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# Study of the Utilization of WRF Model Output Data to Produce Daily Flood Forecast Maps in the North Sumatra Region

**[1,2]Mega Sirait, [1*]Syahrul Humaidi, [1,3]Marzuki Sinambela, [1]Marhaposan Situmorang, [1]Erna Frida**

[1] Department of Physics, Faculty of Mathematics and Natural Sciences – University of North Sumatra, Jl. Dr. T. Mansur No.9, Padang Bulan, Kec. Medan Baru, Kota Medan, Sumatera Utara, Indonesia. Postal code: 20222

[2] BMKG – Kualanamu Meteorological Station, Jl. Tengku Heran Pasar V Kebun Kelapa, Kec. Beringin, Kab. Deli Serdang, Sumatera Utara, Indonesia. Postal code: 20552

[3] School of Meteorology, Climatoly and Geophysics (STMKG), Jl. Perhubungan I No.5, Pd. Betung, Kec. Pd. Aren, Kota Tangerang Selatan, Banten, Indonesia. Postal code: 15221

*Corresponding Author e-mail: syahrul1@usu.ac.id

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**Abstract**

Flood is a natural disaster that often occurs in Indonesia. Currently, flood events are relatively difficult to predict because floods generally occur suddenly in uncertain periods. Extreme rainfall is a major factor for the occurrence of floods. Considering that floods can be caused by heavy rainfall events within a few hours, it is necessary to produce daily flood forecasts for flood disaster mitigation. This study aims to test the accuracy of utilizing rainfall forecast data from the Weather Research and Forecasting (WRF) model to create daily flood forecast maps. The data used in this study include Global Forecast System (GFS) data, BMKG rainfall measurement data which spread across several points in North Sumatra Province, and flood incident reports from BNPB. Data processing is carried out by Geospatial Information System (GIS) using Quantum-GIS, which includes weighting and scoring the parameters of soil type, slope, land elevation, river density, and land cover to produce Flood Prone Maps, then integrated with rainfall data to produce Daily Flood Forecast Maps. The case studies of flood events in this study are August 28 and November 28, 2022. The results showed that the spatial forecast of flood potential (WRF) has a pattern in accordance with the flood event area. Therefore, the WRF model output rainfall prediction data can be used to create a daily flood forecast map in the North Sumatra region.

**Keywords**: Daily Flood Map, Weather Research and Forecasting model, Geospatial Information System

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## INTRODUCTION

North Sumatra is a province in the northern part of Sumatra Island which is located at coordinates 1°-4° N and 98°-100° E, and which is geographically grouped into 4 parts, namely the west coast, east coast, and highlands/mountains, and islands (DPRD Prov Sumut, 2021). Flood is a natural disaster that always occurs in the territory of Indonesia and cannot be limited by government administrative areas (BNPB, 2021a). Floods can be caused by static natural conditions, such as geography, topography, and river flow geometry, as well as dynamic natural events such as high rainfall (BNPB, 2021b).

The mean rainfall in the west coast region of North Sumatra is higher than the east coast region. Diurnally, high rainfall predominantly occurs at night - early morning in coastal areas, while in highland areas in the afternoon - late afternoon (Saragih, 2020). The graph of flood events from 2010-2022 (Figure 1) shows an increasing trend in the distribution of flood events in North Sumatra. The highest flood events with an intensity of 30-40 events were found in Medan, Langkat, Asahan, South Tapanuli, and Mandailing Natal. The BNPB data indicates that spatially, there are more flood events on the east coast of North Sumatra than on the west coast, which means that the flood-prone areas in North Sumatra are dominant on the east coast..

