding forests exacerbate the situation, impeding water flow and increasing the risk of flooding (Indrastuti & Yunita, 2020).

Flooding in Batam not only affects the social and economic life of the community but also damages infrastructure, affects industrial activities, and reduces the quality of life of local residents. Therefore, it is important to conduct research on flooding in Batam to find out the underlying causes, impacts, and workable solutions to reduce the risk of flooding in the future.

Nongsa, located in the eastern part of Batam, is one of the fastest growing areas, especially in the tourism and housing sectors. It is also home to many industrial estates and other facilities that support Batam's economy. Although Nongsa is not as densely populated as some other areas in Batam, it still has the potential for flooding, especially during the rainy season with heavy rainfall.

One of the factors affecting flood potential in Nongsa is heavy rainfall. Batam in general experiences a tropical climate with relatively heavy rainfall, especially during the rainy season which lasts between November and March. Heavy rainfall in a short period of time can lead to a large volume of water and potentially cause flooding, especially in lowlands and areas close to rivers.

The topography of Nongsa is highly varied, with some areas being lowlands and potentially submerged in water during heavy rainfall (Indrastuti & Yunita, 2020). Lowlands tend to have less than optimal drainage channels. Poor drainage systems and clogged drains can lead to widespread inundation.

Rapid development in the Nongsa area, especially in the housing, property, and tourism sectors, is sometimes not matched by good environmental management planning and drainage management. Reduced urban green spaces and increased land conversion for residential or industrial use can reduce the absorption of water into the soil, increasing the potential for flooding.

Some areas in Nongsa are close to rivers and waterways that can overflow during heavy rainfall. If these rivers do not have enough capacity to accommodate rainwater, overflowing rivers can cause flooding around the area. In addition, environmental degradation around the river, such as sedimentation or destruction of natural habitats, can reduce the flow capacity of the river. Limited drainage infrastructure is one of the main problems often faced by fast-growing urban areas due to inadequate development and maintenance of drainage infrastructure. Poor or inappropriate drainage systems that do not match the development of the area can lead to the accumulation of rainwater on the ground surface, which has the potential to cause flooding.

Some areas that have the potential to flood in Nongsa include areas around the coast and lowlands. Areas near the coast tend to have low elevations and are more prone to inundation. New settlement areas and newly developed residential areas, especially if the drainage infrastructure development is inadequate, are more prone to flooding. Areas close to small rivers or poorly managed waterways can be submerged and cause localized flooding.

To reduce the potential for flooding in Nongsa, one of the mitigation measures that must be considered is the improvement of drainage infrastructure through the construction and maintenance of good drainage systems, especially in flood-prone areas, to accelerate the flow of rainwater and prevent water accumulation. Waterways and rivers must be cleaned and maintained so water can flow smoothly. Sedimentation control and pollution prevention are also very important. Sustainable land management raises awareness of the importance of maintaining the balance of nature by maintaining urban green spaces and reducing uncontrolled land conversion. Environmentally friendly urban planning is needed by considering disaster mitigation aspects in any new development. Communities need to be educated on the importance of maintaining waterways as well as ways to prevent flooding such as disposing of garbage in its proper place.

This research aims to show that flooding in Nongsa is caused by various factors, both natural and human. Key factors include heavy rainfall, land cover, drainage system, soil type, and slope. The impacts are extensive, involving social, economic, and environmental losses.

2. Research Method

2.1 Research Location

This research was conducted in Nongsa, Batam. Nongsa consists of four sub-districts, which are Batu Besar, Sambau, Kabil, and Ngenang.

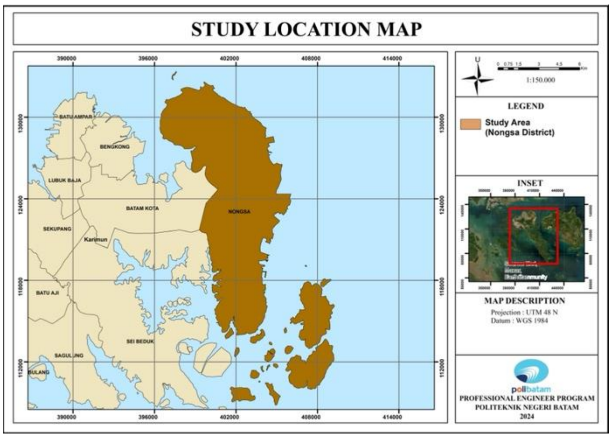

Fig 1. Map of research location.

2.2 Flowchart

The land condition mapping process for the proposed data center development in the Nongsa Special Economic Zone begins with a literature study (Fig 2), which aims to review relevant theories, methodologies, and previous studies related to land assessment, flood zoning, and GIS-based mapping. This step helps to establish a strong theoretical foundation and identify data requirements.

Following this, the data collection phase is conducted, combining both terrestrial surveys and aerial photogrammetry. This stage involves gathering primary and secondary data, including topographic data, rainfall, soil types, slope, and drainage characteristics, which are essential for land condition evaluation.

The collected data are then used to produce several thematic maps. This involves two parallel activities: (1) Preparation of contour/topography maps from aerial photography, cut-and-fill volume maps, and profile maps (longitudinal and transverse). These maps provide a detailed understanding of surface elevation and landform features, (2) creation of slope maps, soil type maps, rainfall maps, land cover maps, and drainage density maps. These layers serve as critical inputs in determining the land's susceptibility to flooding and its overall suitability for development.