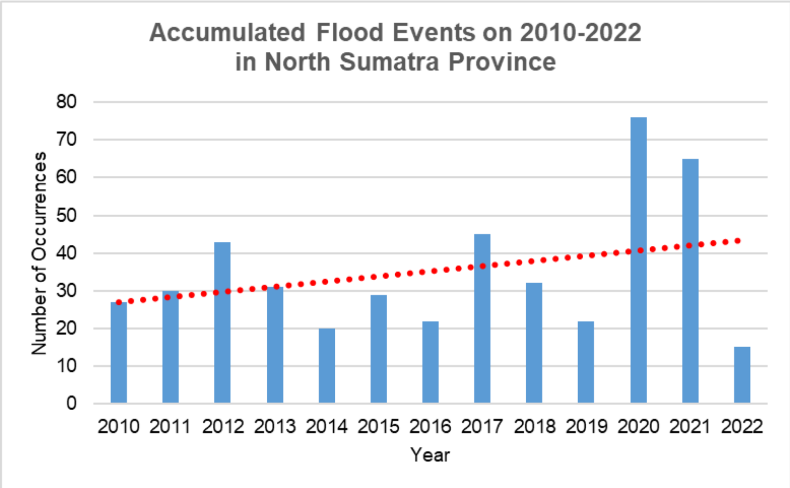


**Figure 1.** Graph of accumulated flood events in North Sumatra for the period 2010-2022

Geographic Information Systems (GIS) has been used to create flood-prone maps but it is still limited to observational rainfall data (Dahlia et al., 2018; Haryani, 2017; Novaliadi & Hadi, 2014; Nuryanti et al., 2018). This research tries to use rainfall forecast data from the Weather Research and Forecasting model (WRF) as input data for making daily flood forecast maps in the North Sumatra region. Weighting the accumulated daily rainfall value of the WRF model output is then combined with the weighting results of flood-prone areas. The daily flood forecast map was then verified using flood event reports by BNPB.

## METHOD

The case study chosen in this research is the flood event in North Sumatra on August 28 and November 28, 2022. The study area is limited by the coordinates of the North Sumatra region, namely 1°-4°N and 98°-100°E.

The data used in this study are as follows:

1) Global Forecast System (GFS) data from NCEP GFS 0.25 Degree Global Tropospheric Forecast Grids with a duration of 36 hours per case study where the first 12-hours as a spin-up model;
2) Flood event reports in North Sumatra Province from BNPB (accessed at: https://gis.bnpb.go.id/) and the Health Crisis Center of the Indonesian Ministry of Health (accessed at: https://pusatkrisis.kemkes.go.id/);
3) Daily rainfall accumulation data from BMKG rain gauges in the North Sumatra region (Figure 2); and
4) Shapefile data from BIG (accessed at: https://tanahair.indonesia.go.id/)

This study uses a WRF model with 2 domains and a model configuration scheme as shown in Figure 3 and Table 1.

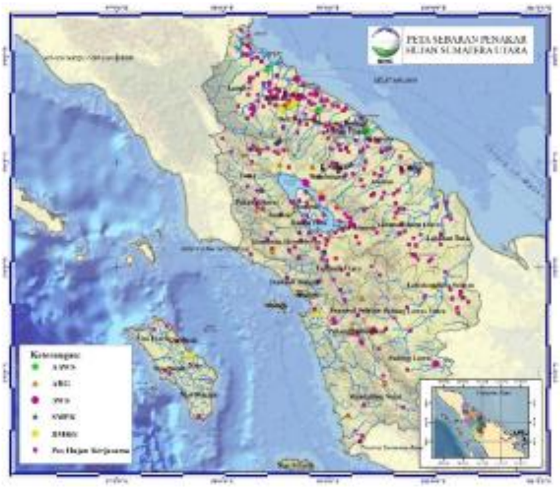

**Figure 2.** Distribution of BMKG rain gauges in the North Sumatra region
*(Data Source: Deli Serdang Climatology Station)*

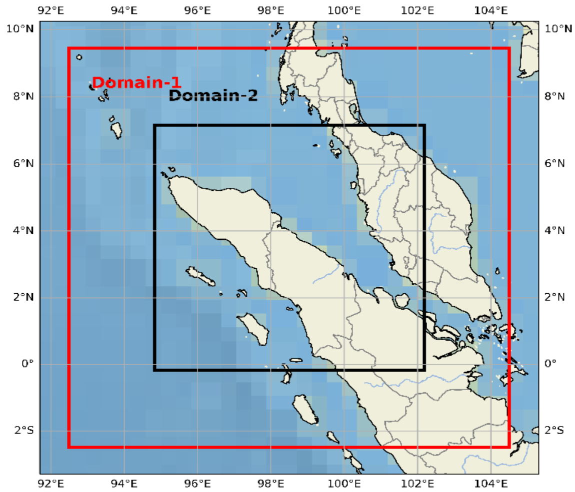


**Figure 3.** WRF domain map used in the study

**Table 1.** WRF model configuration used in the study

| Configuration scheme | Domain-1 | Domain-2 |
|---|---|---|
| *run-hours* | 36 | |
| *time-step* | 18 | |
| *ref_lat* | 2,5°N | |
| *ref_lon* | 99,0°E | |
| *geog_data_res* | 5m | 30s |
| *Dx* | 9 km | 3 km |
| *Dy* | 9 km | 3 km |
| *e_we and e_sn* | 250 | 238 |
| *e-vert* | 34 | |
| *parameterization scheme* | *TROPICAL physics scheme* | |