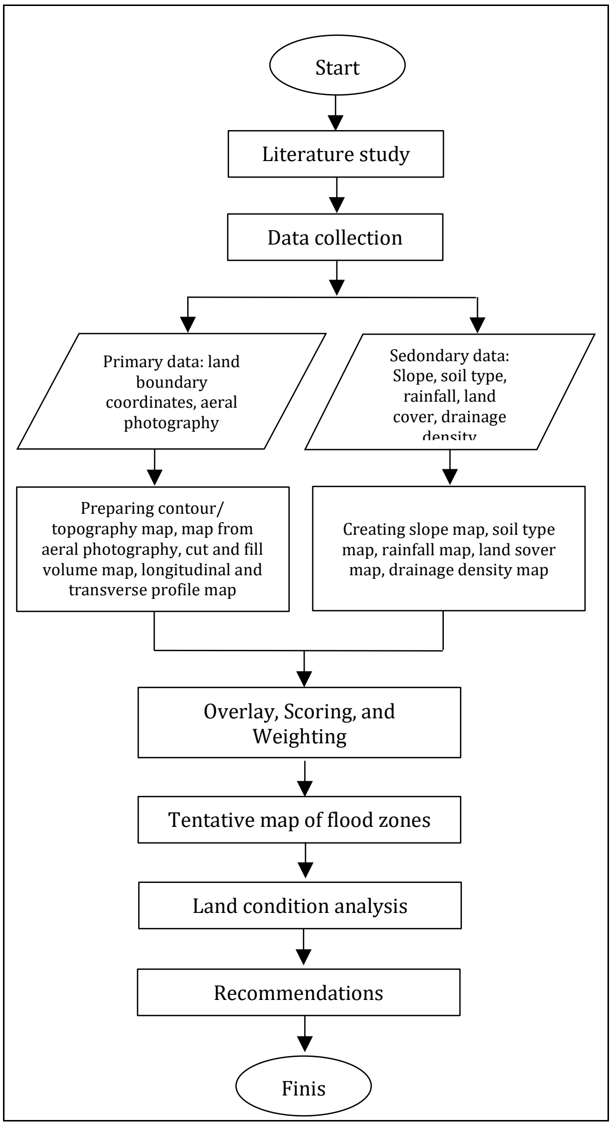

Fig 2. Research flow diagram

Next, the thematic maps are integrated using overlay, scoring, and weighting techniques in a GIS environment. This step allows for the evaluation of each land parameter by assigning weights based on its influence on flood potential and land stability. The output of this spatial analysis is a tentative map of flood zones, identifying areas with varying levels of flood risk. This map serves as a basis for further analysis of land conditions in relation to data center infrastructure requirements.

Subsequently, a comprehensive land condition analysis is carried out, synthesizing the spatial and physical parameters to assess site suitability. This includes consideration of accessibility, elevation stability, drainage, and development constraints.

2.3 Tools and Materials

The tools and materials used for this research include Trimble Total Station, single prism, stative, RTK drone, tape measure, umbrella, stakes/nails, laptop, ArcMap 10.8, QGIS 3.28.8, Google Earth, Microsoft Word, and Microsoft Excel.

2.4 Data Collection

There are two types of data collected, which are primary data and secondary data. The primary data collected are location and elevation data, which are taken using Total Station, RTK, GPS, and aerial photography data taken using RTK drone. The secondary data collected was obtained from various sources. The following are 6 secondary data used in this study.

a. Rainfall
The data used in this parameter is rainfall data for 2023. The data source is the climate hazards infrared precipitation with station (CHIRPS).

b. Land cover
The data used in this parameter is land cover data in 2023. The data was acquired from from Badan Pusat Statistik of Batam.

c. Soil type
The data used in this parameter is the soil type data from Badan Pengusahaan Batam.

d. Slope
The data used in this parameter is the National Digital Elevation Model (DEMNAS) data from Ina-Geoportal.

e. Water density
Water density data is obtained from Badan Informasi Geospasial.

f. Base Map
The administrative data containing the shapefile of Batam's administrative boundaries comes from Badan Pusat Statistik. This data includes details such as roads, buildings, vegetation, and vacant land.

2.5 Data Processing

The primary data was used to create a contour/topographic map, a longitudinal and transverse profile map, and a cut-and-fill volume map. The topographic contour data obtained from the field was processed using ArcGIS. The contour map was created for every 2 meters for minor contours and every 8 meters for major contours, with a scale of 1:1300. The longitudinal and transverse profiles were created using AutoCAD using topographic data, by inserting alignment lines, using the section/profile feature, adding elements, and finishing with map layout. The creation of the volume composite map started from creating a triangulated irregular network (TIN) model from the existing topographic data. Then, the cut-and-fill volume was determined.

Secondary data collected on each flood-causing parameter were processed by scoring and weighting. Then, the resulting maps of the five parameters were overlaid to obtain the index and areas in the flood hazard map of Batam. The score, weight, and flood index can be seen in Table 1 to Table 6.

Table 1. Rainfall.

Rainfall (mm/year)	Score
<1500	1
1500-2000	3
2000-2500	5
2500-3000	7
>3000	9

Table 2. Land cover.

Land Cover	Score
Vacant Land	1
Plantation/Forest	3
Rice Field/Pond	5
Settlement/Built-up Land	7
Water Body	9

Table 3. Soil type.

Soil Type	Score
Lithosols, Organosols, Rendzinas	1
Andosols, Podzols, Podzolic	3
Mediterranean Soil	5
Latosols	7
Alluvial, Planosols, Groundwater Laterite	9

Table 4. Slope.

Slope	Score
0–8%	9
8–15%	7
15–25%	5
25–45%	3
>45%	1

Table 5. Water density.

Density km/km^2	Score
0–211.21	9
211.21–422.42	7
422.43–633.63	5
633.64–844.84	3
>844.85	1

Table 6. Score weight.