The mapping of regional flood vulnerability or making maps of potential flood-prone areas is generally carried out using a geomorphological approach, which uses the parameters of land cover, slope, and rainfall (Nuryanti et al., 2018). These three factors are then detailed into several parameters, namely elevation, slope, soil type, land cover, and based on several parameters, namely land elevation map, slope map, soil type map, land cover map, and river buffer (Nuryanti et al., 2018). The weighting of these parameters can be made using Geospatial Information System (GIS) methods (Kurnia Darmawan and Andri Suprayogi, 2015; Novaliadi & Hadi, 2014; Nuryanti et al., 2018; Purnama, 2008).

Database development is carried out in several stages, including the creation of land cover classification maps, soil type classification maps, slope classification maps, land elevation classification maps, river density classification maps, and rainfall classification maps. In this study, a flood-prone map was created based on the results of weighting and scoring the parameters of land cover, soil type, slope, land elevation, and river density to determine the distribution of areas prone to flooding based on geomorphological conditions (static factors). Then continued with the integration and scoring of potential flood events using rainfall parameters (dynamic factors).

Flood vulnerability is a condition that describes whether or not an area is prone to flood, based on natural factors that affect flooding. Land slope or slope is the percentage ratio between vertical distance (land height) and horizontal distance (length of flat land). The steeper the land slope, the more water is passed on. Water that is on the land will be more quickly forwarded to a lower place, so the possibility of overflowing or flooding in areas with steep land slopes will be smaller. Table 2 below shows the values for the land slope parameters used in this study.

**Table 2.** Classification and scoring of land slope parameters (Matondang et al., 2013)

| Slope (%) | Description | Weight | Value | Slope Score |
|---|---|---|---|---|
| 0-2 | flat | 0.20 | 5 | 1.00 |
| >2-15 | slope | 0.20 | 4 | 0.80 |
| >15-25 | slightly steep | 0.20 | 3 | 0.60 |
| >25-40 | steep | 0.20 | 2 | 0.40 |
| >40 | very steep | 0.20 | 1 | 0.20 |

Land altitude or elevation is a measure of the height of a location above sea level. In theory, it is known that the elevation parameter has an influence on flood vulnerability. The lower an area is, the more potential for flooding. On the other hand, the higher an area, the safer it is from flooding. Table 3 below shows the classification and scoring of land height or elevation parameters used in this study.

**Table 3.** Classification and scoring of land height or elevation parameters (Theml, 2008)

| Elevation (m) | Weight | Value | Slope Score |
|---|---|---|---|
| <10 | 0.10 | 5 | 0.50 |
| 10-50 | 0.10 | 4 | 0.40 |
| 50-100 | 0.10 | 3 | 0.30 |
| 100-200 | 0.10 | 2 | 0.20 |
| >200 | 0.10 | 1 | 0.10 |

It is theoretically known that the type of soil in an area is very influential in the process of water absorption, or the infiltration process. Infiltration is the process of water flowing vertically through the soil due to gravitational potential. Physically, there are several factors that affect the infiltration process such as soil type, soil density, soil moisture, and overlying plants. A decrease in infiltration rate is caused by an increase in soil moisture, or saturated soil. The greater the absorption or infiltration of soil to water, the smaller the level of flood vulnerability. On the other hand, the smaller the soil infiltration ability increases the potential for flooding (Matondang et al., 2013). Table 4 below shows the classification and scoring of soil type or texture parameters used in this study.

**Table 4.** Classification and scoring of soil type or texture parameters (Matondang et al., 2013)

| Soil Type | Infiltration Rate | Weight | Value | Score Soil Type |
|---|---|---|---|---|
| Alluvial, Planosol, Gray hydromorph, Groundwater lateric | Insensitive | 0.20 | 5 | 1.00 |
| Latosol | Slightly sensitive | 0.20 | 4 | 0.80 |
| Brown forest soil, Mediterranean soil | Moderate sensitive | 0.20 | 3 | 0.60 |
| Andosol, Lateric, Grumosol, Podsol, Podsolic | Sensitive | 0.20 | 2 | 0.40 |
| Regosol, Litosol, Organosol, Renzina | Highly sensitive | 0.20 | 1 | 0.20 |

Land use or land cover parameters also affect the level of flood vulnerability in an area. Differences in land use play a role in the amount of runoff water resulting from rain that has exceeded the infiltration rate. Areas that are heavily planted with trees will find it difficult to drain runoff water due to the large capacity of water absorption by trees and the slow flow of runoff water due to being retained by the roots and trunks of trees, so the possibility of flooding will be smaller than areas that are not planted with vegetation. Table 5 below shows the classification and scoring of the land cover or land use parameters used in this study.

**Table 5.** Classification and scoring of land use or cover parameters (Theml, 2008)

| Land Cover Type | Weight | Value | Land Cover Score |
|---|---|---|---|
| Civilization | 0.15 | 5 | 0.75 |
| Rice Fields/Ponds | 0.15 | 4 | 0.60 |
| Field/Flat/Garden | 0.15 | 3 | 0.45 |
| Shrubs | 0.15 | 2 | 0.30 |
| Forest | 0.15 | 1 | 0.15 |

The parameter streamflow density (Dd) is defined as the calculated value of streamflow length (Ln) per watershed area (A). The higher the flow density value indicates the better the drainage system in the area, which also means that the greater the amount of total flow and the smaller the groundwater absorbed in the area (the smaller the infiltration) (Matondang et al., 2013). The following equation calculates the river flow density used in this study.

$$Dd = \sum \frac{Ln}{A} \tag{1}$$

The value of Dd as stream density (km/km$^2$), Ln as river length (km), and A as watershed area (km$^2$). Table 6 shows the classification and scoring of stream density parameters and the assessment used in this study.

**Table 6.** Classification and scoring of streamflow density parameters (Matondang et al., 2013)

| Flow density (km/km$^2$) | Weight | Value | Score Flow density |
|---|---|---|---|
| <0.62 | 0.10 | 5 | 0.50 |
| 0.62-1.44 | 0.10 | 4 | 0.40 |
| 1.45-2.27 | 0.10 | 3 | 0.30 |
| 2.28-3.10 | 0.10 | 2 | 0.20 |
| >3.10 | 0.10 | 1 | 0.10 |

The classification results of slope, land elevation, soil type, land cover, and river flow density parameters were then integrated to calculate and determine flood-prone and non-flood-prone areas. The results of determining flooded and non-flooded areas are then integrated with rainfall parameters to create a mapping of potential flood areas in this study.

Flood Vulnerability Score = [(Slope Score)+(Land Cover Score)+(Soil Type Score)+(Elevation Score)+(River Fragility Score)] (2)

Potential Flood Score = (Flood Prone Score)*(Rainfall Score) (3)

Rainfall is the amount of rainwater that falls on an area within a certain time. Rainfall information and forecasts are needed for flood control design in an area. The higher the rainfall, the more potential for flooding. Table 7 below shows the classification and scoring of rainfall parameters used in this study.

**Table 7.** Classification and scoring of rainfall parameters (Theml, 2008)

| Category | Rainfall Intensity | Score |
|---|---|---|
| very dry | < 5 mm/day | 1 |
| dry | 5-20 mm/day | 2 |

| Category | Rainfall Intensity | Score |
|---|---|---|
| normal/humid | 20-50 mm/day | 3 |
| wet | 50-100 mm/day | 4 |
| very wet | > 100 mm/day | 5 |

The results of the flood vulnerability classification in this study are plotted into daily flood forecast maps in several color categories, namely safe, low, medium, high, and very high. Verification of the flood forecast maps was conducted using flood incident reports compiled from BNPB reports.

## RESULTS AND DISCUSSION

### Classification of Flood Prone Areas in North Sumatra

The results of the classification of slope parameters (Figure 4) show that the flat slope type areas that have a high risk of flooding are concentrated on the east coast of North Sumatra. Areas that have a flat slope type with a slope of 0-2% include Simalungun, Asahan, Sibolga, West Nias, Dairi, Langkat, Tanjung Balai, Serdang Bedagai, Medan, Karo, North Tapanuli, Batubara, Deli Serdang, Binjai, South Tapanuli, Nias, Samosir, Tebing Tingi, and Mandailing Natal. The classification results of the slope parameter (Figure 5) show that areas with an elevation of <10 m that have a high risk of flooding are concentrated on the east coast of North Sumatra, namely Simalungun, Asahan, West Nias, Langkat, Tanjung Balai, Serdang Bedagai, Labuhan Batu, Medan, Batubara, Deli Serdang, North Nias, South Nias, Central Tapanuli, and Mandailing Natal.