Parameter	Weight
Rainfall	30%
Land Cover	30%
Soil Type	15%
Water Density	10%
Slope	15%

2.6 Flood Hazard Index

The following is the formula for determining flood hazard.

Flood Hazard = Score x *Weight* (1)

The following is the formula for determining the flood hazard index.

Index Difference = Maximum score / Number of flood classes (2)

The score of each class in each parameter is multiplied by the predetermined weight. The flood hazard index in this study, after the calculation, can be found in Table 7.

Table 7. Flood hazard index.

Flood Hazard Index	Class
0–2.25	Low
2.25–4.45	Medium
4.45–6.75	High
6.75-9	Very high

3. Results and Discussion

3.1 Topographic Map

The resulting topographic map is presented in Figure 3. This was the condition of the land before land maturation activities were carried out.

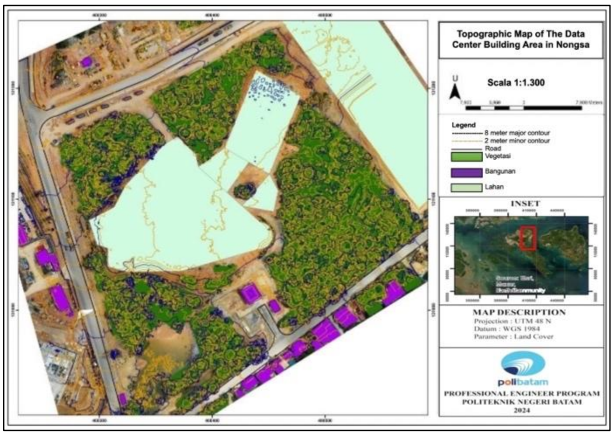

Fig 3. Topographic map (before maturation).

The topographic map is the result of primary data collection in the field using the DJI Phantom RTK drone, which produced aerial photographs as the basemap, contours (from DEM data), and situation details (from the results of digitization). After combining the data, a topographic map was produced (Figure 3).

3.2 Longitudinal and Transverse Profile Map

The longitudinal and transverse profiles are presented in C1 and L3, as shown in Figure 4.

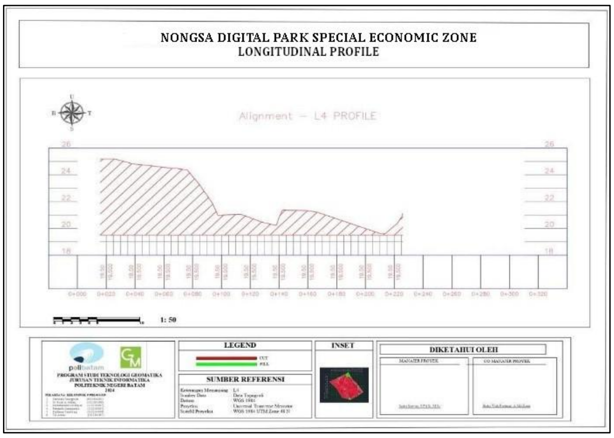

Fig 4. Longitudinal section and transverse section at Nongsa SEZ.

Figure 4 is a sample of the longitudinal section and transverse section generated using the CAD application. The longitudinal section and transverse section were based on the contour and volume data created in Figure 5. From Figure 4, we can see the sample sections C3 and L1. C stands for cross or transverse. L stands for long or longitudinal. C3 and L1 are shown in red. This means that areas in C3 and L1 are cut. Areas shown in green are filled, which are absent in C3 and L1. The cut interval is 20 meters.

3.3 Composite Map of Volume

The cut-and-fil volumes based on the intended reference heights are presented in Figure 5.

Here are some explanations of the map. Red indicates cut sections and green indicates fill sections. The volumes of the cut-and-fill sections are 65685.35 Cu. M and 315.12 Cu. M respectively. The reference elevation for determining the height of the cut-and-fill is 19.5 meters. AutoCAD Civil 3D is used in the processing.

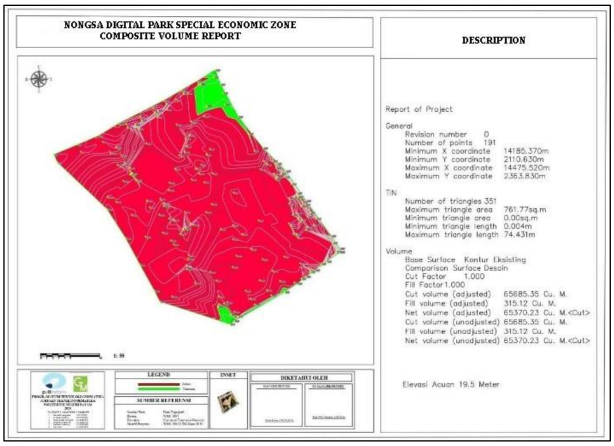

Fig 5. Map of the cut-and-fill volume in a data center building construction area.

3.4 Digital Surface Model (DSM) Contour Map Before and After Land Maturation

The DSM contour maps before and after land maturation are presented in Figure 6a and Figure 6b.

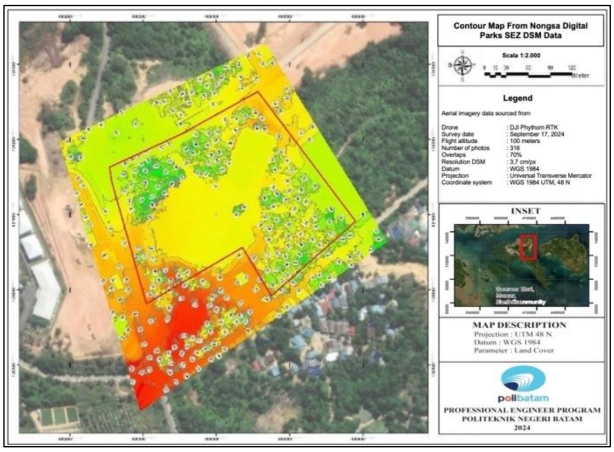

Fig 6a. DSM contour map (before maturation).