The results of the classification of soil type parameters (Figure 6) show that the North Sumatra region is dominated by soil types with moderate infiltration rates, namely brown forest soils and mediteran soils. Soil types with low infiltration rates that have a high risk of flooding are found in the eastern and southern coastal areas of North Sumatra. The results of the land cover parameter classification (Figure 7) show that the North Sumatra region is dominated by plantations with a moderate risk of flooding. Settlement-type land cover with a high risk of flooding is concentrated in the east coast of North Sumatra, including Simalungun, Asahan, Langkat, Tanjung Balai, Serdang Bedagai, Medan, Karo, Binjai, Batubara, and Deli Serdang. The classification results of the river flow density parameter (Figure 8) show that the North Sumatra region is dominated by a river flow density of 1.45-2.27 km/km2 or with a moderate risk of flooding. Areas that have low stream flow density show a small number of tributaries.

The scoring results of the parameters of slope, land elevation, soil type, land cover, and stream density are then used to calculate the flood vulnerability score using Equation 2. The calculation results (Figure 9) show that flood-prone areas are almost evenly distributed in North Sumatra. It can be seen that non-flood areas are dominant in the northwest of North Sumatra, which is a mountainous area of Bukit Barisan.

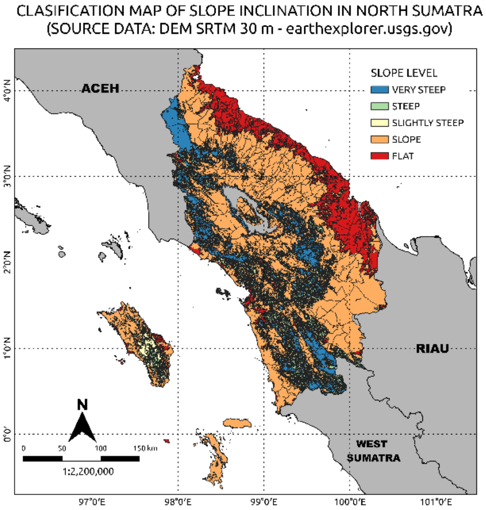


**Figure 4.** Map of slope parameter classification results

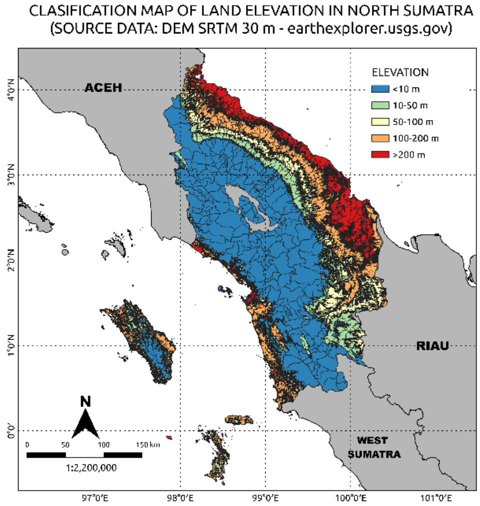


**Figure 5.** Land elevation parameter classification result map

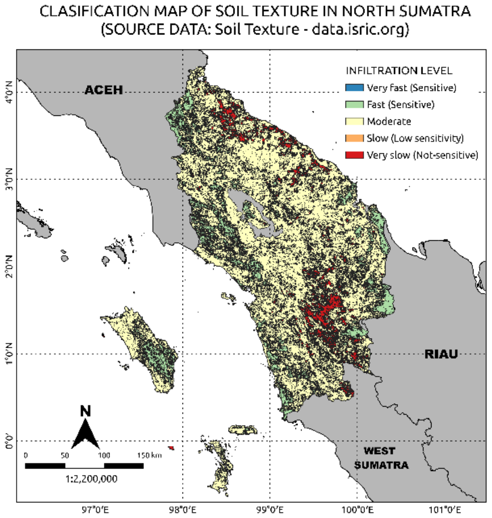