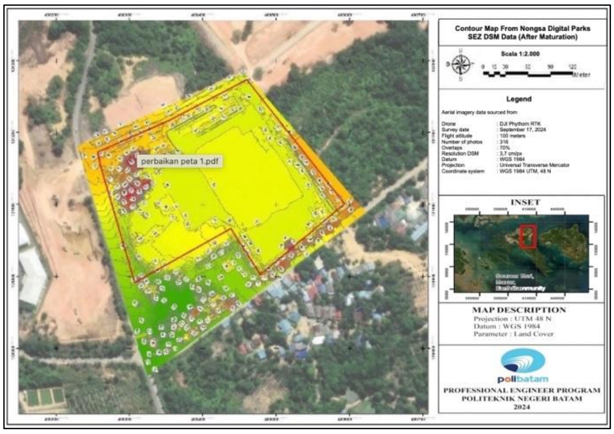

Fig 6b. DSM contour map (after maturation).

DSM data is a model of the Earth's surface that describes all visible objects on the Earth's surface. The shape of the earth's surface is visible in the photo. The DSM maps were created by rendering aerial photo data in Agisoft Metashape. After that, the data were exported and reprocessed using ArcGIS. The data were processed into contours and assigned a color classification to mark the height of the area before land maturation (Figure 6a).

The DSM map was created by rendering aerial photography data in Agisoft Metashape. After the data had been exported, it was reprocessed using ArcGIS. The data were processed into contours and assigned a color classification to indicate the height of the area after land maturation (Figure 6b).

3.5 Digital Terrain Model (DTM) Contour Map Before and After Land Maturation

The DTM contour maps before and after land maturation are presented in Figure 7a and Figure 7b.

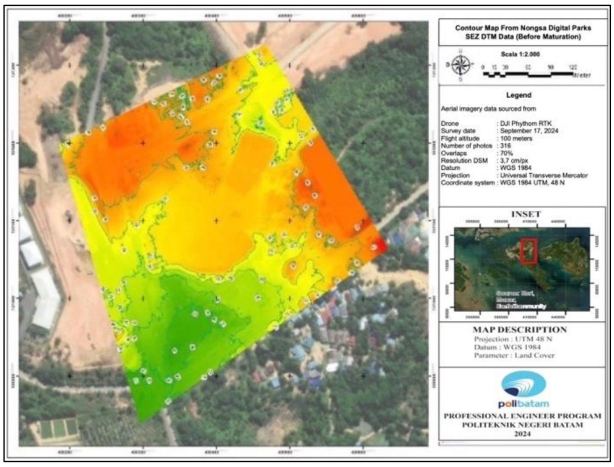

Fig 7a. DTM contour map (before maturation).

DTM data consists of an elevation surface representing the bare earth referenced to a vertical datum. Each DTM point regularly follows the shape of the earth's surface. The DTM map was created by rendering aerial photography data in Agisoft Metashape. After that, the data were exported and reprocessed using ArcGIS. The data were processed into contours and assigned a color classification to indicate the height of the area before land maturation (Figure 7a).

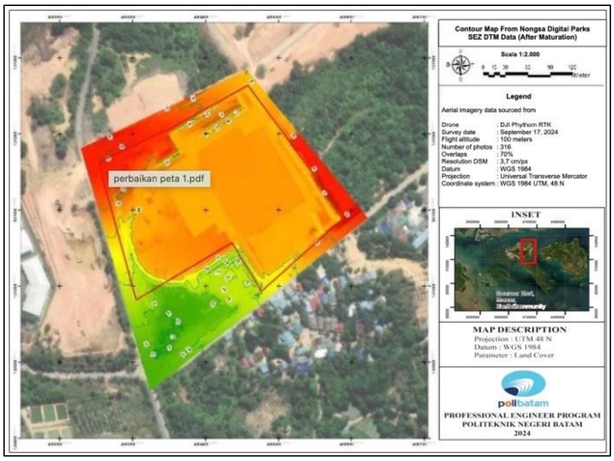

Fig 7b. DTM contour map (after maturation).

The DTM map was created by rendering aerial photography data in Agisoft Metashape. After that, the data were exported and reprocessed using ArcGIS. The data were processed into contours and assigned a color classification to indicate the height of the area after land maturation (Figure 7b).

3.6 Map from Aerial Photo Before and After Land Maturation

The aerial photography data was taken on September 17, 2024, using the DJI Phantom RTK drone with a height of 100 m. The flight duration for data collection was 09:25 minutes. Sidelap and Frontlap were 70% and 80% respectively. The rendering was carried out using Agisoft Metashape. The resulting map from the aerial photo before land maturation can be seen in Figure 8a.

Fig 8a. Map from aerial photo (before maturation).

Aerial photography data was taken on November 7, 2024, using the DJI Phantom RTK drone with a height of 100 m. The flight duration for data collection was 09:25 minutes. Sidelap and Frontlap were 70% and 80% respectively. The rendering was done in Agisoft Metashape. The resulting map from the aerial photo can be seen in Figure 8b.

Fig 8b. Map from aerial photo (after maturation).

3.7 Rainfall Map

The map in Figure 9 shows the color system used to indicate the level of rainfall.

Dark blue indicates a high rainfall intensity of more than 3000 mm, with an area of 40.31 km^2. Light blue indicates the lowest rainfall intensity (between 1500 and 2000 mm), with an area of 36.03 km^2. Most of Sambau experiences rainfall between 2000 and 2500 mm. Batu Besar must endure heavy rainfall of more than 3000 mm. Most of Kabil and Ngenang encounter rainfall between 1500 and 2000 mm, although a small number of areas have recorded more than 3000 mm.

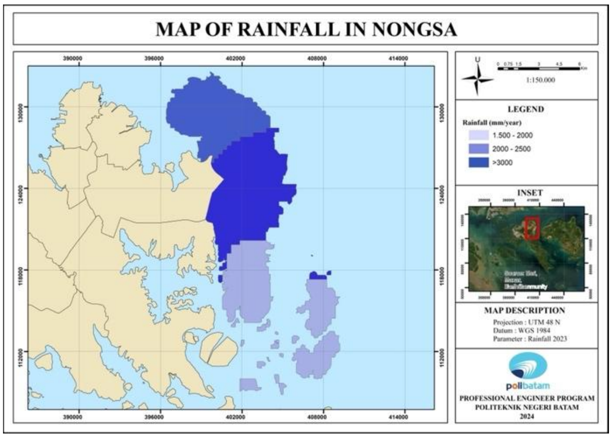

Fig 9. Rainfall map.

Table 8. Rainfall table.

Rainfall (mm)	Area
1500–2000	36.03 km^2
2000–2500	28.43 km^2
>3000	40.31 km^2

3.8 Land Cover Map

Figure 10 shows that Sambau, Batu Besar, and Kabil are dominated by residential or built-up land, indicating the rapid development of settlements in these areas. Meanwhile, Ngenang is dominated by plantations or forests, indicating land use for agriculture and forestry. Overall, Nongsa has the most residential or built-up land at 51.14 km^2. This large settlement area has the potential to increase the risk of flooding if it is not matched by adequate drainage systems and water absorption facilities. On the other hand, the smallest land area in this sub-district is rice fields or ponds, which only cover an area of 0.31 km^2.

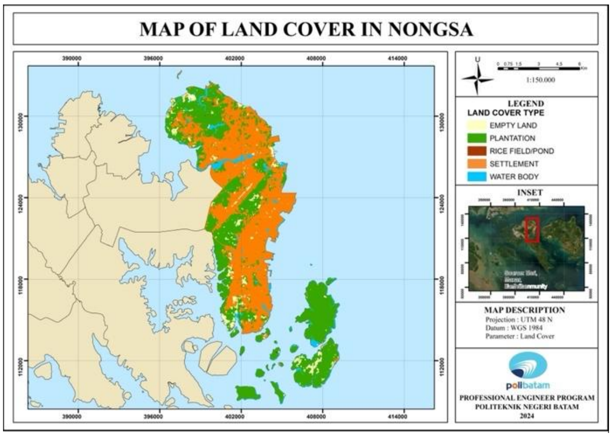

Fig 10. Land cover map.

Despite its limited size, the existence of rice fields or ponds is still important for the sustainability of the agricultural and aquaculture sectors in the region.

Table 9. Land cover table.

Land Cover	Area
Vacant Land	5.30 km^2
Plantation/Forest	48.14 km^2
Rice Field/Pond	0.31 km^2
Settlement/Built-up Land	51.14 km^2
Water Body	5.15 km^2

3.9 Soil Type Map

Figure 11 shows that the soil type in Sambau is alluvial soil, although it only covers an area of 1.07 km². Although better at absorbing water, this soil type can cause flooding in lowlands or areas along riverbanks, especially during heavy rainfall or strong river currents. Areas such as Batu Besar, Kabil, and Ngenang are dominated by latosols and podzolic soils. Nongsa is dominated by podzolic, with an area of 86.81 km².

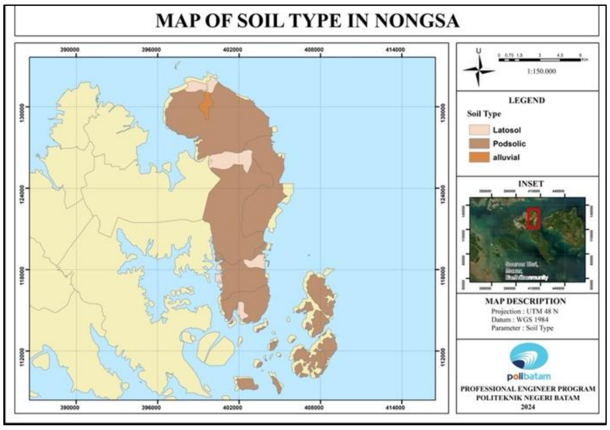

Fig 11. Soil type map.

Podzolic soils tend to have low water absorption due to their high acidity and limited organic matter. This soil type is prone to surface runoff as rainwater is slow to absorb, which can increase the risk of flooding, especially if there is heavy rainfall over a short period of time.

Table 10. Soil type.

Soil Type	Area
Latosols	7.77 km²
Podzolic	86.81 km²
Alluvial	1.07 km²

3.10 Slope

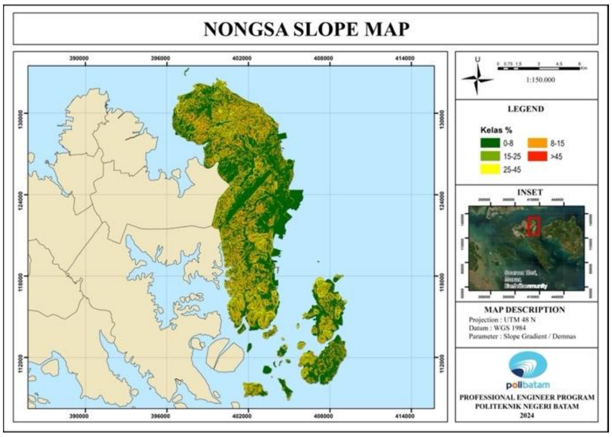

Fig 12. Slope map.