**Figure 6.** Map of classification results of soil type or texture parameters

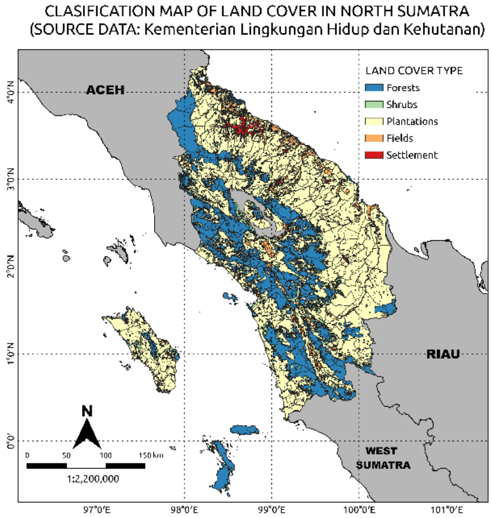


**Figure 7.** Map of classification results of land use or land cover parameters

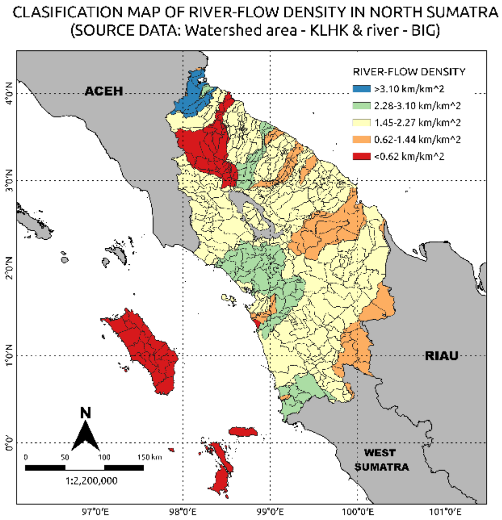


**Figure 8.** Classification result map of streamflow density parameter

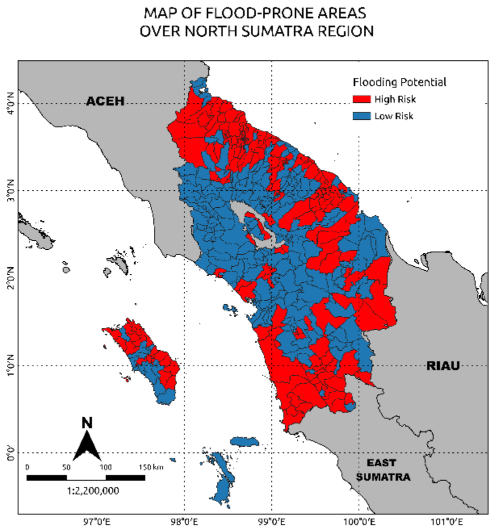


**Figure 9.** Map of flood-prone areas in North Sumatra region

## The Production of Daily Flood Forecast Maps

1) Case study on August 18, 2022

In the case study of August 18, 2022, the daily flood forecast map (Figure 10) shows that areas predicted to experience flooding are spread across the east coast of North Sumatra. The potential for very high category flooding is found in the Bandar Pasir Mandoge sub-district (Asahan) and Aek Natas sub-district (Labuhanbatu Utara). High category flood potential is found in Asahan, Deli Serdang, Karo, North Labuhanbatu, Langkat, Mandailing Natal, and Padang Lawas. While the potential for moderate category flooding is concentrated in the eastern slopes and east coast of North Sumatra.

Based on the flood incident report from BNPB, it is known that on August 18, 2022 there was a flood triggered by high intensity rain in the Deli Serdang and Medan areas (red mark in Figure 11). The daily flood forecast map on August 18, 2022 was confirmed by the daily rainfall observation map. It can be seen in Figure 12 that rainfall >50 mm/day is found on the eastern slope to the east coast of North Sumatra. The highest rainfall value reached 80 mm/day at Tanjung Morawa Rain Post (Deli Serdang).