Figure 12 shows that Nongsa as a whole has areas with slopes between 0 and 8%, covering an area of 58.05 km². These areas with relatively flat slopes are more prone to flooding, mainly due to their topographical characteristics that allow the accumulation of rainwater. The larger the area with a low slope, the greater the likelihood of inundation during high rainfall intensity. Meanwhile, areas with slopes of more than 45% only cover an area of 0.05 km². These areas, with very steep slopes, are at greater risk of landslides and soil erosion, although they are less prone to flooding.

Overall, slope affects how water flows, how long it stays on the surface and how much potential damage it can cause. Flat areas with poor drainage systems are particularly prone to flooding, while steep areas are more at risk of landslides and erosion.

Table 11. Slope.

Slope	Area
0–8%	58.05 km²
8–15%	32.49 km²
15–25%	14.78 km²
25–45%	2.70 km²
>45%	0.05 km²

3.11 Water Density

Figure 13 shows that the most extensive overall water density lies between 633.64 and 844.84, with an area of 29.03 km² per km². This area shows a more evenly distributed water density, potentially affecting water flow and distribution patterns within the area. The area with a water density greater than 844.85 is only 12.00 km² per km².

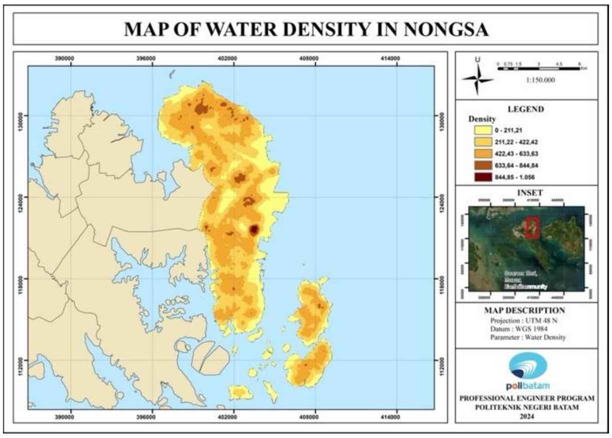

Fig 13. Water density map.

Areas with higher water density are characterized by more concentrated water absorption or distribution, which could affect water resources and flood management.

Table 12. Water density.

Density km/km²	Area
0–211.21	16.74 km/km²
211.21–422.42	22.04 km/km²
422.43–633.63	28.91 km/km²
633.64–844.84	29.03 km/km²
>844.85	12.00 km/ km²

3.12 Nongsa Flood Hazard Map

Figure 14 shows that Sambau, Ngenang, and Batu Besar are dominated by areas that fall into the medium flood hazard category. This indicates that these areas have a moderate risk of flooding, with factors such as slope, soil type, and other factors influencing the likelihood of flooding. Meanwhile, Kabil is dominated by areas with high flood hazards, indicating that these areas are very prone to flooding due to factors such as heavy rainfall, surface conditions, and existing infrastructure.

Overall, Nongsa has the largest area of moderate flood hazard at 61.16 km², indicating that most of this area has a moderate risk of flooding. These findings must be considered in natural resource management planning and disaster mitigation.

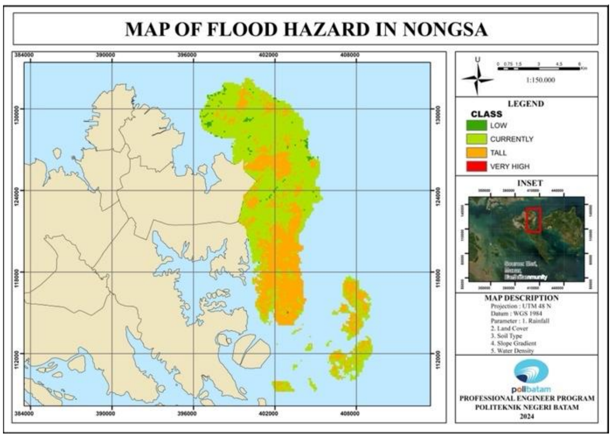

Fig 14. Nongsa flood hazard map.

Table 11. Flood zones.

Area	Class
1.13 km2	Low
61.16 km2	Medium
34.32 km2	High
0.0078 km2	Very high

This study introduces a comprehensive approach to land condition mapping by integrating terrestrial surveys, photogrammetry, and GIS, resulting in improved accuracy and detailed spatial information for data center development in the Nongsa Special Economic Zone. The findings highlight the advantages of multi-source data integration, which enhances mapping precision and provides a more reliable basis for infrastructure planning. A key outcome of this research is the creation of 11 thematic maps that support data-driven decision-making, particularly in assessing land feasibility, flood risk, and environmental impact. The detailed flood risk analysis offers valuable insights for disaster mitigation, while the study's methodology contributes to sustainable spatial planning and can serve as a replicable model for similar infrastructure projects in other regions.

4. Conclusion

The conclusion from the map overlay analysis shows that most of Nongsa falls into the medium flood hazard category, covering an area of 61.16 km². Factors that influence the high risk of flooding in this area include heavy rainfall, reduced land cover, soil type with low absorption capacity, low water density, and steep slopes. All of these factors contribute to increased flood risk by accelerating water flow and reducing the soil's ability to absorb rainwater. In addition, based on the analysis, the area with very high flood hazard is only 0.0078 km², indicating that although there are areas with very high flood hazard, their size is very small compared to other areas that are also prone to flooding with a moderate level of hazard.

References

Anis, M., Idrus, A., Amijaya, H., & Subagyo, S., 2017. Utilizing coal remaining resources and post-mining land use planning based on GIS-based optimization method: study case at PT Adaro coal mine in South Kalimantan. Journal of Geoscience, Engineering, Environment, and Technology, 2(2), 141-148. doi: https://doi.org/10.24273/jgeet.2017.2.2.307

Demissie, Z., Rimal, P., Seyoum, W. M., Dutta, A., & Rimmington, G., 2024. Flood susceptibility mapping: integrating machine learning and GIS for enhanced risk assessment. Applied Computing and Geosciences, 100183. doi: https://doi.org/10.1016/j.acags.2024.100183

Diriba, D., Takele, T., Karuppannan, S., & Husein, M., 2024. Flood hazard analysis and risk assessment using remote sensing, GIS, and AHP techniques: a case study of the Gidabo Watershed, main Ethiopian Rift, Ethiopia. Geomatics, Natural Hazards and Risk, 15(1), 2361813. doi: https://doi.org/10.1080/19475705.2024.2361813

Efraimidou, E., & Spiliotis, M., 2024. A gis-based flood risk assessment using the decision-making trial and evaluation laboratory approach at a regional scale. Environmental Processes, 11(1), 9. doi: https://doi.org/10.1007/s40710-024-00683-w

Guven, D. S., Yenigun, K., Isinkaralar, O., & Isinkaralar, K., 2024. Modeling flood hazard impacts using GIS-based HEC-RAS technique towards climate risk in Şanlıurfa, Türkiye. Natural Hazards, 1-19. doi: https://doi.org/10.1007/s11069-024-06945-y

Hamdany, F. D., & Saputra, A. J., 2024. The Effect of Urbanization on the Effectiveness of Drainage Systems and Flood Risk in Batam City. Journal of Civil Engineering and Planning (JCEP), 5(2), 287-291. doi: https://doi.org/10.37253/jcep.v5i2.9619

Hossain, M. N., & Mumu, U. H., 2024. Flood susceptibility modelling of the Teesta River Basin through the AHP-MCDA process using GIS and remote sensing. Natural Hazards, 120(13), 12137-12161. doi: https://doi.org/10.1007/s11069-024-06677-z

Indrastuti, I., Yunita, Y., 2020. Analisis Sistem Drainase Terhadap Genangan (Banjir) Di Kota Batam (Studi Kasus: Jalan Duyung Kecamatan Batu Ampar). Journal Of Civil Engineering And Planning 1, 183–189. doi: https://10.37253/jcep.v1i1.7249

Irawan, S., Fitriania, T., Sari, L. R., Natali, S. D., & Aji, S. B., 2024. Drought Management in Batam using Combined NDVI-TCT Algorithm to Create a Classification Level Map. Journal of Geoscience, Engineering, Environment, and Technology, 9(3), 288-294. doi: https://doi.org/10.25299/jgeet.2024.9.3.13033

Irawan, S., Halim, F. M., Aji, S. B., Natali, S. D., & Sismanto, S., 2024. Mapping potential surface runoff areas in Batam with geographic Information system for flood mitigation. In Eighth Geoinformation Science Symposium 2023: Geoinformation Science for Sustainable Planet (Vol. 12977, pp. 516-527). SPIE. doi: https://doi.org/10.1117/12.3009757

Iskandar, B., Zannah, F., & Ansari, R., 2023. Impact of Land Use Change on Land Capability in Katingan Regency, Central Kalimantan, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology, 8(3), 229-235. doi: https://doi.org/10.25299/jgeet.2023.8.3.12423

Iskandarsyah, T. Y. W. M., Brilian, C. H., Trisnadiansyah, M. R., Listiawan, Y., Barkah, M. N., Sulaksana, N., & Hendarmawan, H., 2024. Geo-Environment Aspects Assessment Applied In Land Stability Determination Of A Disaster-Prone Area: A Case Study Around The Lembang Active Fault Zone, On The Western Part Of Bandung Basin, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology, 9(3), 328-334. doi: https://doi.org/10.25299/jgeet.2024.9.3.18062

Kader, Z., Islam, M. R., Aziz, M. T., Hossain, M. M., Islam, M.

R., Miah, M., & Jaafar, W. Z. W., 2024. GIS and AHP-based flood susceptibility mapping: a case study of Bangladesh. Sustainable Water Resources Management, 10(5), 170. doi: https://doi.org/10.1007/s40899-024-01150-y

Kausarian, H., Masdriyanto, S., Batara, B., Suryadi, A., & Zainuddin Lubis, M., 2023. Geomorphology and geology studies using digital elevation model (dem) data in the watershed area of kampar regency, riau province. Journal of Geoscience, Engineering, Environment, and Technology, 8(3). doi: https://doi.org/10.25299/jgeet.2023.8.3.14454

Kementerian Kehutanan, 2013. Peraturan Direktur Jenderal Bina Pengelolaan Daerah Aliran Sungai Dan Perhutanan Sosial Nomor P. 4/V-SET/2013 Tentang Petunjuk Teknis Penyusunan Data Spasial Lahan Kritis [WWW Document]. Juknis Penyusunan Lahan Kritis. URL https://www.scribd.com/doc/170279262/Juknis-Penyusunan-Lahan-Kritis (accessed 1.16.25).