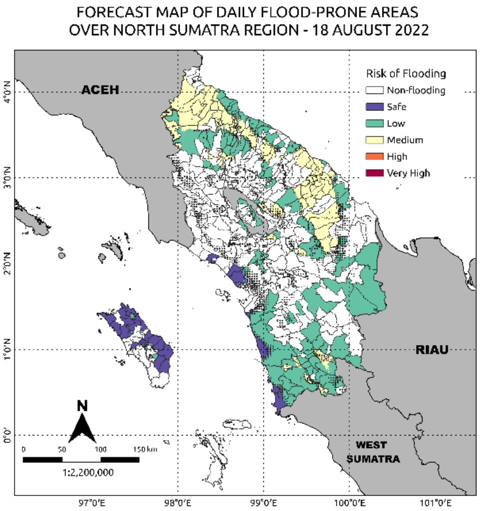


**Figure 10.** Flood forecast map on August 18, 2022

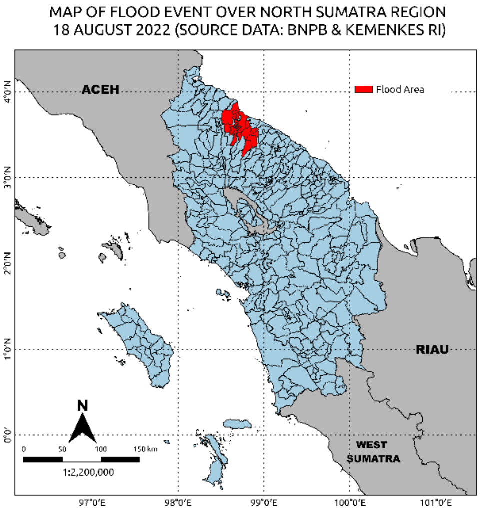


**Figure 11.** Flood event map of August 18, 2022

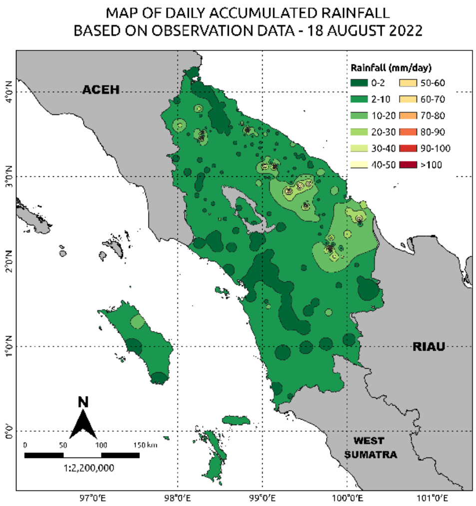


**Figure 12.** Map of daily rainfall accumulation on August 18, 2022 (observation data)

2) Case study on November 18, 2022

In the case study of November 18, 2022, the daily flood forecast map (Figure 13) shows that the areas predicted to experience flooding are spread across the northeastern part of the east coast of North Sumatra. The potential for high category flooding is found in the Bandar Pasir Mandoge sub-district (Asahan), Biru-biru and STM Hilir sub-districts (Deli Serdang), and Besitang sub-district (Langkat). The potential for moderate category flooding is found in Medan, Deli Serdang, Binjai, Langkat, and Asahan.