Maulita, M., Nurdin, N., & Taufiq, T., 2024. Mapping of Flood and Landslide Prone Areas using Composite Mapping Analysis Method Based on Geographic Information System in East Aceh. Sistemasi: Jurnal Sistem Informasi, 13(6), 2359-2374. doi: https://doi.org/10.32520/stmsi.v13i6.4483

Peker, İ. B., Gülbaz, S., Demir, V., Orhan, O., & Beden, N., 2024. Integration of HEC-RAS and HEC-HMS with GIS in flood modeling and flood hazard mapping. Sustainability, 16(3), 1226. doi: https://doi.org/10.3390/su16031226

Rakuasa, H., Helwend, J.K., Sihasale, D.A., 2022. Pemetaan Daerah Rawan Banjir Di Kota Ambon Menggunakan Sistim Informasi Geografis. Jurnal Geografi : Media Informasi Pengembangan dan Profesi Kegeografian 19, 73–82. doi: https://10.15294/jg.v19i2.34240

Ramadhan, A. G., Handayani, H. H., & Darminto, M. R., 2022. Analisis Peta Rawan Banjir Metode Pembobotan dan Peta Genangan Banjir Metode NDWI terhadap Kejadian Banjir (Studi Kasus: Kabupaten Sidoarjo). Geoid, 17(2), 232-244.

Ramsof, R. A., Zakaria, Z., Sophian, I., & Afriadi, A., 2025. Potential Hazards of Erosion and Conservation Strategis in the Sail Sub-Watershed, Pekanbaru City, Riau Province, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology, 10(1). doi: https://doi.org/10.25299/jgeet.2025.10.1.20795

Ruzgienė, B., Kuklienė, L., Kuklys, I., Jankauskienė, D., & Lousada, S., 2025. The use of kinematic photogrammetry and LiDAR for reconstruction of a unique object with extreme topography: a case study of Dutchman's Cap, Baltic seacoast, Lithuania. Frontiers in Remote Sensing, 6, 1397513. doi: https://doi.org/10.3389/frsen.2025.1397513

Sevil-Aguareles, J., Pisani, L., Chiarini, V., Santagata, T., & De Waele, J., 2025. Gypsum cave notches and their palaeoenvironmental significance: A combined morphometric study using terrestrial laser scanning, traditional cave mapping, and geomorphological observations. Geomorphology, 471, 109576. doi: https://doi.org/10.1016/j.geomorph.2024.109576

Sihombing, S., Sunardi, B., & Darmawan, H.,2024. Tsunami Modeling Using DEMNAS and DEM Data from UAV Surveys for Planning Evacuation Routes on Samas Coast, Bantul Regency. Journal of Geoscience, Engineering, Environment, and Technology, 9(2), 152-157. doi: https://doi.org/10.25299/jgeet.2024.9.2.14777

Sitorus, I.H.O., Bioresita, F., Hayati, N., 2021. Analisa Tingkat Rawan Banjir Di Daerah Kabupaten Bandung Menggunakan Metode Pembobotan Dan Scoring. Jurnal Teknik ITS 10, C14–C19. doi:10.12962/j23373539.v10i1.60082

Suhardono, S., Adicita, Y., Sari, M. M., Tehupeiory, A., & Suryawan, I. W. K. (2024). Coastal Degradation in Tanjung Uma, Batam City, Indonesia: A SWOT Analysis of Environmental Challenges and Opportunities. Indonesian Journal of Social and Environmental Issues (IJSEI), 5(1), 88-98. doi: https://doi.org/10.47540/ijsei.v5i1.1060

Sulaiman, M.E., Setiawan, H., Jalil, M., Purwadi, F., Adio S., C., Brata, A.W., Jufda, A.S., 2020. Analisis Penyebab Banjir Di Kota Samarinda. Jurnal Geografi Gea 20, 39–43. doi:10.17509/gea.v20i1.22021

Tajuddin, T., & Masniar, M. (2025). Feasibility Analysis of the Sorong Special Economic Zone (SEZ) Location, Provinsi Papua Barat Daya. Jurnal Geografika (Geografi Lingkungan Lahan Basah), 5(2), 157-169. doi: https://doi.org/10.20527/jgp.v5i2.13536

Wang, H., Chen, W., Li, X., Liang, Q., Qin, X., & Li, J., 2025. CUG-STCN: A seabed topography classification framework based on knowledge graph-guided vision mamba network. International Journal of Applied Earth Observation and Geoinformation, 136, 104383. doi:https://doi.org/10.1016/j.jag.2025.104383

Wardhono A, Pratomo G, Prakoso B, Qori'ah C.G., 2012. Countermeasures Flood Disaster Sampean River Policy In Situbondo District. GSTF International Journal of Law and Social Sciences 2, 118–122. doi: https://10.5176/2251-2853_2.1.65

Wibowo, Y. T., 2025. Risk Assessment of the Implementation of PPP Scheme in Natural Gas Network Project for Households (Case Study: Natural Gas Network for Households in Batam City). Eduvest-Journal of Universal Studies, 5(3), 2835-2850. doi: https://doi.org/10.59188/eduvest.v5i3.1789.

Zhran, M., Ghanem, K., Tariq, A., Alshehri, F., Jin, S., Das, J., ... & Mousa, A., 2024. Exploring a GIS-based analytic hierarchy process for spatial flood risk assessment in Egypt: a case study of the Damietta branch. Environmental Sciences Europe, 36(1), 1-25. doi: https://doi.org/10.1186/s12302-024-01001-9

Zhu, J., Dang, P., Cao, Y., Lai, J., Guo, Y., Wang, P., & Li, W., 2024. A flood knowledge-constrained large language model interactable with GIS: enhancing public risk perception of floods. International Journal of Geographical Information Science, 38(4), 603-625. doi: https://doi.org/10.1080/13658816.2024.2306167