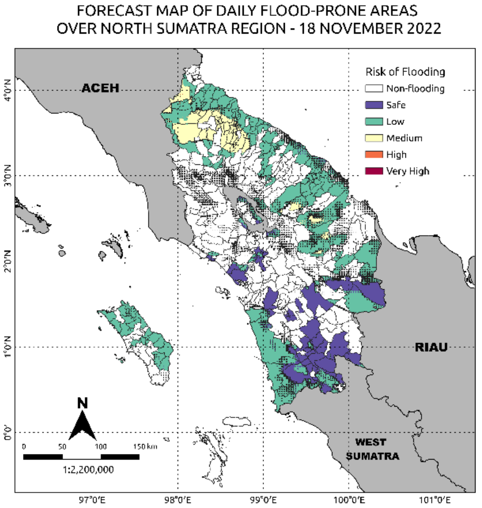


**Figure 13.** Flood forecast map of November 18, 2022

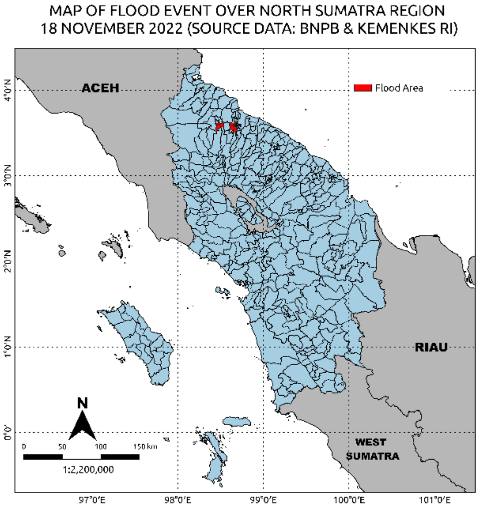


**Figure 14.** Flood event map of November 18, 2022

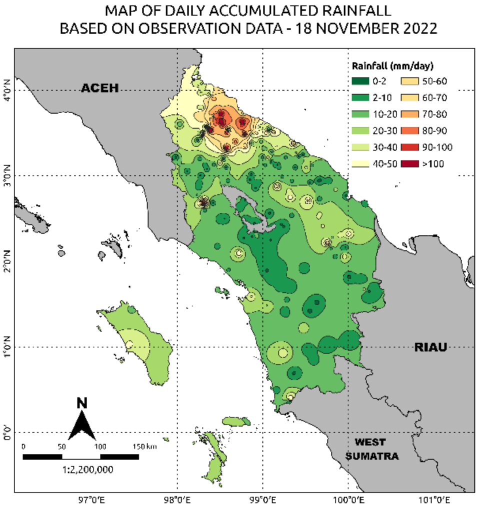


**Figure 15.** Map of daily rainfall accumulation on November 18, 2022 (observation data)

Based on the flood incident report from BNPB, it is known that on November 18, 2022 there was a flood triggered by high intensity rain in the Medan and Binjai areas (red mark in Figure 14). The daily flood forecast map on November 18, 2022 was confirmed by the daily rainfall observation map. It can be seen in Figure 15 that rainfall >50 mm/day is concentrated in the northeastern part of the east coast of North Sumatra. The highest rainfall values reached 171 mm/day at Batang Kuis Rain Post (Deli Serdang) and 145 mm/day at Binjai Utara Rain Post (Binjai).

## CONCLUSION

The scoring results of the parameters of slope, land elevation, soil type, land cover, and stream density used to calculate the flood vulnerability score show that flood-prone areas are almost evenly distributed in North Sumatra. It can be seen that non-flood areas are dominant in the northwest of North Sumatra, which is the Bukit Barisan mountainous area. Spatially, the creation of a daily flood prone map using WRF model output rainfall prediction data has a pattern that corresponds to the map of flood occurrence areas and the Rain Post rainfall observation map. The verification results show that the areas predicted to have high and very high potential are in accordance with the flood event areas based on the BNPB report. Thus, the daily flood forecast map can be used as an early warning of flood disasters in the North Sumatra region.

## RECOMMENDATION

It is necessary to test the performance of flood forecast maps on more flood event case studies and test the threshold for scoring rainfall classes to improve the accuracy of flood forecast maps in the North Sumatra region.

## REFERENCES


BNPB. (2021a). *Definisi Bencana*. https://www.bnpb.go.id/definisi-bencana

BNPB. (2021b). *Potensi Ancaman Bencana*. https://www.bnpb.go.id/potensi-ancaman-bencana

Dahlia, S., Nurharsono, T., & Rosyidin, W. F. (2018). Analisis Kerawanan dan Exposure Banjir Menggunakan Citra DEM SRTM dan LANDSAT di DKI Jakarta. *GEA Jurnal Pendidikan Geografi*, *18*(1), 81–95.

DPRD Prov Sumut. (2021). *Tentang Sumatera Utara*. http://dprd-sumutprov.go.id/page/tentang-sumut

Haryani, N. (2017). Analisis Zona Potensi Rawan Banjir Menggunakan Data Penginderaan Jauh dan SIG di Kalimantan Timur. *Proceedings of the Seminar Nasional Penginderaan Jauh Ke-4 Tahun 2017*.

Kurnia Darmawan dan Andri Suprayogi. (2015). Analisis Tingkat Kerawanan Banjir Di Kabupaten Sampang Menggunakan Metode Overlay Dengan Scoring Berbasis Sistem Informasi Geografis. *Jurnal Geodesi Undip*, *4*(1).

Matondang, J. P., Kahar, S., & Sasmito, B. (2013). Analisis Zonasi Daerah Rentan Banjir Dengan Pemanfaatan Sistem Informasi Geografis. *Jurnal Geodesi Undip*, *2*(April).

Novaliadi, D., & Hadi, M. P. (2014). Pemetaan Kerawanan Banjir dengan Aplikasi Sistem Informasi Geografis di Sub DAS Karang Mumus Provinsi Kalimantan Timur. *Jurnal Bumi Indonesia*, *3*(4).

Nuryanti, N., Tanesib, J. L., & Warsito, A. (2018). Pemetaan Daerah Rawan Banjir dengan Penginderaan Jauh dan Sistem Informasi Geografis di Kecamatan Kupang Timur Kabupaten Kupang Provinsi Nusa Tenggara Timur. *Jurnal Fisika: Fisika Sains Dan Aplikasinya*, *3*(1), 73–79.

Purnama, A. (2008). *Pemetaan Kawasan Rawan Banjir di Daerah Aliran Sungai Cisadane Menggunakan Sistem Informasi Geografis* [Tugas Akhir]. Institut Pertanian Bogor.

Saragih, I. J. A. (2020). Identifikasi Pola Diurnal Curah Hujan di Sumatera Utara (Studi Kasus Tahun 2019). *Seminar Nasional Fisika PPS Universitas Negeri Makassar*, 24–27.

Theml. (2008). Katalog Methodologi Penyusunan Peta Geo Hazard dengan GIS. Badan Rehabilitasi dan Rekonstruksi (BRR) NAD-Nias. Banda Aceh. *Jurnal Geodesi Undip*, *6*(1).